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Applied Ergonomics

Xingzhou Guo, Yunfeng Chen, Jiansong Zhang

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AUTHORS

Xingzhou Guo, PhD
Assistant Professor
Department of Civil Engineering
University of Minnesota Duluth

Yunfeng Chen, PhD
Associate Professor
School of Construction Management Technology
Purdue University
(765) 494-6374
chen428@purdue.edu
Corresponding Author

Jiansong Zhang, PhD
Associate Professor
School of Construction Management Technology
Purdue University

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16. Abstract

Ergonomic injuries and solutions have been extensively studied in the construction industry; however, the prevalence of work-related injuries, risky activities, and effective solutions in the transportation industry are not understood. This study aims to explore the prevalence of work-related injuries, risky activities, and potentially ergonomic solutions among transportation workers. The approach to this study included exploration of worker type, injury types, and activities of top concern through historical injury data, an online survey, and proposal and evaluation of ergonomic solutions through onsite observations and field experiments. Results from this study found that back injuries were the most common type of injury sustained. Performing lifting and pushing/pulling activities have caused the most injuries. Back exoskeletons and ergonomic handles were identified as potential solutions to help reduce the risk of injury. Additionally, higher platforms were also suggested to help prevent workers from being forced to perform activities by exerting their back excessively.

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EXECUTIVE SUMMARY

Introduction

Ergonomic hazards are a significant concern for construction workers since they can lead to occupational health and safety issues. These hazards can arise when workers are involved in construction activities that exceed their physical capabilities and limitations (Inyang et al., 2012; Seo et al., 2019). In the United States about two million workers suffer from work-related musculoskeletal disorders (WMSDs) annually and about a half million workers lose time from work due to WMSDs (Jeffress, 2000). Common ergonomic risk factors for WMSDs include repetitive motion, excessive force, and awkward posture (Jaffar et al., 2011). As identified by various studies, these risk factors can lead to stress on workers' muscles and tendons during activities like heavy lifting or bending (Jaffar et al., 2011; Omar et al., 2004; Parida & Ray, 2012). The construction industry, along with transportation and warehousing, saw the highest number of occupational deaths in Indiana in 2020, with a total of 57 fatalities (IDOL, 2021). As a government agency responsible for maintaining transportation infrastructure, the Indiana Department of Transportation (INDOT) plays an active role in both the transportation and construction sectors. Therefore, it is crucial for INDOT to prioritize the health and safety of its workers. Previous research related to transportation safety mainly focused on the issues caused by vehicle drivers instead of the transportation activities. In addition, the applicability of the findings about worker safety in activities from similar industries (e.g., construction industry) to the transportation industry may be limited due to variations in the duration, intensity, and frequency of specific contexts within transportation. Also, the efficacy of previous ergonomic solutions has only been evaluated in laboratory settings, and the practicability of employing them on transportation job sites may differ given complex and ever-changing outdoor conditions.

Findings

- Worker type of top concern.
  - Transportation maintenance workers are the type of transportation workers with the most injuries.

- Injury type of top concern.
  - The highest proportion of reported injuries, 31.58%, were related to the back, followed by leg injuries at 21.05%, shoulder injuries at 15.79%, and arm injuries accounting for 10.53%.

- Activities of top concern.
  - Lifting and pushing/pulling activities were identified as the main concern due to workers' perception of these activities causing back and shoulder injuries, the frequency with which they engage in these activities, and the historical injury cases associated with them.

- Tasks of top concern.
  - Lifting bags of materials and sign stands were identified as the most concerning lifting tasks, based on workers' perceived likelihood of these tasks causing back and shoulder injuries, the frequency of performing these tasks, and the historical injury cases related to them.
  - Shoveling gravels and pulling a dead deer were highlighted as the most concerning pushing/pulling tasks, considering workers' perceived likelihood of these tasks causing back and shoulder injuries, the frequency of performing these tasks, and the historical injury cases associated with them.

- Proposed ergonomic solutions.
  - Lifting bags of materials: use of a back exoskeleton, different weights of bags, and different heights of platforms.
  - Lifting sign stands: use of a shoulder exoskeleton, and different placing approaches, including vertical on the ground, vertical on the waist height, and horizontal on the waist height.
  - Shoveling gravels: use of a back exoskeleton and use of an ergonomic handle.
  - Pulling dead deer: use of a back exoskeleton.

- Evaluation of proposed ergonomic solutions.
  - Lifting bags of materials (please see Section 8.2.1 for details).
    - Perceived muscle exertion, muscle contraction, heart rate, and skin conductance are significantly different when wearing and not wearing a back exoskeleton when workers lift 50-pound or 80-pound bags.
    - Muscle contraction, heart rate, and skin conductance are significantly different for lifting 31.5-pound, 50-pound, and 80-pound bags when workers wear and do not wear back exoskeleton.
    - Muscle contraction is significantly different between workers with less than 5 years of working experience and with more than 5 years of working experience.
    - Muscle contraction is significantly different when lifting from less than 20 inches and for more than 20 inches.

  - Shoveling gravel (please see Section 8.2.2 for details).
    - Perceived muscle exertion and muscle contraction are significantly different when shoveling with a regular shovel and shoveling with an ergonomic handle.

  - Lifting sign stands (please see Section 8.2.3 for details).
    - Perceived muscle exertion, perceived pressure, and muscle contraction are significantly different when lifting from waist height, compared with lifting from the ground.
    - Perceived usability shows a low usability rate of a shoulder exoskeleton when lifting sign stands.

  - Pulling deer (please see Section 8.2.4 for details).
    - No significant differences were found between wearing and not wearing a back exoskeleton when handling a dead deer.

Implementation

Based on the finding described above, the following implementation recommendations are made for the four activities.

- Lifting bags of materials.
  - The utilization of back exoskeletons is recommended when dealing with items of 31.5-pound or more in weight.
  - Lifting 31.5-pound bags is considered to be a safer option than lifting 50- or 80-pound bags.
  - To further minimize the risk of back injuries, the platform height from which the item is being lifted should be at least 20 inches.
  - Controlling the speed at which tasks are being performed can help reduce the likelihood of muscle fatigue.

- Shoveling gravels.
  - Ergonomic handles may lower the risk of straining back muscles, but concurrently increase the risk of arm injuries.
  - Not surprisingly, the complexity associated with wearing shoulder exoskeletons has made them an impractical consideration.

- Lifting sign stands.
  - The height of the platform from which the item is being lifted should be at waist height in order to further reduce the possibility of injuries.
  - A shoulder exoskeleton is not preferred due to its complexity to wear and its limited effectiveness.

- Pulling deer.
  - The proposed solution of a back exoskeleton did not receive scientific support for its effectiveness.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

Ergonomic hazards are a significant concern for construction workers, leading to occupational health and safety issues. These hazards can arise when workers are involved in construction activities that exceed their physical capabilities and limitations (Inyang et al., 2012; Seo et al., 2019). In the United States (U.S.), about two million workers suffer from work-related musculoskeletal disorders (WMSDs) annually and about half million workers lose time from work due to WMSDs (Jeffress, 2000). Common ergonomic risk factors for WMSDs include repetitive motion, excessive force, and awkward posture (Jaffar et al., 2011). These risk factors can lead to stress on workers' muscles and tendons during activities such as heavy lifting or bending, as identified by various studies (Jaffar et al., 2011; Omar et al., 2004; Parida & Ray, 2012). The construction industry, along with transportation and warehousing, saw the highest number of occupational deaths in Indiana in 2020, with a total of 57 fatalities (IDOL, 2021). As a government agency responsible for maintaining transportation infrastructure, Indiana Department of Transportation (INDOT) plays an active role in both the transportation and construction sectors. It is crucial for INDOT to prioritize the health and safety of its workers. Previous work related to transportation safety mainly focused on the issues caused by vehicle drivers instead of the transportation activities. In addition, the applicability of the findings of worker safety in activities from similar industry (e.g., construction industry) to the transportation industry may be limited due to variations in the duration, intensity, and frequency of the specific contexts within transportation. Also, the efficacy of previous ergonomic solutions has only been evaluated in laboratory settings. Nevertheless, the practicability of employing them on transportation job sites may differ given the complex and ever-changing outdoor conditions.

2. PROBLEM STATEMENT

While there are numerous assessment methods and technologies available to prevent WMSDs, there is a lack of specialized technologies, practices, and processes designed to protect INDOT workers from the specific injuries that are of utmost concern to the organization. More importantly, the previously proposed technologies, practices, and processes were developed in the construction industry. Due to discrepancies in the specific contexts of transportation, such as variations in duration, intensity, and frequency, the generalizability of the findings to the transportation industry may be limited. The following inquiries will be addressed through this research.

1. What are workers, activities, injury types, and root causes that are of top concern specifically to INDOT?
2. What are current injury prevention practices and efforts in INDOT?
3. How to develop effective technologies, practices, and processes to improve workers' health and safety?

INDOT has recognized the importance of applied ergonomics in improving construction workers' safety and health. Specific objectives of this study include the following.

1. Identify workers, activities, injury types and their root causes that are of top concern specifically to INDOT.
2. Identify and evaluate the current injury prevention practices and efforts in INDOT.
3. Propose ergonomically effective technologies, practices, and processes to improve workers' health and safety.
4. Evaluate the effectiveness of the proposed new technologies, practices, and processes to improve workers' health and safety.

3. LITERATURE REVIEW

Presently, safety research within the transportation industry has primarily centered on addressing safety concerns arising from vehicle operators, as opposed to safety issues related to transportation activities themselves. For instance, the development of driver assistance technologies like adaptive cruise control has been geared towards improving driving safety (Varotto et al., 2022). Various technologies have been introduced to minimize the exposure of work zone workers to hazards and aid drivers in safely passing through work zones (Nnaji et al., 2020). These technologies include the automated flagger assistant device (Finley, 2013), lighting for nighttime highway construction (Abdelmohsen & El-Rayes, 2018), lateral clearance between live lane and traffic work zone (Abdelmohsen & El-Rayes, 2018), etc. These technologies mainly focus on the safety issues caused by motorists to work zone workers, without addressing the musculoskeletal injuries resulting from unsafe actions by work zone workers themselves.

In the construction industry, technologies and practices have been developed to prevent WMSDs. However, these strategies have never been tested for improving the health and safety of transportation workers. The applicability of the findings to the transportation industry may be limited due to variations in the duration, intensity, and frequency of the specific contexts within transportation. For example, ergonomically designed hand tools, such as power tools and textured rubber handles, can reduce injuries (Choi et al., 2016). The flex and stretch program is also designed to help workers improve their health and safety by increasing the feasibility and then minimizing potential WMSDs (Choi et al., 2017). For example, a 10-minute warm-up exercise can significantly increase the lower back mobility (Holmström & Ahlborg, 2005). In addition, exoskeleton has been widely used in the manufacturing industry to help workers prevent WMSDs, because exoskeleton can habituate workers to safe postures and support human body with extra strength (Cho et al., 2018; Copilusi et al., 2015; Yu et al., 2015).

Evaluating ongoing construction operations and then developing a new design that fits workers' capabilities can also prevent workers from WMSDs (Golabchi et al., 2018). A lot of effort had been devoted to ergonomically assessing activities. However, most of these developed solutions have limitations when they are applied in a real job site. For example, traditional ergonomic analysis approaches, such as onsite observations for monitoring all activities, are error prone and require significant time for laborious construction tasks (Golabchi et al., 2018). Onsite observations can be useful in identifying ergonomic problems and suggesting solutions, but they may not be practical for ongoing monitoring. While exoskeletons have been tested for simulated lifting tasks in a controlled laboratory setting, their effectiveness in real-world job sites with dynamic outdoor environments may differ. To address these challenges, wearable sensors, video, and computer vision technologies are being used to track workers' movements and analyze workplace activities. This approach can provide feedback to workers and generate data for redesigning workspaces and tasks (Akhavian & Behzadan, 2016; Golabchi et al., 2018; Guo et al., 2016; Han & Lee, 2013). Physiological status has also been used for WMSDs assessment. For example, electromyography (EMG) has been adopted to monitor the extent of muscle activity (Lloyd & Besier, 2003). Heart rate, respiration rate, movement speed, and body posture, when they are integrated with real-time location information, can also be used to detect excessive bend due to material handling (Cheng et al., 2013; Gatti et al., 2011).

4. METHODOLOGY

The health and safety of workers involved in transportation activities is crucial. The transportation sector in the U.S. often experiences work-related injuries, as reflected in both national and statewide data. Specifically, Bureau of Labor Statistics data reveals that 1,282 work-related fatalities, or 26.9%, took place in construction occupations across the U.S. (BLS, 2022). Additionally, the Indiana Census of Fatal Occupational Injuries reported 26 fatal injuries in the transportation and warehousing industry and 31 fatal injuries in the construction industry in 2020 (IDOL, 2021). In order to tackle high-risk injuries and suggest solutions, researchers have collaborated with INDOT, an organization that plays an active role in both the transportation and construction sectors, to conduct further inquiries.

The research methodology presented in Figure 4.1 consists of four phases. The first phase involves reviewing historical injury data to determine the types of workers who are most injured, the types of injuries that are most frequently reported, and the activities that pose the greatest risk. Next, an online survey is conducted to the identified type of workers to further investigate the specific tasks that are of concern. Onsite observations are then conducted to confirm the procedures involved in performing the identified tasks and to suggest possible ergonomic interventions. Finally, field experiments are conducted to evaluate the effectiveness of the proposed solutions. Details regarding the specific methods used for each phase can be found in Sections 5.1, 6.1, 7.1, and 8.1.

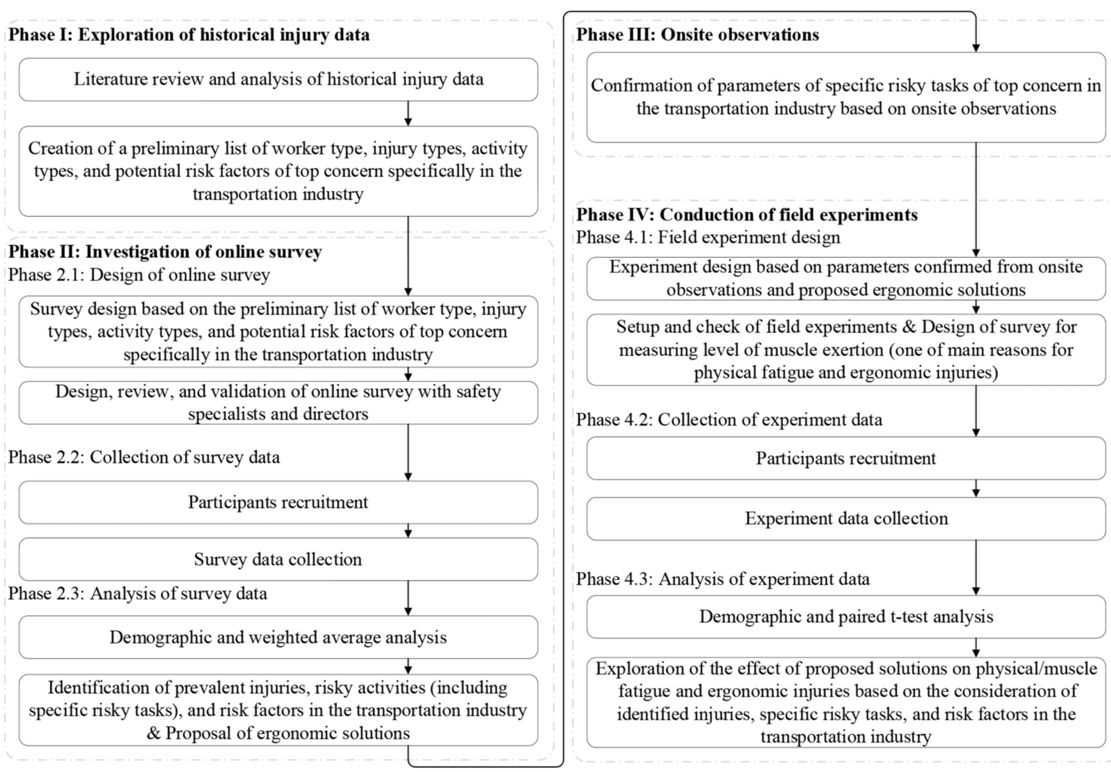


Figure 4.1 Flow chart of research methodology.

5. PHASE I: PRELIMINARY EXPLORATION THROUGH HISTORICAL INJURY DATA

5.1 Methods

In the initial stage, the investigation was commenced by examining the historical records of injuries to acquire a broad understanding of the focus areas. The data pertaining to injuries was obtained from INDOT's insurance partner, and it was discovered that there were 1,318 reported cases of injuries that happened between July 1st, 2014, and June 30th 2020. Subsequently, the injury data was further analyzed to determine the worker type that suffered the most injuries, the activities that were the primary cause of these injuries, and the most common injuries that occurred. Additionally, the existing measures of injury prevention utilized by INDOT were also investigated.

5.2 Results and Discussion

The results and discussion section presents the findings of preliminary exploration through historical injury data and current prevention practices.

5.2.1 Identified Worker Types, Injuries, and Activities of Top Concern

Injuries in the transportation industry not only affect the workers themselves but also cause emotional distress on their families and financial burden on INDOT. Improving workers' health and safety can be beneficial for both INDOT and construction workers. In light of this, the research team commenced the work by examining statistical data disclosed by INDOT to explore the areas of concern, including what types of workers have most injuries; what activities are most risky; what injuries are most common; and what their root causes could be. By the analysis of various documents shared by INDOT, including documents describing INDOT workers' compensation claims, illustrating INDOT workers' nature of injury between 2016–2019, and recording INDOT workers' loss and injury details between 07/01/2014 and 06/30/2020, the team identified the following key areas of concern as shown in Figure 5.1.

1. Worker type: 69% of injuries happened to maintenance general workers.
2. Body part: low back area (14%) and shoulder (6%) accounted for the majority of claim counts from 07/01/2014 to 06/30/2020.
3. Nature of injury: the nature of injury of the most frequent ergonomic injuries is sprain/strain (48%) from 07/01/2014 to 06/30/2020.
4. Claim cause: lifting, pushing, or pulling is the activity accounting for the most strain/sprain injuries (17%) from 07/01/2014 to 06/30/2020.
5. Gender: male workers accounted for 86% of total claims from 07/01/2014 to 06/30/2020.
6. Age range: workers in their 50s accounted for 31% of total claims from 07/01/2014 to 06/30/2020.
7. Tenure range: workers who have worked for INDOT less than 2 years accounted for 38% of total claims from 07/01/2014 to 06/30/2020.

By considering these factors, target INDOT workers with ergonomic issues of top concern can be selected for this project. Specifically, as shown in Table 5.1, when all criteria are selected (case one), which means for a

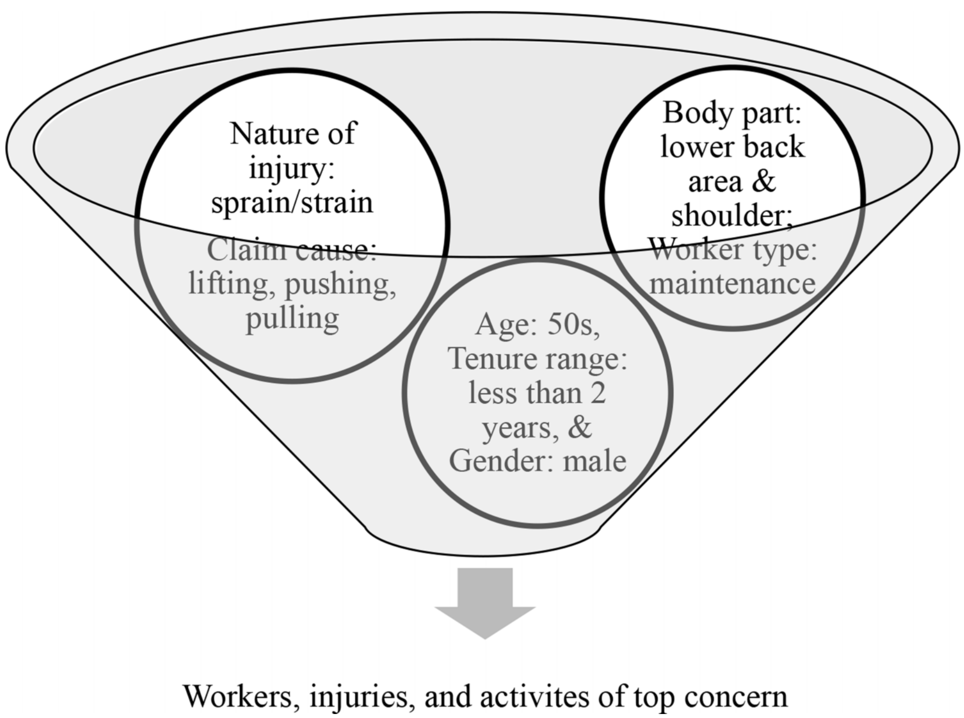


Figure 5.1 Identification of workers, injuries, and activities of top concern.

TABLE 5.1
Criteria selection and the corresponding number of reported injuries

Selected Criteria		Number of Reported Injuries from 07/01/2014 to 06/30/2020
Case One	All criteria	3
Case Two	Without the criteria of gender and tenure range	28
Case Three	Without the criteria of gender, tenure range, and age range	92

maintenance general worker who is in his/her 50s and has worked for INDOT less than 2 years, three cases were found to meet these criteria based on the historical injury data. This kind of worker usually experiences strain to their low back area or shoulder when performing lifting, pushing, or pulling jobs. When the criteria of gender and tenure range were not considered and all other criteria were considered (case two), 28 reported injuries were found. When the criteria of gender, tenure range, and age range were not considered and all other criteria were considered (case three), 93 reported injuries were found. To ensure that the field experiments accurately represent the most common injuries, it is recommended that the criteria of gender, tenure range, and age range not be considered when selecting participants. Specifically, the researchers will focus on exploring the lifting, pushing, and pulling activities that are typically performed by maintenance workers and that commonly result in sprains or strains to the low back or shoulder areas. The goal is to identify effective solutions that can be applied across a broad range of workers and situations, rather than focusing on specific demographic groups.

To identify the specific tasks that commonly lead to injuries among INDOT workers, the researchers analyzed incident descriptions from a document detailing worker losses and injuries between 07/01/2014 and 06/30/2020. The researchers identified numerous activities that were involved in these incidents and categorized them based on their similarity or association. Additionally, the activities were ranked according to the number of reported injury cases and the average cost per claim. All specific tasks under each activity category will be further investigated in the online survey phase to confirm whether it is of top concern.

1. Group #1 of similar lifting activities of concern, with $11,227.39 per claim.
   a. Lift, pick up, load metal plates, tables, tire rings, litter, pumps, UPM mix, mold, boxes, and carbides (10 injuries reported)
   b. Lift, pick up, load bags of sands, asphalts, concretes, and stones (7 injuries reported)
   c. Lift, pick up signs (4 injuries reported)
2. Group #2 of similar pulling/pushing activities of concern, with $18,425.13 per claim.
   a. Pull tools, valves, T-posts, grinders, deer, cables, grate, and T-post (7 injuries reported)
   b. Push plywood, tail gates, and box (3 injuries reported)
3. Group #3 of similar cutting activities of concern, with $32,451.35 per claim.
   a. Cut brush trees (5 injuries reported)
4. Group #4 of similar cleaning activities of concern, with $13,345.91 per claim.
   a. Clean pipes, drains, trucks, debris, bridge decks, and hot mix box (6 injuries reported)
5. Group #5 of similar repair activities of concern, with $4,353.69 per claim.
   a. Install, repair, replace sign, cable, light, brake chamber, bridge reflectors, and plow blades (8 injuries reported)

5.2.2 Identified Current Injury Prevention Practices

This study also examined the injury prevention practices currently in place at INDOT and identified opportunities for improvement. Specifically, INDOT currently recommends field stretching exercises for workers prior to the start of their shift as depicted in Figure 5.2. Previous literature show that stretching exercise can increase range of motion, reduce the risk of sprain or strain injuries, control postural fatigue, warm muscles, reduce internal friction and stiffness, and improve worker comfort (Holmström & Ahlborg, 2005; Liu et al., 2019). However, participation rates in these stretching exercises are currently low among INDOT workers. To address the issue of worker injuries related to performing specific tasks, INDOT may want to consider hiring stretching exercise professionals to encourage and assist workers in performing stretching exercises that can help prevent injuries. Additionally, INDOT could benefit from better advertising the potential benefits of field stretching exercises and making participation mandatory instead of voluntary. By implementing these measures, INDOT could help reduce the incidence of injuries among its workers and create a safer work environment.

5.2.3 Gathered Example of Ergonomic Issues

Appendix A shows a practical example shared by the INDOT safety director. There is currently a task that needs bagged material to be loaded into a thermoplastic paint truck, which requires the employee to take the bagged material, turn around, step up onto a short platform, and then shove the bag into the door of

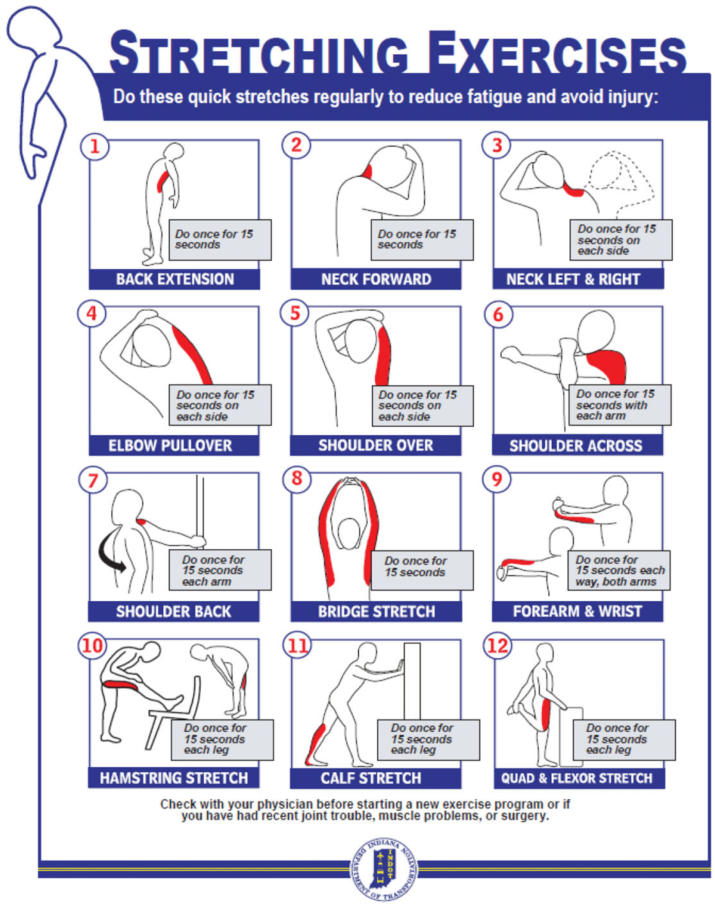


Figure 5.2 Stretching exercises recommended by INDOT.

thermoplastic paint truck. However, in the given scenario, the platform is too short, which means that the employee has to lift the bagged material to a height that is equal to or even slightly above their shoulder level. This puts the employee at a high risk of developing shoulder injuries.

To solve this issue, a higher platform could then be adopted. However, in this case, the employee is experiencing tripping hazards because s/he needs to move up and down. To solve this newly raised tripping issue, two employees are used so one can pass bags of material to another one to load the material. However, this requires the employee, who loads the material to the thermoplastic paint truck, to twist their back to hand over the material to the other worker. This twisting motion could cause some back injuries.

This example highlights that problems related to workplace safety and injury prevention that can be addressed by redesigning the activity or the workplace. For instance, using an elevator to lift the bagged material to the required height or utilizing a conveyor to transport the material can reduce the risk of shoulder injuries in employees. Furthermore, exoskeletons can also be used to assist workers in completing tasks that involve heavy lifting and minimize the risk of injury. By implementing these solutions, employers can improve workplace safety and reduce the incidence of injuries among their workers.

6. PHASE II: EXPLORATION THROUGH ONLINE SURVEY

6.1 Methods

The second phase of this study involves exploring which activities and specific tasks are of the highest concern. To achieve this, an online survey was conducted to gather the perceptions and experience of transportation maintenance workers regarding the identified five groups of activities (lifting, pushing/pulling, cutting, cleaning, and repairing). The survey was designed to identify the specific tasks that are most likely to result in injuries, and the data collected from the survey will be used to inform the subsequent phases of the study.

6.1.1 Design of Survey Questionnaires

A questionnaire survey was developed, comprising of four main sections. The first section sought participants' demographic information. The second section involved ranking activities based on their perceived likelihood of causing injuries and the frequency with which they perform each activity/task. The third section included detailed parameters of each activity. Lastly, the fourth section provided information on the adoption of safety protective equipment and the implementation of stretching exercises. The questionnaire mainly consisted of multiple-choice questions, with some questions utilizing the five-point Likert scale, and others being open-ended. For instance, participants were asked to rate the likelihood of activities causing back or shoulder injuries, using a five-point scale where one indicated the least likely and five indicated the most likely, based on their perception. The design and structure of the questionnaire is shown in Figure 6.1. The full survey can be found in Appendix A.

6.1.2 Collection of Survey Data

The survey questionnaire, constructed in Qualtrics, was distributed to INDOT's statewide safety managers and district safety directors for further distribution to potential participants. The survey required approximately 20 minutes to finish. Given the involvement of human subjects in this research, approval was obtained from Purdue University's Institutional Review Board (IRB) prior to the conduction of the study. The survey was conducted between April 4th, 2021, and April 30th, 2021, and a total of 75 INDOT workers were gathered for participation. Of all responses, 48 individuals provided complete responses, which were subsequently analyzed to identify the most commonly occurring injuries, the activities most likely to cause such injuries, the specific tasks most likely to cause such injuries, key parameters involved in those tasks, and the current situation of protection and assistance usage.

6.1.3 Analysis of Survey Data

In this study, two approaches were utilized for data analysis, namely descriptive data analysis and weighted average analysis. In the descriptive data analysis phase, various statistical techniques were employed, including frequency distribution, mean analysis, and percentage calculation. These techniques were utilized to determine the demographic and behavioral attributes of the participants. Second, weighted average analysis was employed to explore injury types that mostly occurred and types of activities that have caused most injures (Dye Management Group, 2014; Guo et al., 2022). In the survey, researchers verified which activities are most likely to cause an injury to back or shoulder. And researchers also checked how often they perform the activity while working. For example, if researchers want to know the weighted total for how likely lifting will cause an injury to back or shoulder, somebody says one as the least likely and other people say five as the most likely, researchers calculate the weight times its corresponding number of responses divided by total responses to get the weighted average.

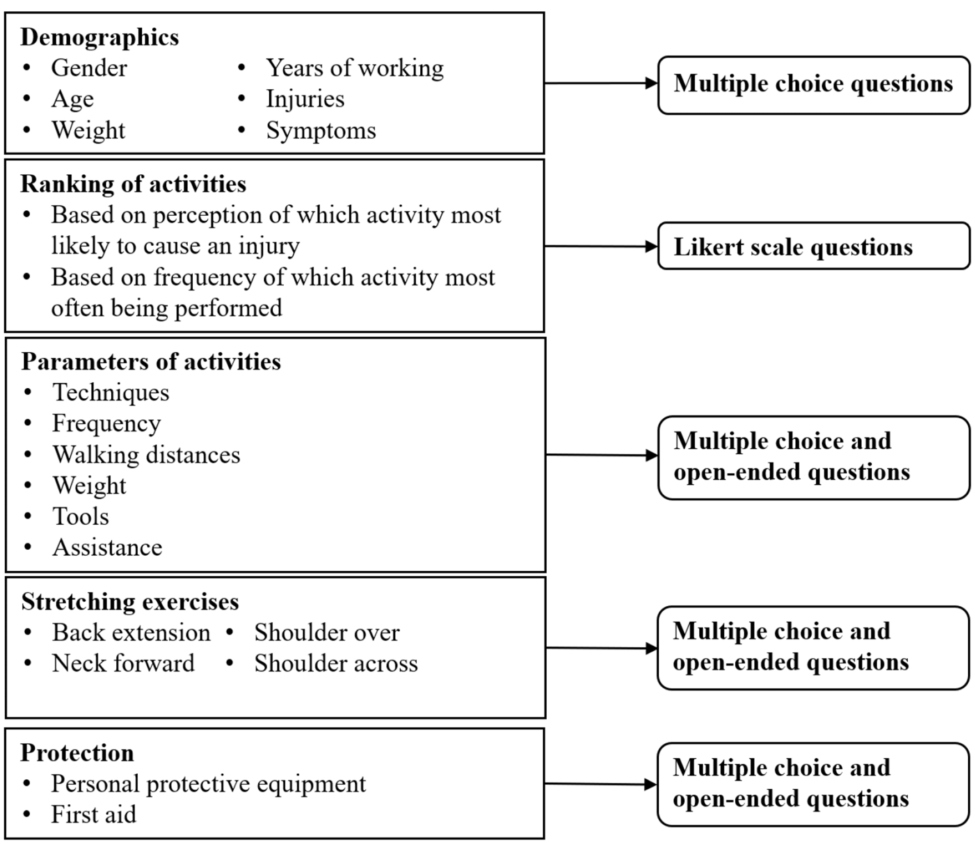


Figure 6.1 Framework of designed survey questionnaire.

6.2 Results and Discussion

The results and discussion section presents the findings of exploration through the online survey conducted with INDOT maintenance workers.

6.2.1 Demographics of Online Survey Participants

This research invited maintenance workers from INDOT. From a total of 75 responses gathered, 48 complete responses were utilized for the purpose of data analysis. A majority of the respondents were male (89.59%), and their ages ranged from their 20s to 60s, with the highest proportion being in their 40s (37.50%). The study also included the duration of tenure, with a majority of the participants having worked as maintenance workers for a period ranging from 5 to 10 years (29.17%), as shown in Table 6.1.

6.2.2 Safety Behaviors of Online Survey Participants

This study investigated the use of stretching exercises among participants, including their level of involvement, the timing of their stretching routine, and their reasons for engaging in such activities. Additionally, data was collected on the utilization of Personal Protective Equipment (PPE) while performing tasks on site. The findings revealed that 72.92% of workers engaged in stretching exercises, while 95.83% used PPEs, as indicated in Table 6.2.

6.2.3 Identified Injuries of Top Concern

The occurrence of various injuries among transportation maintenance personnel was investigated to identify the most frequent injury types. A summary of

TABLE 6.1
Demographic characteristics of online survey participants

Demographic Characteristics		Number	Percentage (%)
Gender	Male	43	89.59
	Female	5	10.41
Age	20s	6	12.50
	30s	5	10.42
	40s	18	37.50
	50s	14	29.17
	60s	5	10.42
Weight	100–199 pounds	14	29.17
	200–299 pounds	29	60.42
	Over 299 pounds	5	10.41
Tenure Range (TR)	TR $\leq$ 2 years	3	6.25
	2 years $<$ TR $\leq$ 5 years	12	25.00
	5 years $<$ TR $\leq$ 10 years	14	29.17
	10 years $<$ TR $\leq$ 15 years	8	16.67
	15 years $<$ TR $\leq$ 20 years	4	8.33
	20 years $<$ TR	7	14.58

TABLE 6.2
Behavioral characteristics of transportation maintenance workers

Behavioral Characteristics		Number	Percentage (%)
Stretching Exercise	Yes	35	72.92
	Time of stretching exercise	17	35.42
	Before the shift	8	16.67
	During the shift	2	4.17
	After the shift	8	16.67
	Whenever as needed		
Reason of Stretching Exercise	Routine or habit	17	34.00
	Feels pain	18	36.00
	No	13	27.08
Use of PPE	Yes	46	95.83
	No, PPE is available	2	4.17

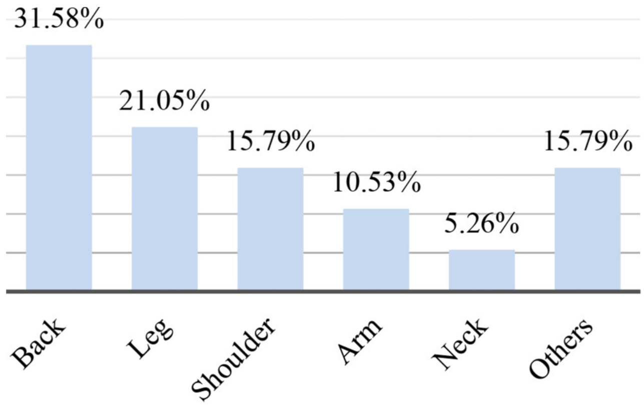


Figure 6.2 Participant injury detail.

common injuries was derived from historical data and incorporated into the survey, enabling respondents to indicate the most common injuries they have encountered. Of the respondents, 70.21% had never been injured, while 29.79% had experienced injuries. Among the injured participants, 31.58% had back injuries, 21.05% had leg injuries, and 15.79% had shoulder injuries, as depicted in Figure 6.2.

6.2.4 Identified Activities of Top Concern

To determine the maintenance activities that pose the highest risk of injury to the participants, the survey employed two questions. Firstly, respondents were requested to rank the activities according to their perception of the likelihood of causing back/shoulder injury, with a score of one indicating the least probability, and five the highest. Secondly, participants were asked to rank the activities based on their frequency of performance, with zero indicating never, one indicating the least frequent, and five indicating the most frequent. The researchers used a weighted average approach, combining the perception and frequency information to rank the activities. The results revealed that lifting and pushing/pulling activities were the most frequently performed and perceived to be the most likely to cause back and shoulder injuries among the workers, with the highest number of past injuries as shown in Figure 6.3.

6.2.5 Identified Lifting Tasks of Top Concern

To identify the specific tasks within the lifting activity that pose the highest risk of injury, three criteria were utilized. These criteria comprised the participants' perception of the probability of sustaining back or shoulder injury resulting from specific activities, the frequency at which they carry out those activities, and the number of past injuries associated with those activities. Based on the analysis of the data, the results indicated that lifting bags of materials, signs, and metal plates were the activities that required the most concern, as shown in Figure 6.4. After a further discussion with the safety director who oversees the transportation

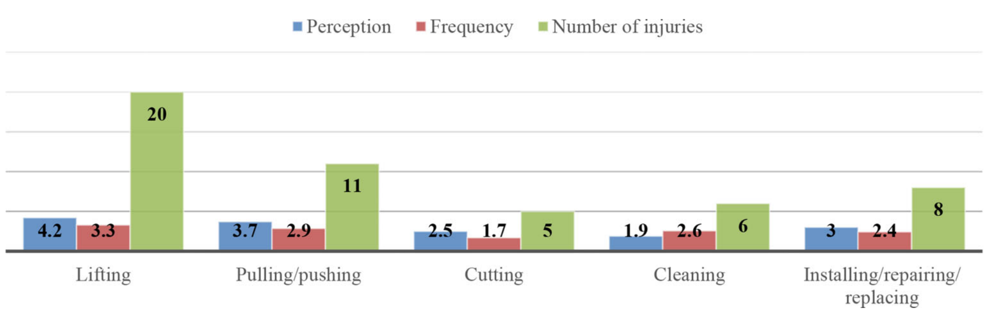


Figure 6.3 Activities of top concern.

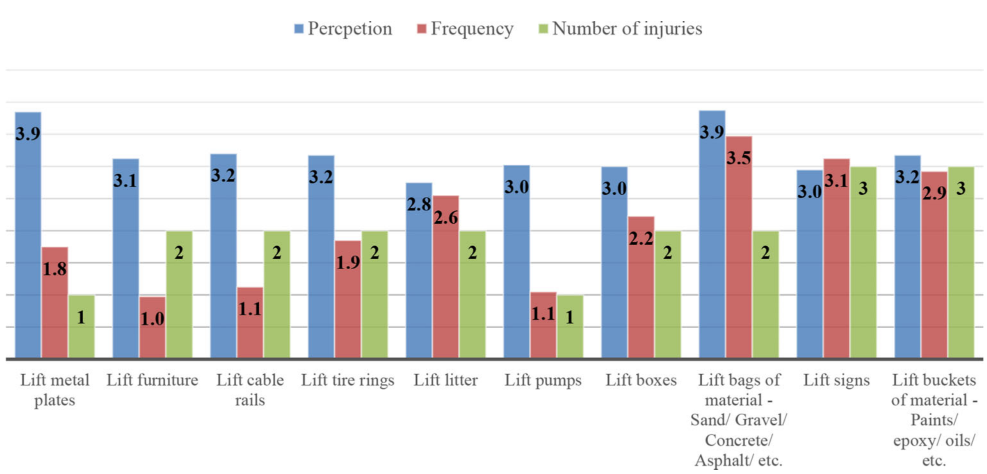


Figure 6.4 Lifting tasks of top concern.

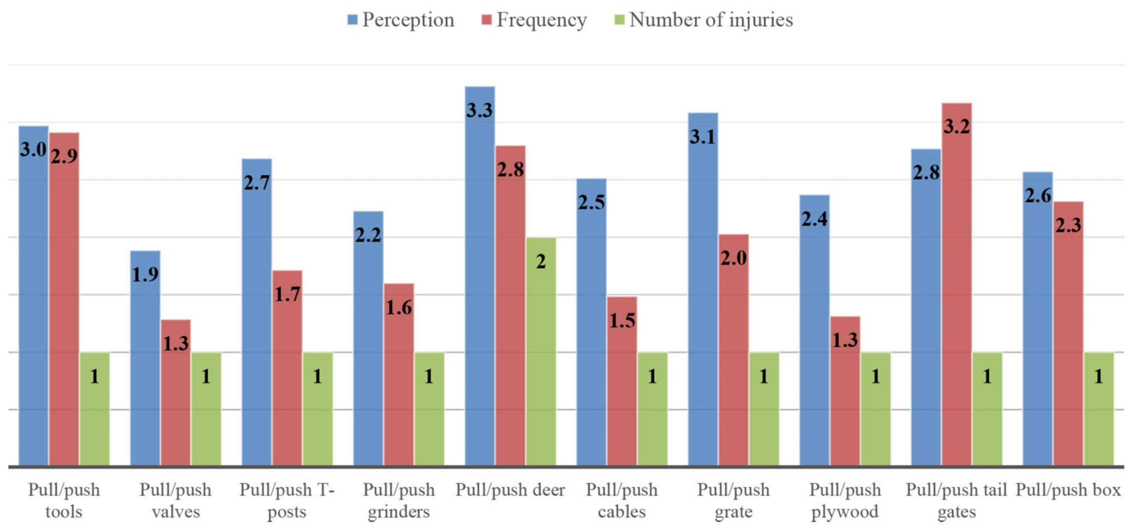


Figure 6.5 Pulling/pushing tasks of top concern.

work across the state, the metal plate could most likely refer to the traffic sign. Therefore, that narrows down three specific tasks (i.e., bags of material, signs, and metal plates) into two tasks (bags of material and signs).

6.2.6 Identified Pulling/Pushing Tasks of Top Concern

Similarly, to identify the specific tasks within the pulling/pushing activity that cause the most injuries, three same criteria were employed. Based on the analysis of the data, the results indicated that pulling/pushing tools (with shoveling as the most frequently used tool) and pulling a dead deer were the activities that required the most concern, as shown in Figure 6.5.

7. PHASE III: PROPOSAL OF ERGONOMIC SOLUTIONS THROUGH ONSITE OBSERVATIONS

7.1 Methods

To develop effective ergonomic solutions for the tasks that were identified as the top concerns, it is necessary to understand how these tasks are typically performed in real-world settings. To achieve this, onsite observations were conducted at one of the maintenance units of INDOT to capture how workers lifted bags and sign stands, and how they pulled or pushed asphalt and dead deer.

7.1.1 Design of Onsite Observation Checklists

Prior to conducting onsite observations, various parameters were prepared for later onsite verification. For instance, during the lifting task, which includes bags of dry concrete mix and sign stands, the research team controlled certain parameters as presented in Appendix C. These parameters were initially derived from literature review, online survey, and discussion with the safety director at INDOT. For instance, when lifting bags, participants should bend their legs to lift, as well as turn around to lift. The weight of each bag of sand was either 30, 40, or 50 pounds. Participants were required to lift the bags from the pallet to the truck with liftgate, and then from the truck with liftgate to the ground at the site. The horizontal distance for lifting bags was fixed at 10 feet. Participants performed the lifting task with or without exoskeleton, and with and without stretching exercises. Similar parameters were employed during the pulling and pushing task, as specified in Appendix D. These parameters were revised based on onsite observation for later discussion with the safety director at INDOT.

7.1.2 Collection of Onsite Observation Data

In order to ensure the precision of the parameters employed in the field experiments, the researchers made two visits to an INDOT maintenance unit at Tipton, Indiana, on September 30, 2021, and December 10, 2021. During these visits, the researchers verified the parameters of how identified activities of top concern are performed, such as the techniques commonly used by workers when performing lifting activities, as well as the horizontal and vertical distances that are typically covered when lifting.

7.1.3 Analysis of Onsite Observation Data

The collected data were manually analyzed and cross-checked with prior studies. Such analyses could be advantageous for proposing ergonomic solutions and designing field experiments.

7.2 Results and Discussion

The results and discussion section presents the findings of onsite observations.

7.2.1 Observed Lifting Activities

7.2.1.1 Lifting bags of dry concrete mix. Due to the need for confidentiality as required by the IRB, the researchers were obligated to mask the workers' faces in any figures presented in this report. The initial activity that was observed is lifting bags of materials, which could be performed in two different ways. The first method is depicted in Figure 7.1, Figure 7.2, Figure 7.3, and Figure 7.4, in which a worker bent their back to lift a bag from a pallet, placed it on the liftgate, raised the liftgate, and subsequently moved the bag onto the truck. In contrast, the second method shown in Figure 7.5 and Figure 7.6, involves a worker lifting a bag from the pallet and directly loading it onto the truck, without using the liftgate.

As shown in Appendix E, a comparison has been made between the values obtained from the site visit and the prior knowledge, which shows that some values are confirmed as correct, while others are different from the previous data. However, it should be noted that this site visit only represents a single district unit and may not be representative of other district units. Therefore, the final values to be employed in the experiment require confirmation from the personnel who oversees a larger area. For instance, lifting bags to the truck with liftgate can be accomplished via two approaches: the first involves lifting the bags to the liftgate and then to the truck, while the second involves lifting the bags directly to the truck with liftgate, which is new information. It was also learned that the loads of lifting commonly used at the site are 80-pound bags, which differs from the prior understanding, owing to its lower unit price. Furthermore, it was initially believed that stretching exercise was practiced at the site based on the survey, but it was discovered that this was not the case and workers did not quite do stretching exercise. In addition, workers actually typically lift bags by bending their backs based on site observation instead of bending their legs as claimed in their survey responses.

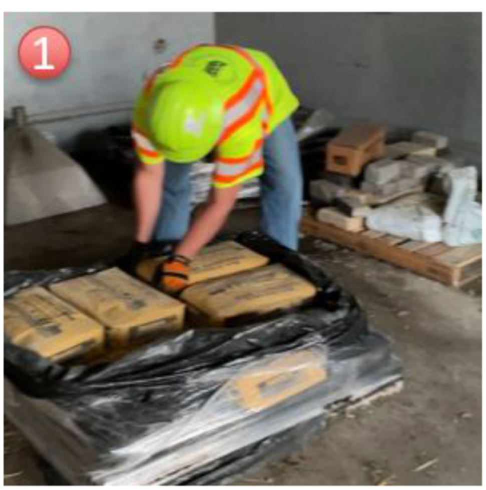


Figure 7.1 Lifting bags of dry concrete mix–step one.

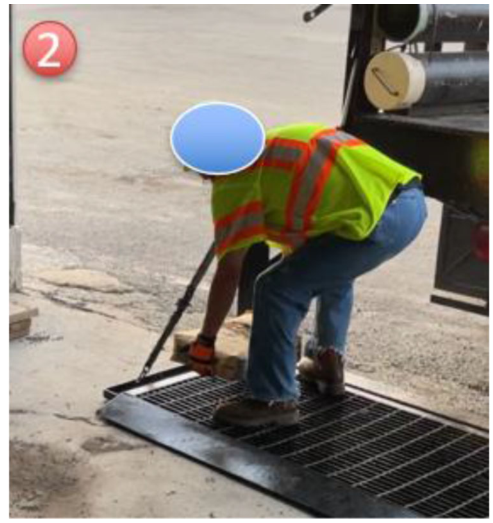


Figure 7.2 Lifting bags of dry concrete mix–step two.

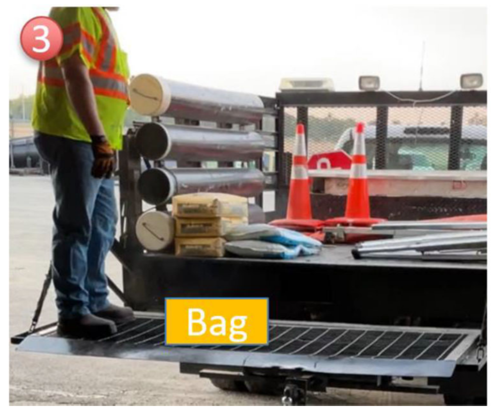


Figure 7.3 Lifting bags of dry concrete mix–step three.

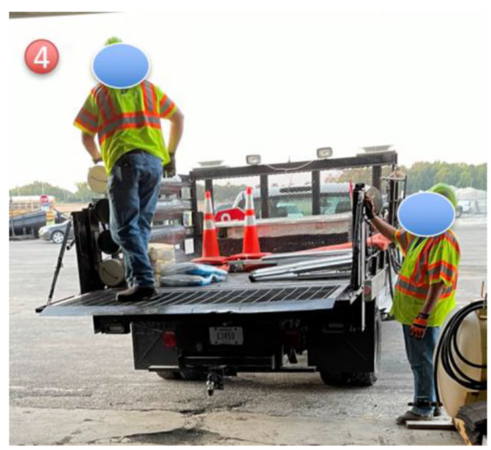


Figure 7.4 Lifting bags of dry concrete mix–step four.

7.2.1.2 Lifting sign stands. During the site visit, the researchers also observed workers lifting sign stands and identified two different approaches. In both approaches, the frames were folded up and two frames were

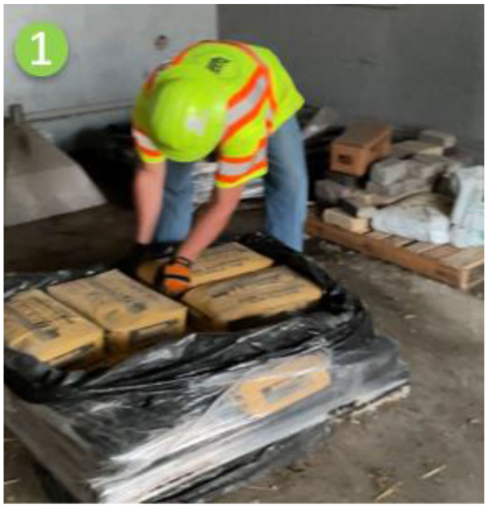


Figure 7.5 Lifting bags of dry concrete mix alternative–step one.

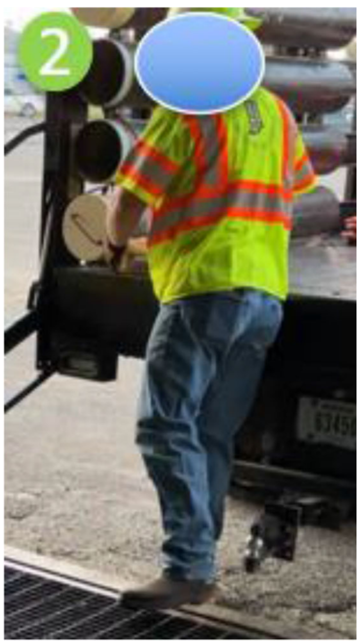


Figure 7.6 Lifting bags of dry concrete mix alternative–step two.

lifted at a time. However, there were differences in how the frames were loaded onto the truck. In one approach, the frames were loaded from the back (Figure 7.7, Figure 7.8, and Figure 7.9), while in the other approach, the frames were loaded from the side (Figure 7.10, Figure 7.11, and Figure 7.12).

As shown in Appendix F, a comparison has been made between the values obtained from the site visit and the prior knowledge, which shows that some values are confirmed as correct, while others are different from the previous data. For example, during the onsite observations of lifting sign stands, it was found that workers bend back a little to lift.

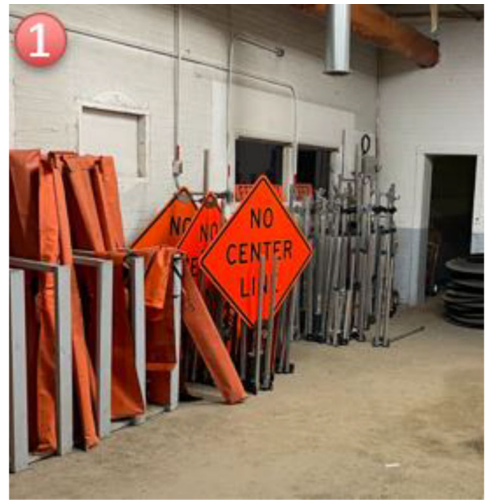


Figure 7.7 Lifting sign stands–step one.

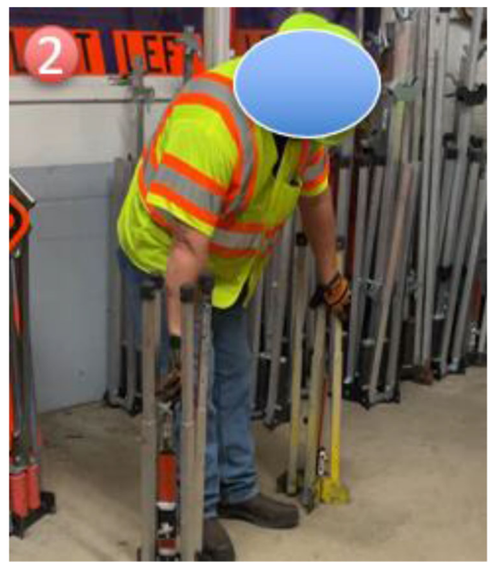


Figure 7.8 Lifting sign stands–step two.

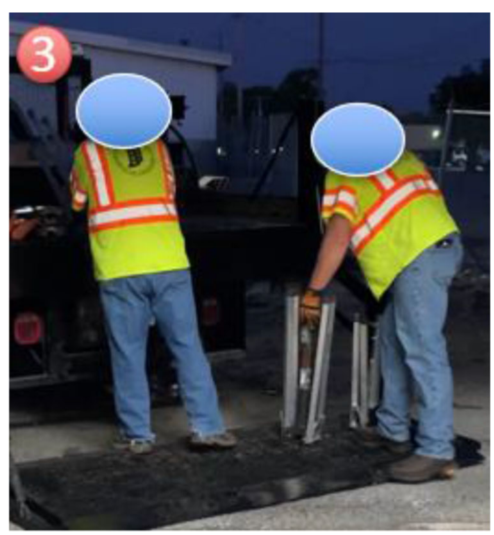


Figure 7.9 Lifting sign stands–step three.

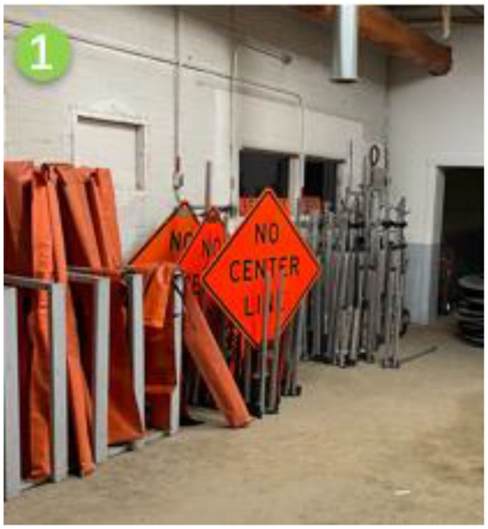


Figure 7.10 Lifting sign stand alternative–step one.

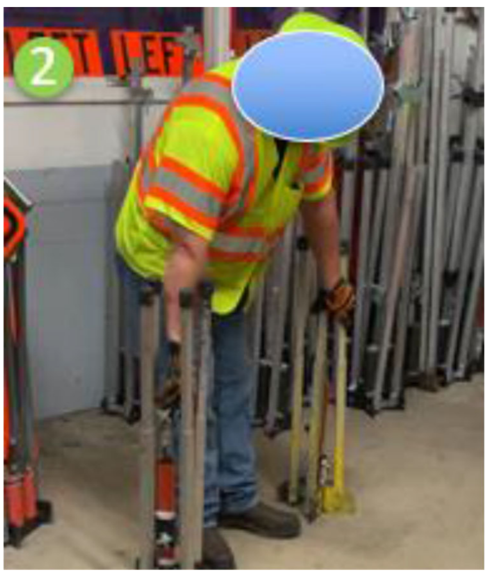


Figure 7.11 Lifting sign stand alternative–step two.

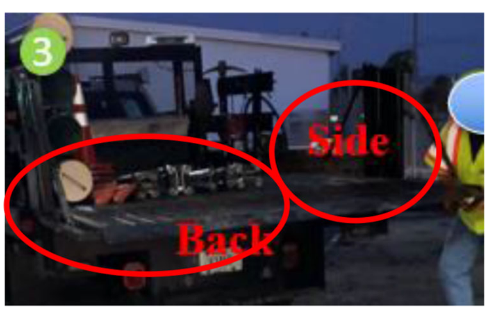


Figure 7.12 Lifting sign stand alternative–step three.

7.2.2 Observed Pulling/Pushing Activities

7.2.2.1 Shoveling asphalts. The researchers also observed how shoveling asphalt is typically performed. As shown in Figure 7.13 through Figure 7.19, initially,

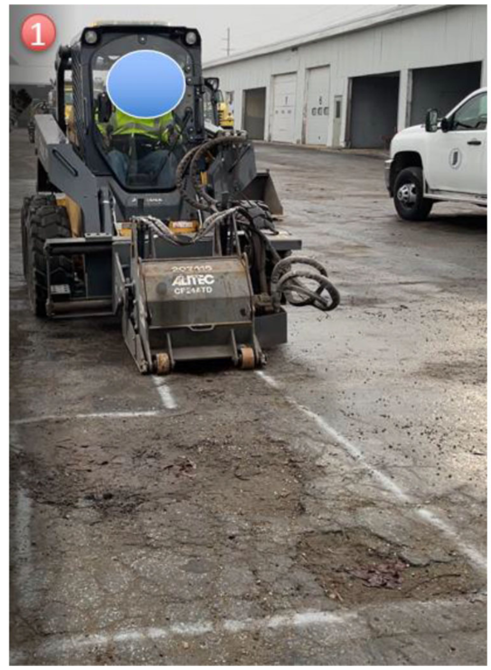


Figure 7.13 Shoveling asphalts–step one.

Figure 7.14 Shoveling asphalts–step two.

workers use a breaker to break up the damaged asphalt into small pieces. Several workers then work together to shovel the asphalt into a loader for complete removal. A broom and blower are then used to clean the pothole. Two common sizes of potholes are shown, and measurements were taken for simulation purposes if required. The asphalt machine is then brought as close as possible to the pothole and workers shovel the asphalt onto the ground. Finally, an asphalt roller is used to make the ground tight and flat. Throughout the asphalt patching process, several potential ergonomic risks to workers were identified, particularly in the steps of asphalt removal and asphalt patching.

7.2.2.2 Pulling dead deer. The researchers also observed how dead deer are typically handled. INDOT workers mocked the process with a bag of concrete mix. Based on the visual representations provided in Figures 7.20 to 7.27, it appears that

Figure 7.15 Shoveling asphalts–step three.

Figure 7.16 Shoveling asphalts–step four.

Figure 7.17 Shoveling asphalts–step five.

pulling a deer is typically a task that requires two workers. During this task, one worker is responsible for monitoring traffic while the other worker pulls the deer from the center of the road to the side. After the deer has been moved to the side of the road, both workers will then pull the deer together to move it to the lift gate. Once the lift gate has been raised, one worker will then pull the deer from the lift gate and load it onto the truck. Workers will also need to do it reversely to pull the deer from truck to a burner.

After conducting onsite observations, it was verified that the workers utilize both hands when pulling the

Figure 7.18 Shoveling asphalts–step six.

Figure 7.19 Shoveling asphalts–step seven.

Figure 7.20 Pulling deer step one–dragging from the road to the curb.

Figure 7.21 Pulling deer step two–dragging from the curb to the liftgate.

Figure 7.22 Pulling deer step three–raising liftgate.

Figure 7.23 Pulling deer step four–dragging from the liftgate to the truck.

Figure 7.24 Pulling deer step five–dragging from the truck bed to the liftgate.

deer. However, they indicated that the weight of the deer could be approximately 200 pounds, which is higher than the previously assumed weight of 125 pounds. The distance required to pull the deer is approximately 18 feet, including the lane width (12 feet) and lift gate width (8 feet). The workers do not employ

Figure 7.25 Pulling deer step six–lowering down the liftgate to let a worker step off.

Figure 7.26 Pulling deer step seven–rising the liftgate to the burner height.

Figure 7.27 Pulling deer step eight–dragging the deer to the burner.

any additional equipment apart from the lift gate to manage the deer. The process requires two workers, one to halt traffic and pull the deer from the road to the side, while two workers work in conjunction to transport the deer to the lift gate of the truck, and one worker pulls the deer from the lift gate and into the truck. Despite knowing the benefits of the exercise program, the workers do not engage in any exercise routines, as shown in Appendix G (pull deer from road to truck) and Appendix H (pull deer from truck to burner).

8. PHASE IV: EVALUATION OF PROPOSED ERGONOMIC SOLUTIONS THROUGH FIELD EXPERIMENTS

8.1 Methods

Experiments were carried out in real-world settings to explore the possible effects of suggested ergonomic interventions on the health and safety of workers performing transportation maintenance tasks.

8.1.1 Design of Field Experiments

8.1.1.1 Physiological and subjective measures. The study encompasses the gathering of two primary categories of information: physiological measurements and personal perceptions, which are common elements in ergonomic investigations, as shown in Figure 8.1 (Rodrigues et al., 2022). Different types of data can provide supplementary information for each other. Specifically, generalized muscle fatigue could be measured by physiological data including heart rate (the number of heart beats per minute) and electrodermal (EDA) activity, also known as skin conductance. In addition, motion sensors will be used to detect any unsafe actions based on trajectories. All these three types of physiological data cannot detect localized muscle fatigue because they monitor body muscle as a whole (Rodrigues et al., 2022). Therefore, electromyography (EMG) sensors will be attached to specific muscles to measure muscle contractions, as shown in Figure 8.2. In addition to physiological data, subjective data will also be collected to help better understand the physiological data, as shown in Appendix K (Aryal et al., 2017; Borg, 1982). The level of muscle exertion is linked to the risk of physical fatigue, so participants will be asked questions to better understand how they feel during each trial. This will help to differentiate between participants who may have a higher heart rate but may not necessarily be experiencing higher levels of physical fatigue. The subjective data collected will be used in conjunction with physiological data to better understand the overall physical fatigue experienced by the participants. In addition, usability scale (Appendix K) (Bangor et al., 2008) and pressure scale (Appendix K) (Antwi-Afari et al., 2021) were also used in the field experiments (Ko et al., 2018). For the usability scale, questions 1, 3, 5, 7, and 9 are positive, while questions 2, 4, 6, 8, and 10 are negative.

8.1.1.2 Experimental procedure of lifting bags of dry concrete mix. Table 8.1 shows the parameters that will be used for simulating the experiment of lifting bags of dry concrete mix, which is the most common material that INDOT transportation maintenance workers need to lift in their daily work. Based on the onsite observations, workers typically lift bags from the pallet

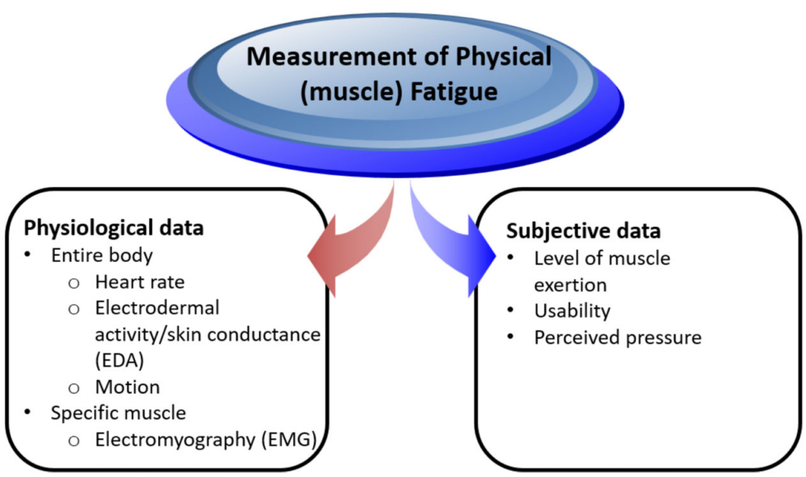


Figure 8.1 Physiological data and subjective data.

Figure 8.2 EMG sensor, EDA sensor, muscle strength tester, and motion sensor (left to right).

TABLE 8.1
Parameters of lifting bags of dry concrete mix

Parameters	Value(s)	Justification or Data Source
Approach to Lifting Bags	Directly lift to the truck	Onsite observation, confirmation with safety director, and confirmation with four highway maintenance technicians
Exoskeleton	Yes/No	Literature
Loads of Lifting	31.5-pound bags/50-pound bags/80-pound bags	Onsite observation and survey
Height of Bags	From 28″ to 4″ by 4″ after every two bags	Onsite observation
Techniques of Lifting	Nature (squat/stoop/combined)	Onsite observation, survey, and literature
Lifting Stuff	Bags of dry concrete patch mix	Onsite observation, survey, confirmation with safety director, and confirmation with two highway maintenance technicians
Vertical Distance	28–4″ (on pallet)/42″ (on truck tailgate)/0″ (on ground)	Onsite observation
Horizontal Distance	7.5′	Onsite observation, and confirmation with two highway maintenance technicians
Other Tools or Help Used	No	Onsite observation, and survey
Number of Bags	12 bags	Onsite observation, confirmation with safety director, and confirmation with two highway maintenance technicians

straight onto the truck's rear, which will be the lifting technique employed by participants during the experiment. They usually lift 80-pound bags on site. Therefore, an 80-pound bag will be one of the testing weights. In addition, a 50-pound bag is another weight that INDOT workers usually lift and is close to the load constant recommended under the ideal condition by National Institute for Occupational Safety and Health (NIOSH). Bags of 31.5 pounds were calculated by using the recommended weight limit (RWL) equation and considering Load Constant (LC), Horizontal Multiplier factor (HM), Vertical Multiplier factor (VM), Distance Multiplier factor (DM), Asymmetric Multiplier factor (AM), Frequency Multiplier factor (FM), and Coupling Multiplier factor (CM) considering work that INDOT workers usually do, as shown in the equation (1) below (Waters et al., 1994). Bags are usually packed and delivered on a pallet with the layout of seven bags per layer and six layers per pallet (28 inches in height). In addition, INDOT maintenance workers usually lift 10–15 bags per time and once per day. To mimic the varying heights workers must lift in their daily tasks, lifting 12 bags has been chosen since it approximates the average number of bags lifted by a worker each day and can replicate different potential lifting heights by arranging two bags per layer. Participants will be required to lift 12 bags straight onto the truck both with and without an exoskeleton. The exoskeleton will be utilized to investigate if its use can assist workers in accomplishing the task under safer conditions.

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM \qquad \text{(Eq. 4.1)}$$

For lifting bags of dry concrete mix, there will be six trials in total, because there are two variables: (1) loads of lifting (31.5-pound bags, 50-pound bags, and 80-pound bags.) and (2) with or without an exoskeleton. Back exoskeleton is selected as the assistance tool because (1) low back pain is the main injury experienced by workers, (2) back exoskeleton will provide support when workers stoop to lift, and (3) the platform height from which bags are lifted and the platform height to which bags are placed are under participant's chest height, which makes back exoskeleton more suitable, compared with shoulder exoskeleton (providing support when performing tasks over chest height). Table 8.2 shows an example of the experiment setup. In trial one, the participant will lift twelve 31.5-pound bags in about 5 minutes from pallet to truck, then take a short break for 5 minutes, and then lift the twelve 31.5-pound bags from truck to ground. Each trial will be separated into a recovery period of 20 minutes, during which exoskeletons will be taken off and subjective responses will be collected. In this situation, for lifting bags (six trials), the total time would be around 270 minutes. Six trials will be ordered by Balanced Latin Squares, which reduces the order effect and carry-over effect. For instance, concerning the order effect, if all participants lift 31.5-pound bags in trial one, 50-pound bags in trial two, and 80-pound bags in trial three, it would be impossible to evaluate whether lifting 80-pound bags leads to more injuries, as the risk accumulates from trial one and trial two. To address the carry-over effect, the Balanced Latin Squares will arrange the sequence of experiment trials such that each trial precedes another trial exactly once when the total number of trials is even (Sheehe & Bross, 1961), as shown in Appendix I.

In the experiment site, six pallets with three different weights of bags are arranged in the order generated by Balance Latin Square. For example, for the first

TABLE 8.2
Experiment of lifting bags of dry concrete mix

No Back Exoskeleton	Back Exoskeleton
A: 31.5-pound bags Trial 1: Pallet to truck with 12 bags (5 minutes) + Break (5 minutes) + Truck to site with 12 bags (5 min) Break Between Trials (20 minutes)	B: 31.5-pound bags Trial 4: Pallet to truck with 12 bags (5 minutes) + Break (5 minutes) + Truck to site with 12 bags (5 minutes) Break Between Trials (20 minutes)
C: 50-pound bags Trial 2: Pallet to truck with 12 bags (5 minutes) + Break (5 minutes) + Truck to site with 12 bags (5 minutes) Break Between Trials (20 minutes)	D: 50-pound bags Trial 5: Pallet to truck with 12 bags (5 minutes) + Break (5 minutes) + Truck to site with 12 bags (5 minutes) Break Between Trials (20 minutes)
E: 80-pound bags Trial 3: Pallet to truck with 12 bags (5 minutes) + Break (5 minutes) + Truck to site with 12 bags (5 minutes) Break Between Trials (20 minutes)	F: 80-pound bags Trial 6: Pallet to truck with 12 bags (5 minutes) + Break (5 minutes) + Truck to site with 12 bags (5 minutes) Break Between Trials (20 minutes)

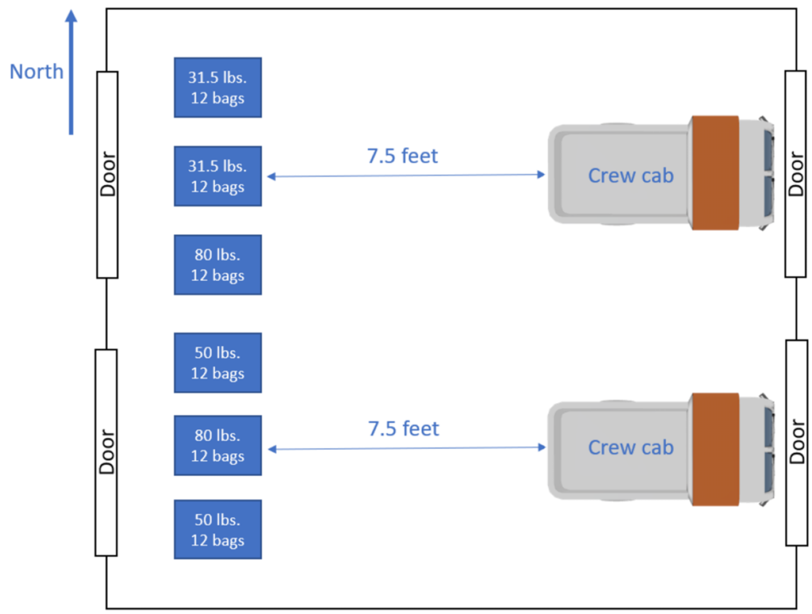


Figure 8.3 Layout of experiment site.

participant, six pallets with weights of 50-pound bags, 80-pound bags, 50-pound bags, 80-pound bags, 31.5-pound bags, 31.5-pound bags from south to north, were placed in line as shown in Figure 7.1. The distance between pallets and the truck was set as 7.5 feet, which is the common distance that an INDOT maintenance worker needs to travel while carrying bags of concrete mix based on onsite observation, and confirmation with two individual workers. On each pallet, a total of 12 bags are placed with two bags on each layer and six layers in total, as shown in Figure 8.3 and Figure 8.4.

8.1.1.3 Experimental procedure of shoveling gravels. Table 8.3 shows the parameters that will be used for simulating the experiment of shoveling gravels, which is one of the most common activities that INDOT workers need to perform. Based on the observations, most workers shovel 10 minutes per time and two times per hour with two hands. Flat shovel is more commonly used. Each time, they will shovel about 10 pounds of gravel. Participants will be asked to shovel when wearing an exoskeleton and without wearing an exoskeleton. In addition, ergonomic shovels have also been investigated as a useful tool to reduce muscle overexertion in previous research about shoveling snow (Huang & Paquet, 2001). It will also be tested in this project.

In total, with two variables, there are four trials including: (1) shovel with no back exoskeleton and with regular shovel, (2) shovel with back exoskeleton and regular shovel, (3) shovel with no back exoskeleton and with an ergonomic handle, and (4) shovel with back exoskeleton and with an ergonomic handle, as shown in Table 8.4. For example, in trial one, the participant will shovel broken gravel for 3 minutes, clean for 1 minute, rest for 5 minutes, shovel new gravel for 3 minutes, and patch for 1 minute. Each trial will be separated by a 20-minute break. In this situation, for shoveling gravel (four trials), the total time would be around 140

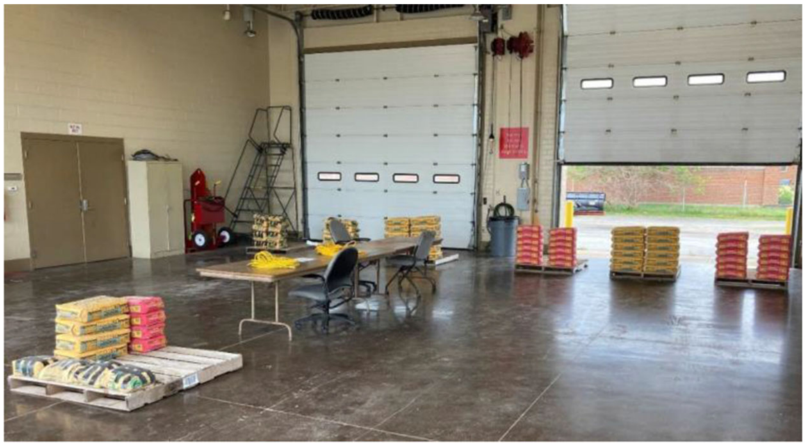


Figure 8.4 Arrangement of bags and pallets.

TABLE 8.3
Parameters of shoveling gravels

Parameters	Value(s)	Justification or Data Source
Techniques of Shoveling Gravels	Two hand push and pull	Onsite observation, confirmation with safety director, and confirmation with two highway maintenance technicians
Assistance	No/back exoskeleton/ergonomic handle/both back exoskeleton and ergonomic handle	Literature
Materials	Gravel	Onsite observation, survey, confirmation with safety director, and confirmation with two highway maintenance technicians
Tools	Flat shovel	Onsite observation, and confirmation with two highway maintenance technicians
Shoveling Direction	Shovel from left to right, and from right to left.	Onsite observation, and confirmation with two highway maintenance technicians
Total Weight to Be Shoveled	About 600 pounds (10 pounds/shovel, 20 shovels/minute, 3 minutes/time)	Onsite observation, and confirmation with two highway maintenance technicians
Distance Between the Standing Point and the Pile	3 feet	Onsite observation, and confirmation with two highway maintenance technicians
Other Tools or Help Used	No	Onsite observation, and confirmation with two highway maintenance technicians

TABLE 8.4
Experiment of shoveling gravels

A: No back exoskeleton + regular shovel Shovel broken gravel (3 minutes) + Clean (1 minute) + Rest (5 minutes) + Shovel new gravel (3 minutes) + Patch (1 minute) Break between trials (20 minutes)	B: Back exoskeleton + regular shovel Shovel broken gravel (3 minutes) + Clean (1 minute) + Rest (5 minutes) + Shovel new gravel (3 minutes) + Patch (1 minute) Break between trials (20 minutes)
C: No back exoskeleton + shovel with ergonomic handle Shovel broken gravel (3 minutes) + Clean (1 minute) + Rest (5 minutes) + Shovel new gravel (3 minutes) + Patch (1 minute) Break between trials (20 minutes)	D: Back exoskeleton + shovel with ergonomic handle Shovel broken gravel (3 minutes) + Clean (1 minute) + Rest (5 minutes) + Shovel new gravel (3 minutes) + Patch (1 minute) Break between trials (20 minutes)

minutes. Figure 8.5 shows an example of the experiment setup.

8.1.1.4 Experimental procedure of lifting sign stand. Table 8.5 shows the parameters that will be used for simulating the experiment of lifting sign frames, which is one of the most common materials that INDOT workers need to lift. Based on the observations, most workers directly lift frames from storage ground to the truck through the side of the truck, which will be the lifting method participants will use in the experiment. Participants will be asked to lift six sign frames when wearing an exoskeleton and without wearing exoskeleton, because they usually need to lift six frames per day. In addition, they usually need to lift those six sign frames four times, including once to load up in the morning, once to offload from the truck and place in the field, once to take down in the field and put back in the truck, and once to offload from the truck and place back in the shop.

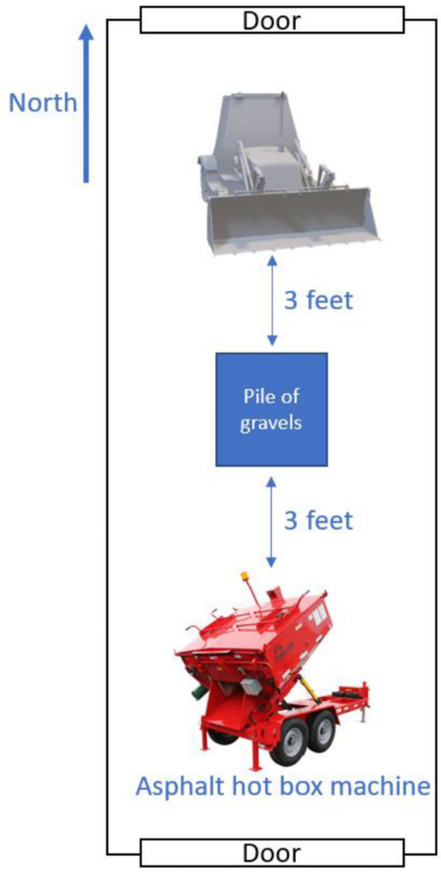


Figure 8.5 Layout of experiment site.

In total, there are six trials, because two parameters are tested here. One parameter is the way to place sign stands, including placing vertically at ground, vertically at waist height, and horizontally at waist height. Another parameter is wearing or not wearing an exoskeleton. For example, in trial one, the participant will lift from storage to truck with 6 sign stands for 2 minutes, have a break for 5 minutes, and lift from truck to site with 6 sign stands for 2 minutes, as shown in Table 8.6. Lastly, the participant will lift all sign stands from truck to storage ground for about 2 minutes. Each trial will be separated by a 20-minute break. In this situation, for lifting sign stands, the total time would be around: 170 minutes. Figure 8.6 shows an example of the experiment setup.

8.1.1.5 Experimental procedure of pulling dead deer. Table 8.7 shows the parameters that will be used for simulating the experiment of pulling deer, which is one of the most common activities that INDOT workers need to perform in their daily work. Based on the observations, two employees are required for this activity. One worker is responsible for halting traffic, while another worker pulls the deer from the road to the side. Next, both workers cooperate to move the deer to the liftgate. As the liftgate rises to the truck's height, one worker pulls the deer from the liftgate into the truck. Upon arriving at the location of the burner (40 inches in height), one worker pulls the deer from the truck to the liftgate. After lowering the liftgate to the burner's height, both workers pull the deer from the

TABLE 8.5
Parameters of lifting sign frames

Parameters	Value(s)	Justification or Data Source
Techniques of Lifting	Turn to lift but do not twist	Onsite observation, survey, and literature
Shoulder Exoskeleton	Yes/No	Literature
Placement of Stands	Vertical on ground/vertical on waist height/horizontal on waist height	Onsite observation, and confirmation with two highway maintenance technicians
Loads of Lifting	2 frames at a time; 6 frames in total for a day	Onsite observation, and confirmation with two highway maintenance technicians
Vertical Distance for Frames	0″ (on ground)/42″ (on truck tailgate)/0″ (on ground)	Onsite observation, and confirmation with two highway maintenance technicians
How is Frame Stored	Sign stands are stored folded up and standing upright on the floor	Onsite observation, confirmation with safety director, and confirmation with two highway maintenance technicians
Horizontal Distance	7.5′	Onsite observation, and confirmation with two highway maintenance technicians
Frequency (Times Per Day)	4 times. Once to load up in the morning. Once to remove from the truck and place in the field. Once to take down in the field and put back in the truck. Once to offload from the truck and place back in the shop.	Onsite observation, survey, and confirmation with two highway maintenance technicians
Other Tools or Help Used	No	Onsite observation, survey, and confirmation with two highway maintenance technicians

TABLE 8.6
Experiment of lifting sign frames

A: No shoulder exoskeleton and vertical at ground Trial 1: Storage to truck with 6 frames (2 minutes) + Break (5 minutes) + Truck to site with 6 frames (2 minutes) Break between trials (20 minutes)	B: Shoulder exoskeleton and vertical at ground Trial 2: Storage to truck with 6 frames (2 minutes) + Break (5 minutes) + Truck to site with 6 frames (2 minutes) Break between trials (20 minutes)
C: No shoulder exoskeleton and vertical waist height Trial 3: Storage to truck with 6 frames (2 minutes) + Break (5 minutes) + Truck to site with 6 frames (2 minutes) Break between trials (20 minutes)	D: Shoulder exoskeleton and vertical waist height Trial 4: Storage to truck with 6 frames (2 minutes) + Break (5 minutes) + Truck to site with 6 frames (2 minutes) Break between trials (20 minutes)
E: No shoulder exoskeleton and horizontal waist height Trial 5: Storage to truck with 6 frames (2 minutes) + Break (5 minutes) + Truck to site with 6 frames (2 minutes) Break between trials (20 minutes)	F: Shoulder exoskeleton and horizontal waist height Trial 6: Storage to truck with 6 frames (2 minutes) + Break (5 minutes) + Truck to site with 6 frames (2 minutes) Break between trials (20 minutes)

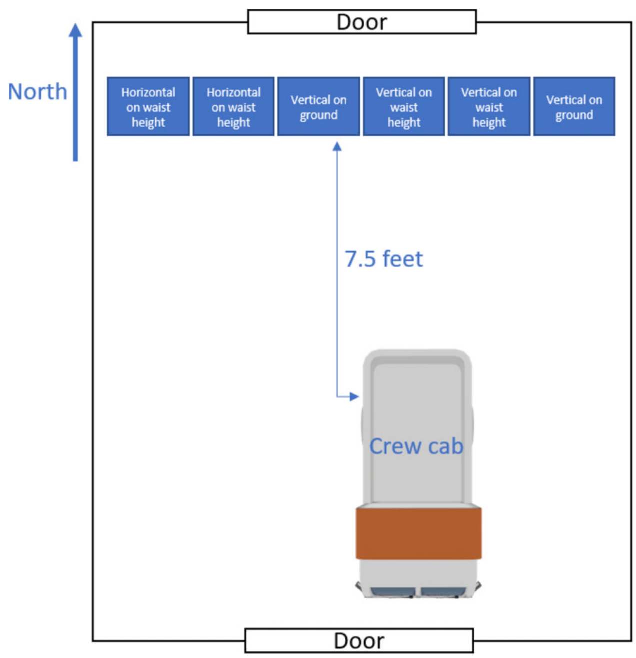


Figure 8.6 Layout of experiment site.

liftgate to the burner. When a worker uses their hands to pull the deer from the road's center to the truck parked at the curb, the pulling distance is approximately 20 feet (i.e., from the center of the two-lane road to the truck's liftgate; 12 feet + 8 feet = 20 feet). Based on the average size of mature white-tail deer and discussions with INDOT maintenance workers, the deer's weight is around 125 pounds.

In total, there are two trials as shown in Table 8.8, because there is only one variable changing: with or without exoskeleton. The back exoskeleton is selected as the assistance tool because (1) low back pain is the main injury experienced by workers and (2) back exoskeleton will provide support when workers stoop to pull. Figure 8.7 shows an example of the experiment setup. For example, in trial one, the participant will drag deer from road to liftgate (1 minute), raise liftgate (1 minute), drag deer from liftgate to truck (1 minute), lower liftgate to let worker step off (1 minute), have a break for traveling to burner (20 minutes), lower and raise liftgate to let worker step on truck (1 minute), drag deer from truck to liftgate (1 minute), lower liftgate to let worker step off (1 minute), raise liftgate to burner height (1 minute), drag deer from liftgate to burner (1 minute). Each trial will be separated by a 20-minute break. In this situation, for pulling deer (two trials), the total time would be around 90 minutes.

8.1.2 Collection of Field Experiments

8.1.2.1 Data collection of lifting bags of dry concrete mix. The population of this study is INDOT highway maintenance technicians. With the help from INDOT, 29 participants including highway maintenance technicians, safety specialists, and supervisors were recruited to participate in this experiment. On each workday, a participant came to the experiment site first thing during her/his scheduled day before doing any other work activities and started to do the experiment at 8:00 AM. The sound and vibration of the participant's mobile phone was turned off, and the phone was securely stored on a table away from the participant. The participant was requested to not check his/her phone until the experiment is complete. The participant was requested to sit in a height-adjustable chair and adjust the height to make herself or himself comfortable. All devices utilized in the experiment were explained to the participant, including muscle strength tester, EMG sensors, EDA sensors, and motion sensors. Cameras were also set up to record the participant's motion and facial expression. The back exoskeleton was also adjusted to fit the participant with the help of the investigator. The participant was then requested to view and sign the consent form if he/she did not have any questions.

Once the consent form is signed, the steps below are followed to complete the experiment.

1. The investigator went through a pre-survey with the participant, which can be found in Appendix J. The pre-survey collects data about the participant's demographic information (gender, age, height, worker type, etc.) and behavior information (smoking habit, drinking habit, etc.).

TABLE 8.7
Parameters of pulling deer

Parameters	Value(s)	Justification or Data Source
Techniques of Pushing/Pulling	Two hand pull	Onsite observation, confirmation with safety director, and confirmation with two highway maintenance technicians
Back Exoskeleton	Yes/No	Literature
Loads of Pushing/Pulling (pounds)	125 pounds	Confirmation with two highway maintenance technicians
Horizontal Distance	20′ (center of the two-lane road to truck tailgate; 12′ + 8′ = 20′)	Onsite observation, and confirmation with two highway maintenance technicians
Vertical Distance	0″ (on ground)/4″ (on tailgate when on ground)/ 42″ (on raised tailgate)/40″ (burner)	Onsite observation
Number of Employees	Two employees are required. One for stopping the traffic. One for pulling the deer from road to side. Two for pulling the deer to lift gate of the truck. One for pulling the deer from the lift gate into the truck.	Onsite observation
Besides the lift gate, other tools used?	No	Onsite observation
Height of the Burner	40″	Onsite observation
How to dump deer to the burner?	Drag deer from truck to liftgate, and lower liftgate. Two employees to drag the deer to the burner from the same side.	Onsite observation

TABLE 8.8
Experiment of pulling deer

A: No back exoskeleton	B: Back exoskeleton
Drag deer from road to liftgate (1 minute) + Rise liftgate (1 minute) + Drag deer from liftgate to truck (1 minute) + Lower liftgate to let worker step off (1 minute) + Break for traveling to burner (20 minutes) + Lower and rise liftgate to let worker step on truck (1 minute) + Drag deer from truck to liftgate (1 minute) + Lower liftgate to let worker step off (1 minute) + Rise liftgate to burner height (1 minute) + Drag deer from liftgate to burner (1 minute)	Drag deer from road to liftgate (1 minute) + Rise liftgate (1 minute) + Drag deer from liftgate to truck (1 minute) + Lower liftgate to let worker step off (1 minute) + Break for traveling to burner (20 minutes) + Lower and rise liftgate to let worker step on truck (1 minute) + Drag deer from truck to liftgate (1 minute) + Lower liftgate to let worker step off (1 minute) + Rise liftgate to burner height (1 minute) + Drag deer from liftgate to burner (1 minute)
Break between trials (20 minutes)	Break between trials (20 minutes)

2. The investigator checked whether the participant wore a t-shirt, shorts, body lotion, and makeup. The requirement to wear a t-shirt and shorts enables the investigator to attach sensors to different body parts of the participant, as shown in Figure 8.8. In this figure, red circles show the placement of EMG sensors, dark yellow dots indicate the placement of motion sensors, and the dark blue dot shows the EDA sensor. The requirement of not wearing any body lotion and makeup allows the EMG sensor to work properly as body lotion and makeup may block the data collection and transmission detected by EMG electrodes. The skin was also cleaned by using alcohol wipes before EMG sensors were attached to participant's body.
3. The participant was requested to have a 10-minute rest for the investigator to record baseline values for EMG and EDA data. Baseline values provide reference for detecting EMG and EDA signals during the lifting work.
4. The EMG data of participant's maximum voluntary contraction was recorded by using the EMG sensors and a muscle tester. The participant was requested to use the maximum force that they can generate by using different muscle parts while the investigator provides manual resistance.

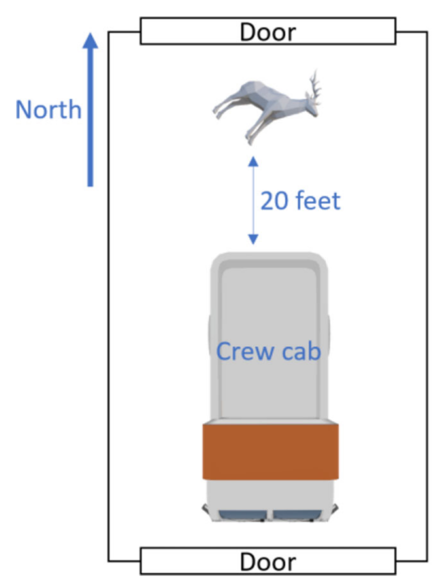


Figure 8.7 Layout of experiment site.

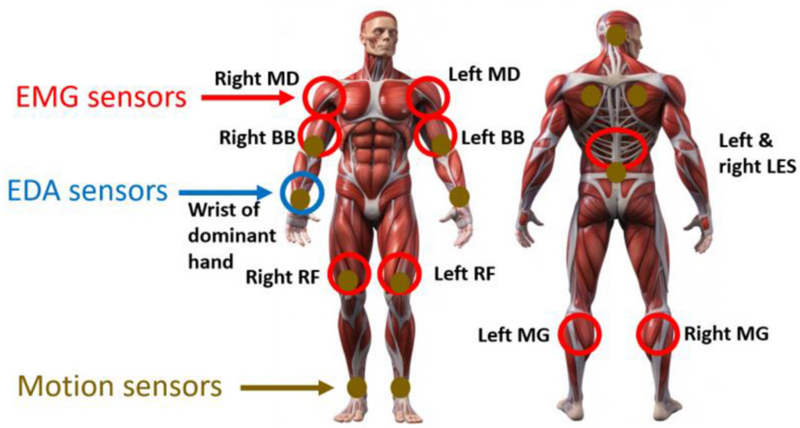


Figure 8.8 Placement of sensors.

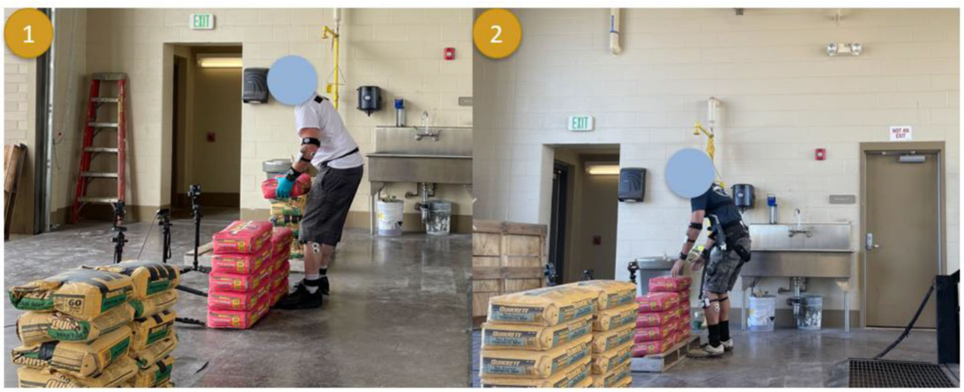


Figure 8.9 Lifting 31.5-pound bags, 50-pound bags, and 80-pound bags: (1) without back exoskeleton and (2) with back exoskeleton.

Figure 8.10 Bags on the truck and bags on the ground.

5. The participant was requested to have a 10-minute rest before the trials can be performed to avoid fatigue caused by the previous step of measuring maximum voluntary contraction.
6. There are six trials in total. In each trial, the investigator first recorded the temperature and humidity, which influence the EDA data. Then the participant lifted 12 bags to the truck with or without the back exoskeleton, depending on the order. The participant was requested to lift the left bag first and then lift the right bag and lift the next layer in the same way once two bags in the previous layer were finished. The participant was requested to finish all six layers (12 bags in total), as shown in Figure 8.9. Such a requirement enables the investigator to compare data for different lifting heights among different workers.
7. Once all the bags were loaded to the truck as shown in Figure 8.10, the participant sat and took the post-survey, which can be found in Appendix K (Aryal et al., 2017; Borg, 1982) and had a 5-minute rest on the chair.
8. After that, the participant offloaded 12 bags from the truck to the ground. The participant was also requested to offload bags from left to right from the top layer to the bottom layer on the truck. And the participant was requested to drop off bags on the ground in the way that they usually drop off bags on site to simulate the real scenario.
9. After that, the participant needed to sit in the chair and take the post-survey again, and to have a 20-minute rest. The post-survey collects data about the participant's (1) perceived level of exertion on their shoulder muscle, upper arm muscle, back muscle, upper leg muscle, and lower leg muscle, (2) perception about the product (back exoskeleton) usability and perceived musculoskeletal pressure.
10. Once all six trials were complete, the data of the participant's maximum voluntary contraction was recorded again with EMG sensor and muscle tester.
11. The participant was requested to wear the exoskeleton by herself or himself, and then finish the survey of product (back exoskeleton) usability, as shown as Question 6 of Appendix K.

8.1.2.2 Data collection of shoveling gravels. The population of this study is INDOT highway maintenance technicians. With the help from INDOT, 26 participants including highway maintenance technicians, safety specialists, and supervisors were recruited to participate in this experiment. A similar procedure as in Section 8.1.2.1 was used. The main differences included (1) there are four trials in total, and (2) in each trial, the investigator first recorded the temperature and humidity, which influences the EDA data. Then the participant shoveled broken gravel for 3 minutes, cleaned for 1 minute, rested for 5 minutes, shoveled new gravel for 3 minutes, and patched for 1 minute, as shown in Figure 8.11.

8.1.2.3 Data collection of lifting sign stands. The population of this study is INDOT highway maintenance technicians. With the help from INDOT, 27 participants including highway maintenance technicians, safety specialists, and supervisors were recruited to participate in this experiment. A similar procedure as in Section 8.1.2.1 was used. The main differences included: (1) There are six trials in total. (2) In each trial, the investigator first recorded the temperature and humidity, which influences the EDA data. Then the participant lifted from storage to truck with 6 frames for 2 minutes, had a break for 5 minutes, lifted from truck to site with 6 frames for 2 minutes, as shown in Figure 8.12.

8.1.2.4 Data collection of pulling dead deer. The population of this study is INDOT highway maintenance technicians. With the help from INDOT, 28 participants including highway maintenance

Figure 8.11 Shoveling with (1) regular shovel, (2) back exoskeleton, (3) ergonomic handle, and (4) both ergonomic handle and back exoskeleton.

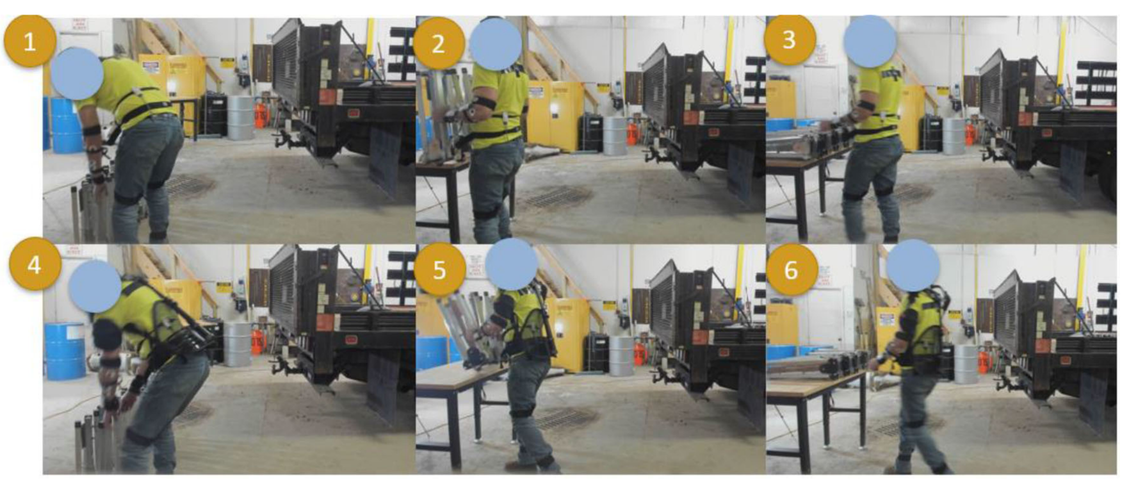


Figure 8.12 Lifting sign stands without shoulder exoskeleton as (1) vertical on ground, (2) vertical on waist height, and (3) horizontal on waist height, and with shoulder exoskeleton as (4) vertical on ground, (5) vertical on waist height, and (6) horizontal on waist height.

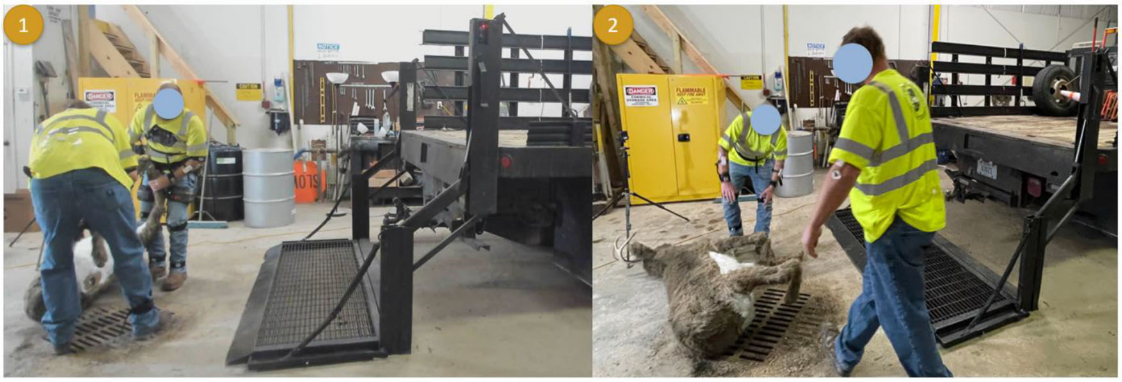


Figure 8.13 Pulling deer (1) with back exoskeleton, and (2) without back exoskeleton.

technicians, safety specialists, and supervisors were recruited to participate in this experiment. A similar procedure as in Section 8.1.2.1 was used. The main differences included: (1) There are four trials in total. (2) In each trial, the investigator first recorded the temperature and humidity, which influences the EDA data. Then the participant dragged deer from road to liftgate (1 minute), raised liftgate (1 minute), dragged deer from liftgate to truck (1 minute), lowered liftgate to let worker step off (1 minute), had a break for traveling to burner (20 minutes), lowered and raised liftgate to let worker step on truck (1 minute), dragged deer from truck to liftgate (1 minute), lowered liftgate to let worker step off (1 minute), raised liftgate to burner height (1 minute), dragged deer from liftgate to burner (1 minute), as shown in Figure 8.13.

8.1.3 Analysis of Field Experiments

Two techniques were utilized for data analysis, comprising descriptive data analysis and paired t-test. Descriptive data analysis was used to determine the demographic and behavioral characteristics of participants using frequency distribution, mean analysis, and percentage calculation. Additionally, a paired t-test was implemented to investigate the impact of different types of assistance on participants' perception of muscle exertion during task performance.

8.2 Results and Discussion

The results and discussion section presents the findings of field experiments.

8.2.1 Lifting Bags of Dry Concrete Mix

8.2.1.1 Demographics of participants of lifting bags. The experiment involved the participation of 29 individuals who were asked to lift bags of concrete mix. The demographic information of the participants is presented as follows. The participants had an average age of 37.45 years and a height of around 70.79 inches. On average, they had a work experience of 3.96 years. Out of the 29 participants, 27 were male and 2 were female.

TABLE 8.9
Demographic information of participants in lifting bags of dry concrete mix, part 1

Demographic	Mean	SD
Age (year)	37.45	9.81
Height (inch)	70.79	3.31
Arm Length (inch)	27.72	2.12
Shoulder Height (inch)	61.14	2.39
Waist Height (inch)	37.86	2.89
Knee Height (inch)	22.50	3.34
Waist Size (inch)	39.21	6.35
Weight (pound)	218.54	49.79
Body Mass index	30.58	5.96
Body Fat (%)	28.21	9.97
Fat Free Body Weight (pound)	151.76	19.26
Subcutaneous Fat (%)	24.02	8.30
Visceral Fat	13.16	5.55
Body Water (%)	51.74	7.41
Skeletal Muscle (%)	47.34	7.28
Muscle Mass (pound)	144.09	18.47
Bone Mass (pound)	7.69	0.82
Protein (%)	16.39	2.36
Basal Metabolic Rate (kcal)	1856.72	188.54
Metabolic Age	38.44	9.47
Tenure (year)	3.96	3.88

The participants had different job titles, including 6 level one highway technicians (HT1), 2 level two highway technicians (HT2), 14 level three technicians (HT3), 2 safety specialists, and 5 supervisors. Ten participants had previous injuries. Most of the participants were right-handed and right footed. Detailed information is available in Tables 8.9 through 8.12.

8.2.1.2 Perceived muscle exertion. Regarding the subjective data analysis, the experiment compared the perceived level of muscle exertion when lifting bags with and without a back exoskeleton, as shown in Table 8.13. The results of the paired t-test revealed that for bags weighing 31.5-pound bags, there was no significant difference in muscle exertion between lifting with and without the exoskeleton for any muscle group. However, for bags weighing 50 pounds, there was a significant difference in the back and upper leg muscles

TABLE 8.10
Demographic information of participants in lifting bags of dry concrete mix, part 2

Demographic	Category	Number of Participants	Ratio (%)
Gender	Male	27	93.10
	Female	2	6.90
Worker Type	HT1	6	20.69
	HT2	2	6.90
	HT3	14	48.28
	Safety specialist	2	6.90
	Supervisor/Manager	5	17.24

TABLE 8.11
Demographic information of participants in lifting bags of dry concrete mix, part 3

Demographic	Category	Number of Participants	Ratio (%)
Injury	Yes	10	34.48
	No	19	65.52
Dominant Hand	Left	6	20.69
	Right	23	79.31
Dominant Foot	Left	5	17.24
	Right	24	82.76

TABLE 8.12
Demographic information of participants in lifting bags of dry concrete mix, part 4

Demographic	Category	Number of Participants	Ratio (%)
Injured	Wrist	1	3.45
	Hand	1	3.45
	Back	4	13.79
	Shoulder	2	6.90
	Leg	1	3.45
	Knee	1	3.45

when using the exoskeleton. This may be because the exoskeleton transferred the load from the back to the upper leg. For bags weighing 80 pounds, there was a significant difference in the back, shoulder, and arm muscles. The exoskeleton provided force to push the worker's back backward, making it easier to lift the bags. As for the shoulder and arm muscles, even though the exoskeleton did not touch or support them, the worker was able to return to a straight position quicker, potentially resulting in a lower perceived level of exertion. However, this result may be limited by subjective bias from the survey. The experiment also cross-checked the survey data with EMG sensor data, but no significant differences were found. It is recommended to use the back exoskeleton when lifting bags weighing 50 pounds and 80 pounds or to change to bags weighing 31.5 pounds to protect the back muscles. To minimize bias in future surveys, the sequence of asking questions should be randomized.

8.2.1.3 Perceived pressure. Regarding the pressure on different muscles, the results indicate that overall pressure was low, and the use of the back exoskeleton did not result in significantly increased pressure on different muscles, as shown in Table 8.14.

8.2.1.4 Perceived usability. The usability of the back exoskeleton was also evaluated through a questionnaire consisting of ten statements (Table 8.15). Participants rated their agreement or disagreement with the statements on a scale ranging from one (strongly disagree) to five (strongly agree). The statements included both positive (P) and negative (N) aspects of the product, and some required reverse scoring to indicate agreement with the product. For example, question nine "I felt very confident using the pro duct" had an average rating of 3.11, indicating agreement with the statement. In contrast, statement ten "I needed to learn a lot of things before I could get going with this product" had an average rating of 2.34, indicating disagreement with the statement, or in other words, ease of use. Overall, the back exoskeleton was found to be acceptable for use based on participant ratings.

8.2.1.5 Muscle contraction. This research employed EMG sensors to evaluate muscle fatigue and evaluate whether there were notable distinctions in muscle activities while lifting varying weights with or without a back exoskeleton. EMG sensors enabled an assessment of the precise physical weariness of specific muscles, which could potentially result in future injuries. Table 8.16 and Table 8.17 present the results of the paired t-tests comparing EMG data. We found that the EMG values obtained from the back muscle varied the most significantly when lifting different weights with and without a back exoskeleton. We did not observe a significant difference when lifting 31.5-pound bags with or without the back exoskeleton. However, when lifting 50-pound and 80-pound bags, there was a significant difference between the two conditions. We also observed a significant increase in heart rate when lifting bags of all weights while wearing the back exoskeleton. This trend was also observed when not wearing the back exoskeleton. Based on these findings, we recommend changing to 31.5-pound bags

TABLE 8.13
Level of muscle exertion comparison

	31.5 Pounds		50 Pounds		80 Pounds	
	With	Without	With	Without	With	Without
Shoulder Muscle	8.71	8.73	10.34	10.44	12.61	13.34*
Arm Muscle	8.93	8.98	10.93	10.94	13.07	13.41*
Back Muscle	9.23	9.29	10.71	11.96*	12.64	13.24*
Upper Leg Muscle	8.89	8.95	10.38	11.48*	12.10	11.63
Lower Leg Muscle	8.53	8.58	9.95	9.97	11.34	10.92

*Significant $p < 0.05$.

TABLE 8.14
Pressure comparison of lifting bags of dry concrete mix

	With Back Exoskeleton Only		
Zero (No Pressure) to Ten (Strong Pressure)	31.5 Pounds	50 Pounds	80 Pounds
Shoulder Muscle	2.17	2.70	3.39
Arm Muscle	2.42	3.00	3.68
Back Muscle	3.12	3.66	4.16
Upper Leg Muscle	3.10	3.55	3.86
Lower Leg Muscle	2.42	2.68	3.18

TABLE 8.15
Usability comparison of back exoskeleton (Bangor et al., 2009)

	31.5 Pounds		50 Pounds		80 Pounds	
One (Strongly Disagree) to Five (Strongly Agree)	P	N	P	N	P	N
1. I think that I would like to use this product frequently.	4.19	–	2.95	–	2.88	–
2. I found the product unnecessarily complex.	–	2.17	–	2.17		1.28
3. I thought the product was easy to use.	3.95		3.74	–	4.26	–
4. I think that I would need the support of a technical person to be able to use this product.	–	1.72	–	1.66	–	1.28
5. I found that the various functions in this product were well integrated.	3.50	–	3.72	–	3.78	–
6. I thought that there was too much inconsistency in this product.	–	2.26	–	2.26	–	2.10
7. I would image that most people would learn to use this product very quickly.	3.74	–	3.91	–	3.74	–
8. I found the product very awkward to use.	–	1.83	–	1.72	–	2.98
9. I felt very confident using the product.	3.40	–	3.24	–	3.22	–
10. I needed to learn a lot of things before I could get going with this product.	–	2.10	–	2.17	–	2.09

TABLE 8.16
EMG comparison with and without exoskeleton

			50 Pounds		80 Pounds	
	With	Without	With	Without	With	Without
EMG - Back	15.08%	16.78%	28.99%	35.79%*	50.79%	61.72%*

*Significant $p < 0.05$.

or using a back exoskeleton when lifting 50-pound and 80-pound bags to reduce the risk of muscle fatigue and potential injuries.

The study also examined whether there were significant differences in EMG values among workers with different levels of tenure. Table 8.18 shows that there was a significant difference between workers with less than 5 years of tenure and those with more than 5 years of tenure. Upon review of the video recordings, it was observed that more experienced workers tended to lift bags at a slower pace, taking at least 10 seconds per lift, whereas less experienced workers tended to rush to complete the task, resulting in increased fatigue and muscle tiredness.

TABLE 8.17
EMG comparison among different lifting weights

	With Back Exoskeleton				Without Back Exoskeleton			
	31.5 Pounds	50 Pounds	50 Pounds	80 Pounds	31.5 Pounds	50 Pounds	50 Pounds	80 Pounds
EMG - Back	15.08%	28.99%*	28.99%	50.79%*	16.78%	35.79%*	35.79%	61.72%*

*Significant $p < 0.05$.

TABLE 8.18
EMG comparison between different tenure range

	With Back Exoskeleton		Without Back Exoskeleton	
	Less than 5 Years	More than 5 Years	Less than 5 Years	More than 5 Years
EMG–Back	32.08%	30.79%	41.87%	34.79%*

*Significant $p < 0.05$.

This study investigated whether varying lifting heights could lead to noteworthy disparities in EMG values among the workers. Table 8.19 demonstrated that there was a significant difference of EMG values in the back muscles when lifting from less than 20 inches compared to greater than 20 inches, regardless of whether an exoskeleton was worn or not. This could be attributed to the fact that lifting from a higher platform lessens the bending angle and the forces needed to lift a material. However, these conclusions have limitations because a Balance Latin Square design was not used. Ideally, a Balanced Latin Square design with 36 trials (6 heights × 3 weights × 2 values for exoskeleton = 36) should be employed to remove the order effect and carry-over effect when examining the impact of varying heights on physiological metrics. A single trial would take 35 minutes, including 5 minutes for lifting bags from pallet to truck, having a short break for 5 minutes, lifting bags from truck to ground for 5 minutes, and having a long break for 20 minutes (also shown in previous Table 8.5). A total of 1,240 minutes (20.67 hours) are needed for each participant, under which condition fatigue will further interfere the collected data and potentially pose workers under ergonomic risks (Shin & Kim, 2007). As a result, the data shown here, and the findings may have been affected by order and carry-over effects. For example, the EMG data recorded at lower levels might be higher not solely due to the increased back exertion it demands, but also because participants had just bent their backs for the prior upper layer(s) and lacked sufficient recovery time from the earlier exertion. The exploration of height with Balanced Latin Square design was explored in the experiments of lifting sign stands. Please refer to Table 8.39 under Section 8.2.3.5 for the insights of how different heights would change muscle activities on lower back region without the interference of order or carry-over effects.

TABLE 8.19
EMG comparison between different heights

	Less than 20 Inches	More than 20 Inches
EMG–Back	46.77%	32.19%*

*Significant $p < 0.05$.

TABLE 8.20
Heart rate comparison with and without exoskeleton

	31.5 Pounds		50 Pounds		80 Pounds	
	With	Without	With	Without	With	Without
HR	75.88	76.78	86.78	90.77*	92.42	100.71*

*Significant $p < 0.05$.

8.2.1.6 Heart rate. In this study, it is investigated if there were notable differences in heart rate when lifting various weights, both with and without a back exoskeleton. Paired t-test results are presented in Tables 8.20 and 8.21. It is generally accepted that a normal resting heart rate falls within the range of 60 to 100 beats per minute, with some variability based on individual factors. While exercising, the heart rate can rise to 130 beats per minute or higher for brief periods, though this varies among individuals. A resting heart rate exceeding 120 beats per minute is deemed hazardous. An elevated heart rate during physical activity may suggest that the heart is exerting more effort to supply oxygen to the body's muscles, potentially leading to increased fatigue. However, determining the specific muscle groups experiencing fatigue requires further analysis, such as measuring lactic acid levels. Importantly, a higher heart rate can signal overall physical fatigue in the body, which could contribute to long-term injury. We observed no

TABLE 8.21
Heart rate comparison among different lifting weights

	31.5 Pounds	50 Pounds	50 Pounds	80 Pounds	31.5 Pounds	50 Pounds	50 Pounds	80 Pounds
HR	75.88	86.78*	86.78	92.42*	76.78	90.77*	90.77	100.71*

*Significant $p < 0.05$.

TABLE 8.22
Skin conductance comparison with and without exoskeleton

	31.5 Pounds		50 Pounds		80 Pounds	
	With	Without	With	Without	Without	Without
EDA	4.47	5.99	11.05	14.89*	25.84	26.34

*Significant $p < 0.05$.

TABLE 8.23
Skin conductance comparison among different lifting weights

	With Back Exoskeleton										
	31.5 Pounds	50 Pounds	31.5 Pounds*	50 Pounds	31.5 Pounds	50 Pounds*	31.5 Pounds	50 Pounds	31.5 Pounds*	50 Pounds	31.5 Pounds
EDA	4.47	11.05	–	11.05	25.84	–	5.99	14.89	–	14.89	26.34*

*Significant $p < 0.05$.

significant difference in heart rate when lifting 31.5-pound bags with or without a back exoskeleton, potentially due to posture or the weight being too light to activate the exoskeleton. However, we observed a significant difference when lifting 50- and 80-pound bags with and without the exoskeleton, with a greater difference observed when lifting 80-pound bags.

8.2.1.7 Skin conductance. In terms of skin conductance, our study aimed to investigate whether there is a significant difference when lifting different weights and when using a back exoskeleton or not, as shown in Table 8.22 and Table 8.23. We utilized a paired t-test to compare the data and found that the use of back exoskeleton did not make a significant difference when lifting 31.5-pound and 80-pound bags. However, it was observed that there was a significant difference when lifting 50-pound bags while using or not using the exoskeleton. Additionally, a trend was noticed in the skin conductance data showing an increase from lifting 31.5-pound to 80-pound bags, regardless of the use of the back exoskeleton. Therefore, it is recommended to either switch to lifting 31.5-pound bags or use the back exoskeleton when lifting 50-pound bags.

8.2.1.8 Potential motion analysis for ergonomic risk report. In the given example of a lifting task, motion skeleton models can be extracted and analyzed for the risk of musculoskeletal disorders (MSD) using the Rapid Entire Body Assessment (REBA) method, which considers the leg component, in contrast to the Rapid Upper Limb Assessment (RULA) method. As demonstrated in Figures 8.14 through 8.19, a comparison between the red scores (without exoskeleton) and green scores (with exoskeleton) reveals that the primary difference in scores is attributed to step two, which involves the trunk position, as shown in Figure 8.17. The red score is consistently higher because of the cumulative effect originating from step two, which is the fundamental cause of lifting the trunk position. As a result, the suggested approach of employing back exoskeletons demonstrates its potential to help workers maintain a safe trunk position and decrease their risk of MSD. With the back exoskeleton, the REBA score of MSD risk is lowered from very high to medium, as depicted in Figure 8.19. Further research will be conducted in a subsequent project to automatically monitor workers' activities and assess the related ergonomic risks using this motion analysis.

8.2.1.9 Summary. Back exoskeletons are suggested to be used when lifting more than 31.5-pound bags. Lifting 31.5-pound bags is suggested, compared with lifting 50-pound bags and 80-pound bags. Lifting from a 20-inch or above height platform could reduce back injuries. Controlling the speed to perform tasks could reduce the risk of muscle fatigue.

8.2.2 Shoveling Gravels

8.2.2.1 Demographics of participants of shoveling gravels. In the study, 26 individuals were recruited to participate in a task involving shoveling gravel. The average age of the participants was 35.35 years, and their height was approximately 70.35 inches. The participants had an average work experience of 3.91 years. Out of the 26 participants, 24 were male and 2 were female. They held various job titles, including 6 HT1, 2 HT2, 14 HT3, 2 safety specialists, and 2 supervisors. Further details regarding the demographic information of the participants can be found in Table 8.24 and Table 8.25.

8.2.2.2 Perceived muscle exertion. In the subjective data analysis, the study aimed to compare the perceived level of muscle exertion during shoveling tasks using different assistance, including a regular shovel, a back exoskeleton, an ergonomic handle, and both the ergonomic handle and back exoskeleton. While no significant difference was observed between shoveling with and without the back exoskeleton, the results in Table 8.26 indicated a significant difference in the lower muscles of the lower arm and back muscles between shoveling with a regular shovel and an ergonomic handle. Notably, the perceived level of muscle exertion increased in the lower arm muscle while decreasing in the back muscles when using ergonomic handles. This finding may be explained by the fact that the ergonomic shovel design requires a different hand grip and arm motion, which could result in more force being exerted on the lower arm muscles. Additionally, the ergonomic shovel is designed to reduce bending of the back and may transfer some of the load to the lower arm muscles, resulting in increased activity in these muscles. The lower arm muscles may be more involved in this task compared to the back muscles because they are more responsible for holding and manipulating the shovel and providing more force to scoop and dump the gravel. Based on these results, it is recommended to use a shovel with an ergonomic handle and not to use a back exoskeleton.

Figure 8.14 Lifting bags motion.

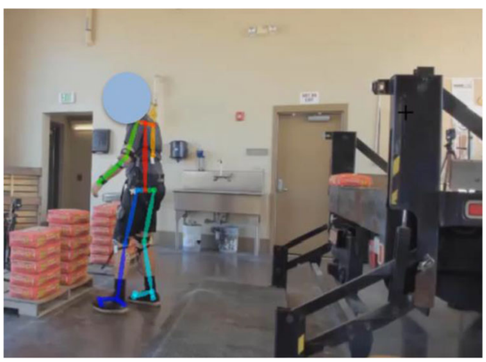


Figure 8.15 Extracted skeleton from lifting bags motion.

8.2.2.3 Perceived pressure. In relation to the pressure placed on different muscles, the findings reveal that the overall pressure exerted was relatively low. Nonetheless, Table 8.27 shows that the ergonomic shovel resulted in the highest pressure on the lower arm muscle, compared with regular shovel, back exoskeleton, and both.

8.2.2.4 Perceived usability. The usability of the ergonomic shovel and back exoskeleton was evaluated using a ten-statement questionnaire (Table 8.28). Participants rated their level of agreement or disagreement with the statements on a scale of one (strongly disagree) to five (strongly agree). The statements included positive (P) and negative (N) aspects of the products, and some required reverse scoring to indicate agreement with the product. For instance, the third statement "I thought the product was easy to use" had an average rating of 3.65 for the ergonomic shovel and

Figure 8.16 Lifting without and with back exoskeleton.

Figure 8.17 Part A neck, trunk, and leg analysis of REBA for evaluating the risk of musculoskeletal disorders associated with tasks (Middlesworth, 2023).

1.89 for the back exoskeleton, indicating a preference for the ergonomic shovel over the back exoskeleton.

8.2.2.5 Muscle contraction. In the current study, we employed EMG sensors to investigate whether there were significant differences in muscle activity when using different assistance during shoveling tasks. Unlike other measures such as heart rate and skin conductance, EMG sensors allowed for the assessment of physical fatigue of specific muscles, which could lead to long-term injuries. The paired t-tests comparing EMG data presented in Table 8.29 revealed that the lower arm muscle showed a significant increase in muscle activity from using a regular shovel to using an ergonomic shovel, while the back muscle indicated the opposite muscle contraction changes. This finding may be explained by the fact that the ergonomic shovel is designed to reduce bending and twisting of the back and may transfer some of the load to the lower arm muscles, resulting in increased activity in these muscles. Therefore, it is recommended to use a shovel with an ergonomic handle and avoid using a back exoskeleton based on the observed results.

8.2.2.6 Heart rate and skin conductance. In this investigation, the effect of diverse forms of assistance on heart rate and skin conductance was also analyzed. Nonetheless, the results revealed no significant differences. This outcome could be attributed to the limited capability of these measures to detect only overall muscle fatigue, as they fail to capture changes in exertion levels of specific muscles, such as the lower arm and back muscles, as shown in Table 8.30.

8.2.2.7 Summary. Ergonomic handles could reduce the risk of injuries on back muscles while increasing the risk of injuries on lower arm muscles when shoveling.

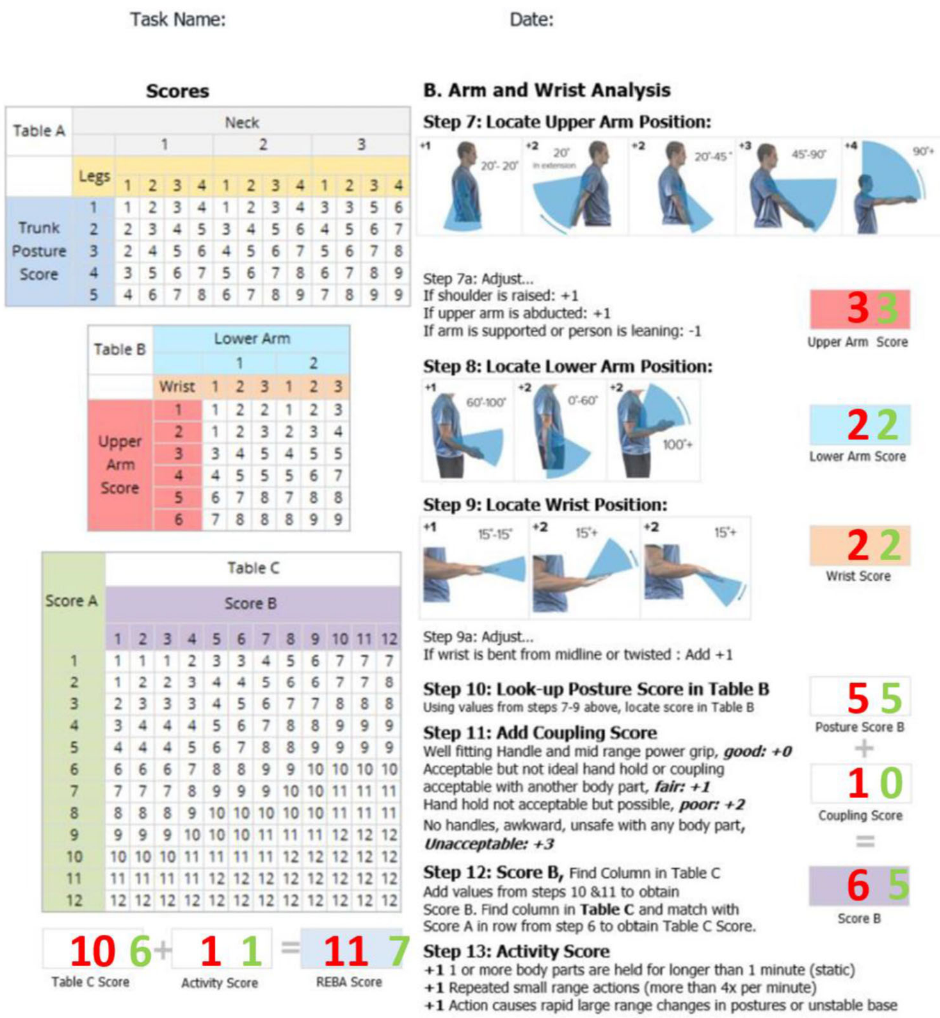


Table A	Neck	1				2				3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table B	Lower Arm	1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Table C Score A	Score B 1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Figure 8.18 Part B arm and wrist analysis of REBA for evaluating the risk of musculoskeletal disorders associated with tasks (Middlesworth, 2023).

Score	Level of MSD Risk
1	negligible risk, no action required
2-3	low risk, change may be needed
4-7	medium risk, further investigation, change soon
8-10	high risk, investigate and implement change
11+	very high risk, implement change

Figure 8.19 REBA for evaluating the risk of musculoskeletal disorders associated with tasks (Middlesworth, 2023).

The back exoskeleton did not show evidence of reducing muscle fatigue.

8.2.3 Lifting Sign Stands

8.2.3.1 Demographics of participants of lifting sign stands. In the study, 27 individuals were recruited to participate in a task involving lifting sign stands. The average age of the participants was 35.56 years, and their height was approximately 70.59 inches. The participants had an average work experience of 3.98 years. Out of the 27 participants, 25 were male and 2 were female. They held various job titles, including 6 HT1, 2 HT2, 15 HT3, 2 safety specialists, and

2 supervisors. Further details regarding the demographic information of the participants can be found in Table 8.31 and Table 8.32.

8.2.3.2 Perceived muscle exertion. In the subjective data analysis, the study aimed to compare the perceived level of muscle exertion during lifting sign stands from different heights and placing positions, with and without exoskeleton. The results in Table 8.33 indicated a significant difference in the back muscles between lifting vertically from the ground and vertically from the table. This may be because the lifting height significantly changes the bending angle to lift. Therefore, it reduced the perceived exertion of back muscle.

8.2.3.3 Perceived pressure. In relation to the pressure placed on different muscles, the findings reveal that the overall pressure exerted was relatively low. Nonetheless, the results in Table 8.34 indicated a significant difference of pressure in the back muscles between lifting vertically from the ground and vertically from the table. However, the lifting either vertically from waist height or horizontally from waist height did not show any significant difference.

8.2.3.4 Perceived usability. The usability of the shoulder exoskeleton was evaluated using a ten-statement questionnaire (Table 8.35). Participants rated their level of agreement or disagreement with the statements on a scale of one (strongly disagree) to five (strongly agree). The statements included positive (P) and negative (N) aspects of the products, and some required reverse scoring to indicate agreement with the product. For instance, the third statement "I thought the product was easy to use" had an average rating of 1.78 for the shoulder exoskeleton, indicating shoulder exoskeleton is not preferred to use.

8.2.3.5 Muscle contraction. In the current study, we employed EMG sensors to investigate whether there were significant differences in muscle activity when lifting from different heights and placing positions, and when using assistance during lifting. Unlike other measures such as heart rate and skin conductance, EMG sensors allowed for the assessment of physical fatigue of specific muscles, which could lead to long-term injuries. The paired t-tests comparing EMG data presented in Table 8.36 revealed that when lifting from the storage, lifting from a waist height could reduce the muscle contractions of the back. In addition, when lifting from the truck, shoulder exoskeleton could help reduce the muscle contractions of the upper arm significantly (see Table 8.37).

8.2.3.6 Heart rate and skin conductance. In this investigation, the effect of diverse forms of assistance (heights, placing positions, and shoulder exoskeleton)

TABLE 8.24
Demographic information of participants in shoveling gravels, part 1

Demographic	Mean	SD
Age (year)	35.35	9.65
Height (inch)	70.35	3.50
Arm Length (inch)	27.54	2.21
Shoulder Height (inch)	60.52	2.55
Waist Height (inch)	37.88	2.76
Knee Height (inch)	22.44	3.65
Waist Size (inch)	39.28	6.48
Weight (pound)	206.17	51.24
Body Mass Index	29.18	6.11
Body Fat (%)	26.06	10.59
Fat Free Body Weight (pound)	147.02	20.37
Subcutaneous Fat (%)	22.31	8.87
Visceral Fat	11.78	5.71
Body Water (%)	53.24	7.90
Skeletal Muscle (%)	47.57	7.31
Muscle Mass (pound)	139.58	19.51
Bone Mass (pound)	7.45	0.88
Protein (%)	16.85	2.52
Basal Metabolic Rate (kcal)	1,810.35	199.45
Metabolic Age	37.70	10.37
Tenure (year)	3.91	4.10

TABLE 8.26
Level of muscle exertion comparison

	Regular Shovel	Ergonomic Handle
Lower Arm	9.71	11.50*
Back	10.40	8.78*

*Significant $p < 0.05$.

TABLE 8.25
Demographic information of participants in shoveling gravels, part 2

Demographic	Category	Number of Participants	Ratio (%)
Gender	Male	24	92.31
	Female	2	7.69
Worker Type	HT1	6	23.08
	HT2	2	7.69
	HT3	14	53.85
	Safety specialist	2	7.69
	Supervisor/Manager	2	7.69

TABLE 8.27
Pressure comparison of shoveling gravels

Zero (no pressure) to Ten (strong pressure)	Regular Shovel	Ergonomic Handle	Back Exoskeleton	Both
Shoulder Muscle	2.46	2.06	1.52	3.00
Upper Arm Muscle	2.71	2.81	1.81	3.33
Lower Arm Muscle	3.19	2.75	2.12	2.33
Back Muscle	4.13	3.52	3.19	3.33

TABLE 8.28
Usability of ergonomic handle and back exoskeleton (Bangor et al., 2009)

	Ergonomic Handle		Back Exoskeleton	
One (Strongly Disagree) to Five (Strongly Agree)	P	N	P	N
1. I think that I would like to use this product frequently.	3.23	–	1.97	–
2. I found the product unnecessarily complex.	–	1.96	–	3.76
3. I thought the product was easy to use.	3.54	–	2.03	
4. I think that I would need the support of a technical person to be able to use this product.	–	1.19	–	1.35
5. I found that the various functions in this product were well integrated.	3.00	–	3.05	–
6. I thought that there was too much inconsistency in this product.	–	1.81	–	2.89
7. I would image that most people would learn to use this product very quickly.	4.23	–	2.97	–
8. I found the product very awkward to use.	–	3.00	–	3.89
9. I felt very confident using the product.	3.65	–	1.89	–
10. I needed to learn a lot of things before I could get going with this product.	–	1.54	–	1.43

TABLE 8.29
EMG comparison between regular shovel and ergonomic handle

	Regular Shovel (%)	Ergonomic Handle (%)
Lower Arm	20.98	45.87*
Back	30.34	20.23*

*Significant $p < 0.05$.

TABLE 8.30
Heart rate and skin conductance comparison

	Regular Shovel	Ergonomic Handle	Back Exoskeleton	Both
HR	85.78	86.08	87.01	88.89
Skin Conductance	11.34	11.89	10.99	12.01

on heart rate and skin conductance was also analyzed. Nonetheless, no results revealed significant differences. This outcome could be attributed to the limited capability of these measures to detect only overall muscle fatigue, as they fail to capture changes in exertion levels of specific muscles. In addition, the lifting sign stands task itself may not be too physically demanding. Therefore, its effect would only show up in the long term.

8.2.3.7 Summary. Lifting from a waist height is safer, compared with lifting from the ground. Shoulder exoskeleton is not preferred due to its complexity to wear and its limited effectiveness.

8.2.4 Pulling Deer

8.2.4.1 Demographics of participants of pulling deer. In the study, 28 individuals were recruited to participate in a task involving pulling deer. The average age of the participants was 35.82 years, and their height was approximately 70.43 inches. The participants had an average work experience of 3.88 years. Out of the 28 participants, 26 were male and 2 were female. They held various job titles, including 6 HT1, 2 HT2, 17 HT3, 2 safety specialists, and 1 supervisor. Further details regarding the demographic information of the participants can be found in Table 8.38 and Table 8.39.

8.2.4.2 Perceived usability. The usability of the back exoskeleton was evaluated using a ten-statement questionnaire (Table 8.40). Participants rated their level of agreement or disagreement with the statements on a scale of one (strongly disagree) to five (strongly agree). The statements included positive (P) and negative (N) aspects of the products, and some required reverse scoring to indicate agreement with the product. For instance, the eighth statement "I found the product very awkward to use" had an average rating of 3.86 for back exoskeleton, indicating the back exoskeleton is not preferred in this type of task.

8.2.4.3 Perceived muscle exertion, perceived pressure, muscle contraction, heart rate, and skin conductance. An analysis was done on perceived muscle exertion, pressure, contractions, heart rate and skin conductance. So far, no evidence has been found to suggest that use of a back exoskeleton is able to reduce muscle contractions. Upon inspecting the video data, this could possibly be attributed to the type of motion being used in the task, which did not involve a great deal of bending of the back, because they drag legs to pull. As a result, the back exoskeleton would not be effective in helping with muscle contractions in the back. In addition, it would not provide any assistance to the other body muscles, regardless of whether the back exoskeleton was worn or not.

8.2.4.4 Summary. Use of a back exoskeleton did not show that it can assist workers with pulling a dead deer. Therefore, it is not suggested to apply a back exoskeleton for future work of deer handling.

TABLE 8.31
Demographic information of participants in lifting sign stands, part 1

Demographic	Mean	SD
Age (year)	35.56	10.31
Height (inch)	70.59	3.38
Arm Length (inch)	27.52	2.19
Shoulder Height (inch)	60.81	2.34
Waist Height (inch)	37.93	2.73
Knee Height (inch)	22.56	3.46
Waist Size (inch)	39.74	6.57
Weight (pound)	213.01	53.57
Body Mass Index	29.96	6.47
Body Fat (%)	27.15	10.90
Fat Free Body Weight (pound)	149.71	20.64
Subcutaneous Fat (%)	23.33	9.13
Visceral Fat	12.66	6.10
Body Water (%)	52.47	8.10
Skeletal Muscle (%)	47.90	7.85
Muscle Mass (pound)	142.15	19.76
Bone Mass (pound)	7.58	0.90
Protein (%)	16.57	2.59
Basal Metabolic Rate (kcal)	1,836.69	202.02
Metabolic Age	37.42	10.08
Tenure (year)	3.98	3.97

TABLE 8.32
Demographic information of participants in lifting sign stands, part 2

Demographic	Category	Number of Participants	Ratio (%)
Gender	Male	25	92.59
	Female	2	7.41
Worker Type	HT1	6	22.22
	HT2	2	7.41
	HT3	15	55.56
	Safety specialist	2	7.41
	Supervisor/Manager	2	7.41

TABLE 8.33
Level of muscle exertion comparison

	Vertically on Ground	Vertically on Waist Height	Vertically on Waist Height	Horizontally on Waist Height
Back	9.89	7.17*	7.17	7.56

*Significant $p < 0.05$.

TABLE 8.34
Pressure comparison of lifting sign stands from different placing positions

	Vertically on Ground	Vertically on Waist Height	Vertically on Waist Height	Horizontally on Waist Height
Back	3.67	1.26*	1.26	1.89

*Significant $p < 0.05$.

TABLE 8.35
Usability of shoulder exoskeleton (Bangor et al., 2009)

	Shoulder Exoskeleton	
One (Strongly Disagree) to Five (Strongly Agree)	**P**	**N**
1. I think that I would like to use this product frequently.	1.89	–
2. I found the product unnecessarily complex.	–	3.96
3. I thought the product was easy to use.	1.78	–
4. I think that I would need the support of a technical person to be able to use this product.	–	3.78
5. I found that the various functions in this product were well integrated.	3.00	–
6. I thought that there was too much inconsistency in this product.	–	3.04
7. I would image that most people would learn to use this product very quickly.	2.89	–
8. I found the product very awkward to use.	–	3.93
9. I felt very confident using the product.	1.44	–
10. I needed to learn a lot of things before I could get going with this product.	–	3.04

TABLE 8.36
EMG comparison when lifting from the storage

	Vertically on Ground	Vertically on Waist Height	Vertically on Waist Height	Horizontally on Waist Height
Back	20.89%	10.36%*	10.36%	11.36%

*Significant $p < 0.05$.

TABLE 8.37
EMG comparison when lifting from the truck

	Without Shoulder Exoskeleton	With Shoulder Exoskeleton
Upper Arm	30.66%	25.78%*

*Significant $p < 0.05$.

TABLE 8.38
Demographic information of participants in pulling deer, part 1

Demographic	Mean	SD
Age (year)	35.82	10.13
Height (inch)	70.43	3.29
Arm Length (inch)	27.64	2.15
Shoulder Height (inch)	60.71	2.35
Waist Height (inch)	37.82	2.80
Knee Height (inch)	22.46	3.42
Waist Size (inch)	39.46	6.61
Weight (pound)	211.87	52.30
Body Mass Index	29.95	6.37
Body Fat (%)	27.13	10.73
Fat Free Body Weight (pound)	149.12	19.81
Subcutaneous Fat (%)	23.31	8.98
Visceral Fat	12.64	6.01
Body Water (%)	52.49	7.97
Skeletal Muscle (%)	47.88	7.72
Muscle Mass (pound)	141.57	18.96
Bone Mass (pound)	7.56	0.86
Protein (%)	16.58	2.54
Basal Metabolic Rate (kcal)	1,830.80	193.81
Metabolic Age	37.79	10.01
Tenure (year)	3.88	3.94

TABLE 8.39
Demographic information of participants in pulling deer, part 2

Demographic	Category	Number of Participants	Ratio (%)
Gender	Male	26	92.86
	Female	2	7.14
Worker Type	HT1	6	21.43
	HT2	2	7.14
	HT3	17	60.71
	Safety specialist	2	7.14
	Supervisor/Manager	1	3.57

TABLE 8.40
Usability comparison of pulling deer (Bangor et al., 2009)

	Back Exoskeleton	
One (Strongly Disagree) to Five (Strongly Agree)	**P**	**N**
1. I think that I would like to use this product frequently.	1.07	–
2. I found the product unnecessarily complex.	–	3.04
3. I thought the product was easy to use.	2.00	–
4. I think that I would need the support of a technical person to be able to use this product.	–	4.07
5. I found that the various functions in this product were well integrated.	2.00	–
6. I thought that there was too much inconsistency in this product.	–	2.79
7. I would image that most people would learn to use this product very quickly.	2.93	–
8. I found the product very awkward to use.	–	3.86
9. I felt very confident using the product.	3.04	–
10. I needed to learn a lot of things before I could get going with this product.	–	3.25

9. SUMMARY AND RECOMMENDATIONS

9.1 Summary

The ergonomic injuries and solutions have been extensively studied in the construction industry; however, the prevalence of work-related injuries, risky activities, and effective solutions in the transportation industry are not as well understood. This study aims to explore the prevalence of work-related injuries, risky activities, and the effectiveness of ergonomic solutions among transportation workers. The approach to this study included a preliminary list created from historical injury data, an online survey, onsite observations, and field experiments. Results from this study found that back injuries were the most common type of injury sustained when performing lifting and pushing/pulling activities. Back exoskeletons, ergonomic handles, and higher platforms were identified as potential solutions to help reduce the risk of injury. In addition, the ergonomic risk assessment method of REBA was used to preliminarily evaluate the risk levels when lifting bags of dry concrete mix. It was found that using a back exoskeleton can reduce the risk level from very high risk (dark red as shown in Figure 9.1) to medium risk (dark yellow as shown in Figure 9.1). Other ergonomic risk assessment methods need to be further explored to help prevent ergonomic risks.

Figure 9.1 Example of potential ergonomic solutions.

9.2 Recommendations

Based on the finding described above, implementation recommendations are made as the following for the four activities.

- Lifting bags of materials, as shown in Figure 9.1.
  - The utilization of back exoskeletons is recommended when dealing with items of 31.5-pound or more in weight.
  - Lifting 31.5-pound bags is considered to be a safer option than lifting 50- or 80-pound bags.
  - To further minimize the risk of back injuries, the platform height from which the item is being lifted should be at least 20 inches.
  - Controlling the speed at which tasks are being performed can help reduce the likelihood of muscle fatigue.

- Shoveling gravels, as shown in Figure 9.1.
  - Ergonomic handles may lower the risk of straining back muscles, but concurrently increase the risk of arm injuries.
  - Not surprisingly, the complexity associated with wearing shoulder exoskeletons has made them an impractical consideration.

- Lifting sign stands.
  - The height of the platform from which the item is being lifted should be at waist height in order to further reduce the possibility of injuries.
  - Shoulder exoskeleton is not preferred due to its complexity to wear and its limited effectiveness.

- Pulling deer.
  - The proposed solution of back exoskeleton did not receive scientific support to prove its effectiveness.

REFERENCES

Abdelmohsen, A. Z., & El-Rayes, K. (2018). Optimizing the planning of highway work zones to maximize safety and mobility. *Journal of Management in Engineering*, *34*(1). https://doi.org/10.1061/(asce)me.1943-5479.0000570

Akhavian, R., & Behzadan, A. H. (2016). Smartphone-based construction workers' activity recognition and classification. *Automation in Construction*, *71*(Part 2), 198–209. https://doi.org/10.1016/j.autcon.2016.08.015

Antwi-Afari, M. F., Li, H., Anwer, S., Li, D., Yu, Y., Mi, H. Y., & Wuni, I. Y. (2021). Assessment of a passive exoskeleton system on spinal biomechanics and subjective responses during manual repetitive handling tasks among construction workers. *Safety Science*, *142*(2021), 105382. https://doi.org/10.1016/j.ssci.2021.105382

Aryal, A., Ghahramani, A., & Becerik-Gerber, B. (2017). Monitoring fatigue in construction workers using physiological measurements. *Automation in Construction*, *82*, 154–165. https://doi.org/10.1016/j.autcon.2017.03.003

Bangor, A., Kortum, P., & Miller, J. T. (2009). Determining what individual SUS scores mean: adding an adjective rating. *Journal of Usability Studies*, *4*(3), 114–123.

Bangor, A., Kortum, P. T., & Miller, J. T. (2008). An empirical evaluation of the system usability scale. *International Journal of Human-Computer Interaction*, *24*(6), 574–594. https://doi.org/10.1080/10447310802205776

BLS. (2022, December 16). *National census of fatal occupational injuries in 2021*. Bureau of Labor Statistics. https://www.bls.gov/news.release/pdf/cfoi.pdf

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise*, *14*(5), 377–381. https://europepmc.org/article/med/7154893

Cheng, T., Migliaccio, G. C., Teizer, J., & Gatti, U. C. (2013). Data fusion of real-time location sensing and physiological status monitoring for ergonomics analysis of construction workers. *Journal of Computing in Civil Engineering*, *27*(3), 320–335. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000222

Cho, Y. K., Kim, K., Ma, S., & Ueda, J. (2018). A robotic wearable exoskeleton for construction worker's safety and health. *Construction Research Congress 2018: Safety and Disaster Management - Selected Papers from the Construction Research Congress 2018*, *April*(1), 19–28. https://doi.org/10.1061/9780784481288.003

Choi, S. D., Rajendran, S., & Ahn, K. (2017). Stretch flex programs: Effects on the reduction of musculoskeletal disorder & injuries. *Professional Safety*, *62*, 38–43.

Choi, S. D., Yuan, L., & Borchardt, J. G. (2016). Musculoskeletal disorders in construction: Practical solutions from the literature. *American Society of Safety Engineers*, *61*, 26–32.

Copilusi, C., Ceccarelli, M., & Carbone, G. (2015). Design and numerical characterization of a new leg exoskeleton for motion assistance. *Robotica*, *33*(5), 1147–1162. https://doi.org/10.1017/S0263574714002069

Dye Management Group. (2014). *Monitoring highway assets with remote technology* (MDOT Report No. RC-1607). Michigan Department of Transportation.

Finley, M. D. (2013). Field evaluation of automated flagger assistance devices in work zones on two-lane roads. *Transportation Research Record*, *2337*(1), 1–8. https://doi.org/10.3141/2337-01

Gatti, U. C., Migliaccio, G. C., & Schneider, S. (2011). Wearable physiological status monitors for measuring and evaluating workers' physical strain: Preliminary validation. *Proceedings of the Congress on Computing in Civil Engineering* (pp. 194–201). https://doi.org/10.1061/41182(416)24

Golabchi, A., Guo, X., Liu, M., Han, S. U., Lee, S. H., & AbouRizk, S. (2018). An integrated ergonomics framework for evaluation and design of construction operations. *Automation in Construction*, *95*, 72–85. https://doi.org/10.1016/j.autcon.2018.08.003

Guo, X., Chen, Y., & Zhang, J. (2022). Exploration of ergonomic injuries and risky activities among transportation maintenance workers. In H. Wei (Ed.), *Proceedings of the International Conference on Transportation and Development 2022* (pp. 129–137).

Guo, X., Golabchi, A., Han, S. U., & Kanerva, J. (2016). 3D modeling of workplaces for time and motion study of construction labor. *Proceedings of the 16th International Conference on Computing in Civil and Building Engineering (ICCCBE)* (pp. 1516–1523). http://www.see.eng.osaka-u.ac.jp/seeit/icccbe2016/Proceedings/Full_Papers/191-080.pdf

Han, S. U., & Lee, S. H. (2013). A vision-based motion capture and recognition framework for behavior-based safety management. *Automation in Construction*, *35*, 131–141. https://doi.org/10.1016/j.autcon.2013.05.001

Holmström, E., & Ahlborg, B. (2005). Morning warming-up exercise–Effects on musculoskeletal fitness in construction workers. *Applied Ergonomics*, *36*(4), 513–519. https://doi.org/10.1016/j.apergo.2004.10.015

Huang, C. T., & Paquet, V. (2001). Kinematic evaluation of snow shoveling. *Proceedings of the Human Factors and*

Ergonomics Society, *45*(14), 957–961. https://doi.org/10.1177/154193120104501436

IDOL. (2021). *Indiana census of fatal occupational injuries: Analysis of the census of fatal occupational injuries (CFOI) results*. Indiana Department of Labor Quality, Metrics and Statistics Division. https://www.in.gov/dol/files/CFOI_2020.pdf

Inyang, N., Al-Hussein, M., El-Rich, M., & Al-Jibouri, S. (2012). Ergonomic analysis and the need for its integration for planning and assessing construction tasks. *Journal of Construction Engineering and Management*, *138*(12), 1370–1376. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000556

Jaffar, N., Abdul-Tharim, A. H., Mohd-Kamar, I. F., & Lop, N. S. (2011). A literature review of ergonomics risk factors in construction industry. *Procedia Engineering*, *20*, 89–97. https://doi.org/10.1016/j.proeng.2011.11.142

Jeffress, C. N. (2000). *Statement of Charles N. Jeffress*. Osha Archive. https://www.osha.gov/news/testimonies/04272000#:~:text=Nearly two million workers suffer, from work as a result

Ko, H. K., Lee, S. W., Koo, D. H., Lee, I., & Hyun, D. J. (2018). Waist-assistive exoskeleton powered by a singular actuation mechanism for prevention of back-injury. *Robotics and Autonomous Systems*, *107*, 1–9. https://doi.org/10.1016/j.robot.2018.05.008

Liu, S.-H., Lin, C.-B., Chen, Y., Chen, W., Huang, T.-S., & Hsu, C.-Y. (2019). An EMG patch for the real-time monitoring of muscle-fatigue conditions during exercise. *Sensors (Switzerland)*, *19*(14), 3108. https://doi.org/10.3390/s19143108

Lloyd, D. G., & Besier, T. F. (2003). An EMG-driven musculoskeletal model to estimate muscle forces and knee joint moments in vivo. *Journal of Biomechanics*, *36*(6), 765–776. https://doi.org/10.1016/S0021-9290(03)00010-1

Middlesworth, M. (2023, November 6). *A step-by-step guide to the RULA assessment tool*. ErgoPlus. https://ergo-plus.com/rula-assessment-tool-guide/

Nnaji, C., Gambatese, J., Lee, H. W., & Zhang, F. (2020). Improving construction work zone safety using technology: A systematic review of applicable technologies. *Journal of Traffic and Transportation Engineering (English edition)*, *7*(1), 61–75.

Omar, A. R., Saad, N. H., & Halim, I. (2004). *Ergonomic assessment using Rula Analysis software to investigate musculoskeletal disorders (MSDs) experienced by material handler in metal stamping industries*.

Parida, R., & Ray, P. K. (2012). Study and analysis of occupational risk factors for ergonomic design of construction worksystems. *Work*, *41*(Supplement 1), 3788–3794. https://doi.org/10.3233/WOR-2012-0679-3788

Rodrigues, S. B., de Faria, L. P., Monteiro, A. M., Lima, J. L., Barbosa, T. M., & Duarte, J. A. (2022). EMG signal processing for the study of localized muscle fatigue—Pilot study to explore the applicability of a novel method. *International Journal of Environmental Research and Public Health*, *19*(20), 13270. https://doi.org/10.3390/ijerph192013270

Seo, J. O., Alwasel, A., Lee, S. H., Abdel-Rahman, E. M., & Haas, C. (2019). A comparative study of in-field motion capture approaches for body kinematics measurement in construction. *Robotica*, *37*(5), 928–946. https://doi.org/10.1017/S0263574717000571

Sheehe, P. R., & Bross, I. D. J. (1961). Latin squares to balance immediate residual, and other order, effects. *Biometrics*, *17*(3), 405–414.

Shin, H.-J., & Kim, J.-Y. (2007). Measurement of trunk muscle fatigue during dynamic lifting and lowering as recovery time changes. *International Journal of Industrial Ergonomics*, *37*(6), 545–551. https://doi.org/10.1016/j.ergon.2007.03.006

Varotto, S. F., Mons, C., Hogema, J. H., Christoph, M., van Nes, N., & Martens, M. H. (2022). Do adaptive cruise control and lane keeping systems make the longitudinal vehicle control safer? Insights into speeding and time gaps shorter than one second from a naturalistic driving study with SAE Level 2 automation. *Transportation Research Part C: Emerging Technologies*, *141*, 103756. https://doi.org/10.1016/j.trc.2022.103756

Waters, T. R., Putz-Anderson, V., & Garg, A. (1994, January). *Applications manual for the revised NIOSH lifting equation* (Publication No. 94-110).

Yu, H., Choi, I. S., Han, K. L., Choi, J. Y., Chung, G., & Suh, J. (2015). Development of a stand-alone powered exoskeleton robot suit in steel manufacturing. *ISIJ International*, *55*(12), 2609–2617. https://doi.org/10.2355/isijinternational.ISIJINT-2015-272

APPENDICES

APPENDIX A. THERMOPLASTIC PAINT TRUCK

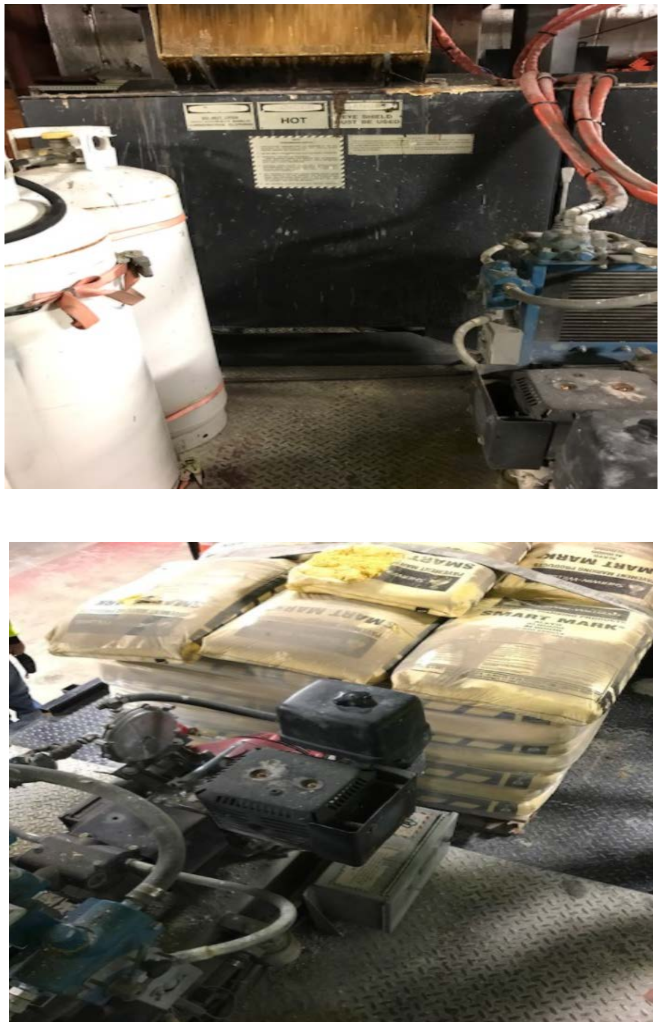


Figure A.1 Thermoplastic paint truck and bagged materials on thermoplastic paint truck.

APPENDIX B. ONLINE SURVEY

Demographic Information

1. What is your age?
2. What is your gender?
   a. Male
   b. Female
   c. Non-binary
   d. Not listed
   e. Prefer not to say
3. What is your weight?
   a. Please specify___ pounds
   b. Prefer not to say
4. What is your height?
   a. Please specify___ ft
   b. Prefer not to say
5. How many years have you worked for INDOT?
6. What is your position?
7. How many years have you worked in this position?
8. Have you ever been injured due to the work at INDOT?
   a. Yes
   b. No
   c. Prefer not to say
9. What **injuries** did you have? Please select all that apply.
   a. Shoulder injuries
   b. Back injuries
   c. Neck injuries
   d. Arm injuries
   e. Leg injuries
   f. Others, please specify
10. Have you had any **symptom/pain** when working?
    a. Yes
    b. No
    c. Prefer not to say
11. What **symptom/pain** did you have? Please select all that apply.
    a. Shoulder related, please specify
    b. Back related, please specify
    c. Neck related, please specify
    d. Leg related, please specify
    e. Hand related, please specify
    f. Foot related, please specify
    g. Others, please specify

Ranking of Activities of Top Interest

12. Please rank the following activities, *based on your perception* of which activity most likely to cause an injury to back or shoulder (with 1 being the least likely and 5 being the most likely).
    a. Lifting activities
    b. Pulling/pushing activities
    c. Cutting activities
    d. Cleaning activities
    e. Installing/repairing/replacing activities
13. Please rank the following activities *based on how often* you perform the activity while working (with 0 being never, 1 being the least frequent and 5 being the most frequent).
    a. Lifting activities
    b. Pulling/pushing activities
    c. Cutting activities
    d. Cleaning activities
    e. Installing/repairing/replacing activities

Detail of Activities of Top Interest

Detail of Lifting Activities of Top Interest

14. Please rank the following **lifting** activities, *based on your perception* of which activity most likely to cause an injury to back or shoulder (with 1 being the least likely and 5 being the most likely).
    a. Lift metal plates
    b. Lift furniture
    c. Lift cable rails
    d. Lift tire rings
    e. Lift litter
    f. Lift pumps
    g. Lift boxes
    h. Lift bags of material – Sand/Gravel/Concrete/Gravel/etc.
    i. Lift signs
    j. Lift buckets of material – Paints/epoxy/oils/etc.
    k. Others, please specify
15. Please rank the following **lifting** activities *based on how often* you perform the activity while working (with 1 being the least frequent and 5 being the most frequent).
    a. Lift metal plates
    b. Lift furniture
    c. Lift cable rails
    d. Lift tire rings
    e. Lift litter
    f. Lift pumps
    g. Lift boxes
    h. Lift bags of material – Sand/Gravel/Concrete/Gravel/etc.

i. Lift signs
j. Lift buckets of material – Paints/epoxy/oils/etc.
k. Others, please specify

16. Do you usually feel any symptom (fatigue, pain, etc.) after performing the lifting activities for a period of time?
    a. Yes, please specify ___ minutes after performing the lifting activities.
    b. No
17. What lifting technique do you usually use to *lift* the material?
    a. Bend back and then lift

    b. Bend leg and then lift

    c. Twist to move/lift

    d. Turn around to move/lift

    e. Others, please specify

18. How often do you usually need to <u>lift</u> the material?
    a. 1 to 5 times an hour
    b. 6 to 10 times an hour
    c. 11 to 15 times an hour
    d. Others, please specify
19. How long do you usually need to lift or hold the material per lift?
    a. 1 to 10 seconds per lift
    b. 11 to 20 seconds per lift
    c. 21 to 30 seconds per lift
    d. Others, please specify
20. What is the typical height of the surface **from** which you need to lift the material (i.e., the height of platform that you **pick up** the stuff)?
    a. Less than 1 foot
    b. Around 1 foot
    c. Around 2 feet
    d. Around 3 feet
    e. Around 4 feet
    f. Around 5 feet
    g. Around 6 feet
    h. Around 7 feet
    i. Others, please specify
21. What is the typical height of the surface **to** which you need to lift the material (i.e., the height of platform that you **drop off** the stuff)?
    a. Less than 1 foot
    b. Around 1 foot
    c. Around 2 feet
    d. Around 3 feet
    e. Around 4 feet
    f. Around 5 feet
    g. Around 6 feet
    h. Around 7 feet
    i. Others, please specify
22. What weight of materials do you usually need to lift?
    a. Less than 10 pounds
    b. Around 10 pounds
    c. Around 20 pounds
    d. Around 30 pounds
    e. Around 40 pounds
    f. Around 50 pounds
    g. Around 60 pounds
    h. Others, please specify
23. What typical shape of materials do you usually need to lift?
    a. Cuboid with handle
    b. Cuboid without handle

c. Sphere with handle
d. Sphere without handle
e. Irregular with handle
f. Irregular without handle
g. Others, please specify

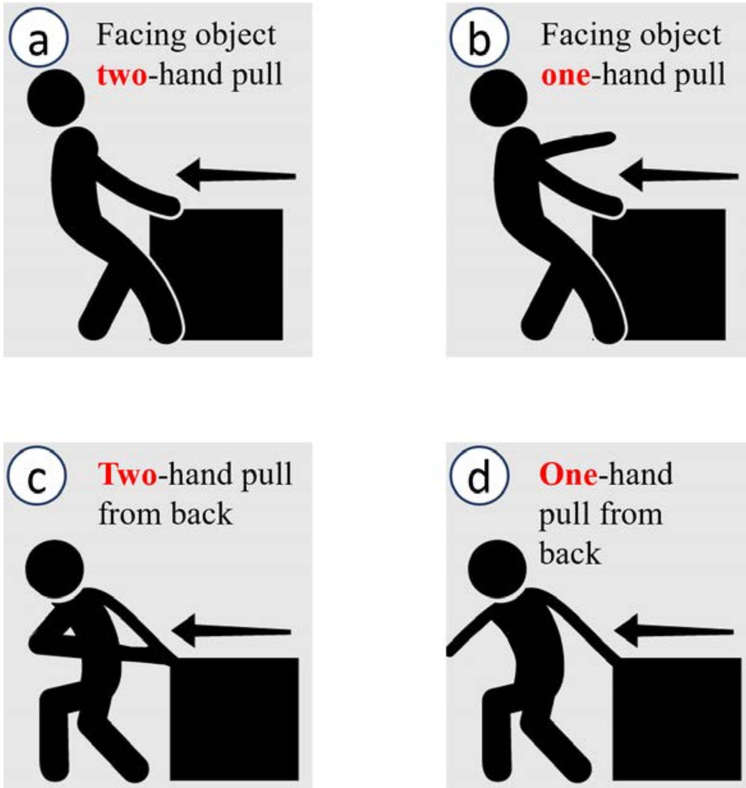
24. Is there any assistance (co-worker, tools, etc.) available to you on site when you perform **lifting** activities?
    a. Yes
    b. No
25. What kind of assistance is used on site when you perform **lifting** activities? Please select all that apply.
    a. Wheel barrow
    b. Cart
    c. Pallet jack
    d. Dolly
    e. Hoist
    f. Hydraulic lift
    g. Gantry crane
    h. Forklift
    i. Skid steer
    j. Back-hoe
    k. End-loader
    l. Additional man-power: Other certified co-workers are available to help.
    m. Other tools or equipment are available, please specify
    n. Others, please specify
26. Is there any other assistance that you wish to apply to improve the safety of **lifting** activities?
    a. No
    b. Yes, please specify

Detail of Pulling/pushing Activities of Top Interest

27. Please rank the following **pulling/pushing** activities, *based on your perception* of which activity most likely to cause an injury to back or shoulder (with 1 being the least likely and 5 being the most likely).
    a. Pull/push tools
    b. Pull/push valves
    c. Pull/push T-posts
    d. Pull/push grinders
    e. Pull/push deer
    f. Pull/push cables
    g. Pull/push grate
    h. Pull/push T-post
    i. Pull/push plywood
    j. Pull/push tail gates
    k. Pull/push box

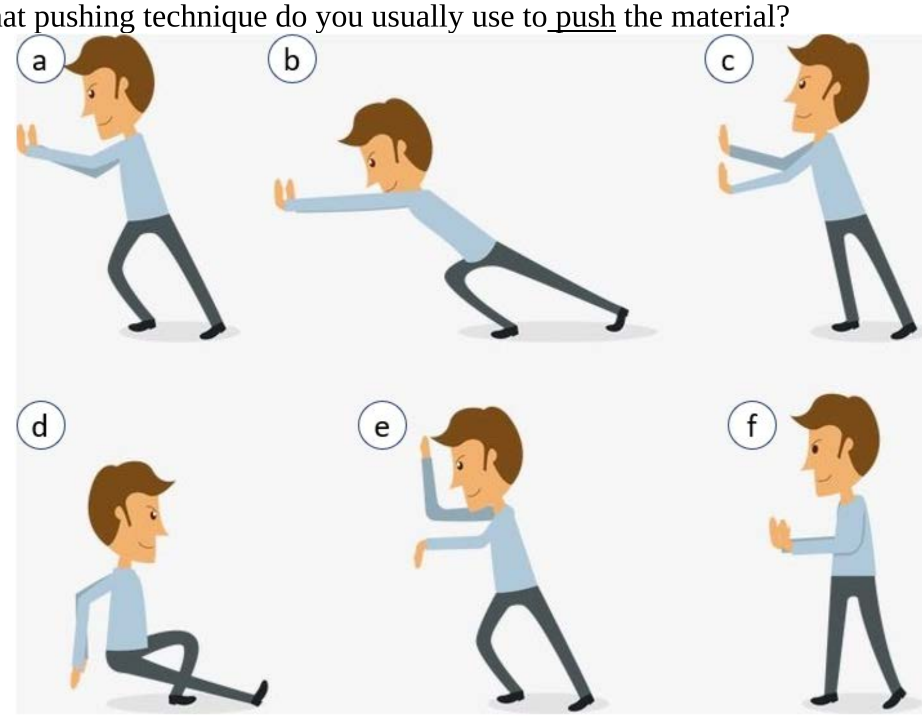
l. Others, please specify

28. Please rank the following **pulling/pushing** activities *based on how often* you perform the activity while working (with 1 being the least frequent and 5 being the most frequent).
    a. Pull/push tools
    b. Pull/push valves
    c. Pull/push T-posts
    d. Pull/push grinders
    e. Pull/push deer
    f. Pull/push cables
    g. Pull/push grate
    h. Pull/push T-post
    i. Pull/push plywood
    j. Pull/push tail gates
    k. Pull/push box
    l. Others, please specify
29. Do you usually feel any symptom (fatigue, pain, etc.) after performing the pulling/pushing activities for a period of time?
    a. Yes, please specify ___ minutes after performing the pulling/pushing activities.
    b. No
30. What tools do you usually use to pull/push?
    a. Wrench
    b. Rake
    c. Pry bar
    d. Shovel
    e. Others, please specify
31. What pulling technique do you usually use to pull the material?



e. Others, please specify

32. What pushing technique do you usually use to push the material?



g. Others, please specify
h. How often do you usually need to pull/push the material?

i. 1 to 5 times an hour
j. 6 to 10 times an hour
k. 11 to 15 times an hour
l. Others, please specify

33. How long do you usually need to *pull/push* the material?
    a. 1 to 10 minutes per time
    b. 11 to 20 minutes per time
    c. 21 to 30 minutes per time
    d. Others, please specify
34. What weight of materials do you usually need to *push*?
    a. Less than 10 pounds
    b. Around 10 pounds
    c. Around 20 pounds
    d. Around 30 pounds
    e. Around 40 pounds
    f. Around 50 pounds
    g. Around 60 pounds
    h. Others, please specify
35. What weight of materials do you usually need to *pull*?
    a. Less than 10 pounds
    b. Around 10 pounds
    c. Around 20 pounds
    d. Around 30 pounds
    e. Around 40 pounds
    f. Around 50 pounds
    g. Around 60 pounds
    h. Others, please specify
36. Is there any assistance (co-worker, tools, etc.) available to you on site when you perform **pulling/pushing** activities?
    a. Yes
    b. No
37. What kind of assistance is used on site when you perform **pulling/pushing** activities? Please select all that apply
    a. Other certified co-workers are available to help.
    b. Tools or equipment are available, please specify
    c. Others, please specify
38. Is there any other assistance you wish to apply to improve the safety of **pulling/pushing** activities?
    a. No
    b. Yes, please specify

Detail of Cutting Activities of Top Interest

39. Please rank the following **cutting** activities, *based on your perception* of which activity most likely to cause an injury to back or shoulder (with 1 being the least likely and 5 being the most likely).
    a. Cut tree/brush
    b. Cut gravel/concrete
    c. Cut metal/wood posts
    d. Cut metal/wood (flat plates or sheets).
    e. Others, please specify
40. Please rank the following **cutting** activities *based on how often* you perform the activity while working (with 1 being the least frequent and 5 being the most frequent).
    a. Cut tree/brush
    b. Cut gravel/concrete
    c. Cut metal/wood posts
    d. Cut metal/wood (flat plates or sheets).
    e. Others, please specify
41. Do you usually feel any symptom (fatigue, pain, etc.) after performing the cutting activities for a period of time?
    a. Yes, please specify ___ minutes after performing the cutting activities.
    b. No
42. What tools do you usually use to *cut*?
    a. Chainsaw
    b. Knife
    c. Saw-z-all
    d. Concrete Saw (hand)
    e. Concrete Saw (walk behind)
    f. Others, please specify
43. What cutting technique do you usually use to *cut*?
    a. Use both hands to hold the cutting equipment, and then cut
    b. Use one hand to hold the cutting equipment, and then cut
    c. Others, please specify
44. How often do you usually need to *cut*?
    a. 1 to 5 times a day
    b. 6 to 10 times a day
    c. 11 to 15 times a day
    d. Others, please specify
45. How long do you usually need to cut per time?
    a. 1 to 10 mins per time
    b. 11 to 20 mins per time
    c. 21 to 30 mins per time
    d. Others, please specify
46. Is there any assistance (co-worker, tools, etc.) available to you on site when you perform **cutting** activities?
    a. Yes

   b. No
47. What kind of assistance is used on site when you perform **cutting** activities? Please select all that apply
   a. Other certified co-workers are available to help.
   b. Tools or equipment are available, please specify
   c. Others, please specify
48. Is there any other assistance you wish to apply to improve the safety of **cutting** activities?
   a. No
   b. Yes, please specify

Detail of Cleaning Activities of Top Interest

49. Please rank the following **cleaning** activities, *based on your perception* of which activity most likely to cause an injury to back or shoulder (with 1 being the least likely and 5 being the most likely).
   a. Clean pipes
   b. Clean drains
   c. Clean trucks
   d. Clean bridge decks
   e. Clean hot mix
   f. Clean concrete boxes
   g. Others, please specify
50. Please rank the following **cleaning** activities based on how often you perform the activity while working (with 1 being the least frequent and 5 being the most frequent).
   a. Clean pipes
   b. Clean drains
   c. Clean trucks
   d. Clean bridge decks
   e. Clean hot mix
   f. Clean concrete boxes
   g. Others, please specify
51. Do you usually feel any symptom (fatigue, pain, etc.) after performing the cleaning activities for a period of time?
   a. Yes, please specify ___ minutes after performing the cleaning activities.
   b. No
52. What tools do you usually use to *clean*?
   a. Vacuum
   b. Pressurized water
   c. Pressurized air
   d. Hand tools - broom
   e. Hand tools - shovel
   f. Hand tools - pipe snakes
   g. Others, please specify
53. What cleaning technique do you usually use to *clean*?
   a. Hold the cleaning equipment with both hands

   b. Hold the cleaning equipment with one hand
   c. Others, please specify
54. How often do you usually need to *clean*?
   a. 1 to 5 times a day
   b. 6 to 10 times a day
   c. 11 to 15 times a day
   d. Others, please specify
55. How long do you usually need to clean per time?
   a. 1 to 10 mins per clean
   b. 11 to 20 mins per clean
   c. 21 to 30 mins per clean
   d. Others, please specify
56. Is there any assistance (co-worker, tools, etc.) available to you on site when you perform **cleaning** activities?
   a. Yes
   b. No
57. What kind of assistance is used on site when you perform **cleaning** activities? Please select all that apply
   a. Other certified co-workers are available to help.
   b. Tools or equipment are available, please specify
   c. Others, please specify
58. Is there any other assistance you wish to apply to improve the safety of **cleaning** activities?
   a. No
   b. Yes, please specify

Detail of Installing/repairing/replacing Activities of Top Interest

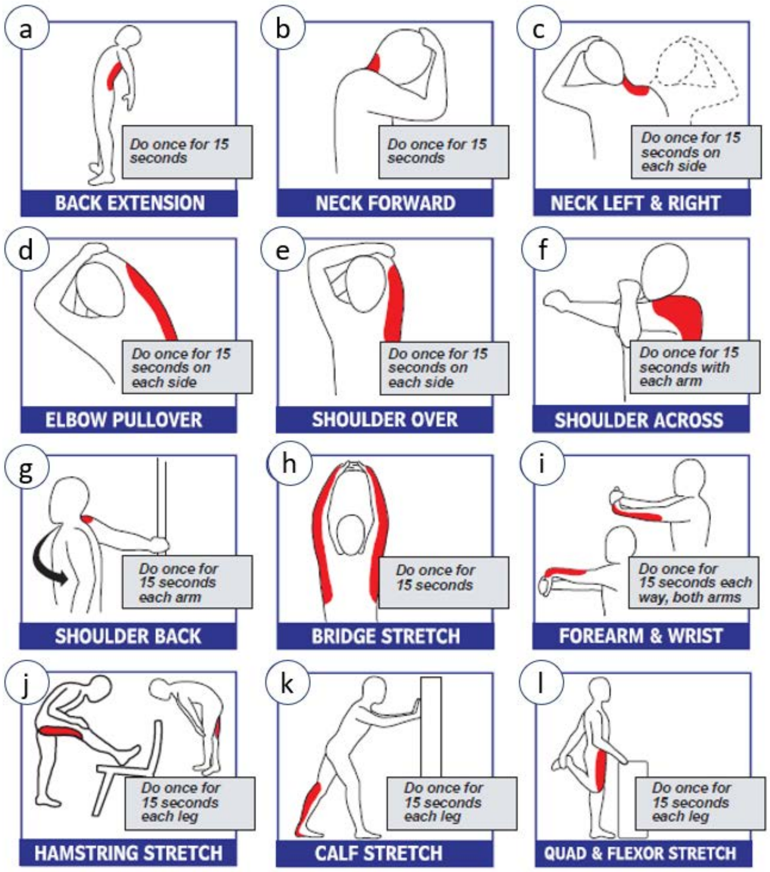
59. Please rank the following **installing/repairing/replacing** activities, *based on your perception* of which activity most likely to cause an injury to back or shoulder (with 1 being the least likely and 5 being the most likely).
   a. Install/repair/replace sign
   b. Install/repair/replace cable
   c. Install/repair/replace light
   d. Install/repair/replace equipment cylinders (brake/hydraulic)
   e. Install/repair/replace bridge reflectors
   f. Install/repair/replace plow blades
   g. Others, please specify
60. Please rank the following **installing/repairing/replacing** activities *based on how often* you perform the activity while working (with 1 being the least frequent and 5 being the most frequent).
   a. Install/repair/replace sign
   b. Install/repair/replace cable
   c. Install/repair/replace light
   d. Install/repair/replace equipment cylinders (brake/hydraulic)
   e. Install/repair/replace bridge reflectors

f. Install/repair/replace plow blades
g. Others, please specify

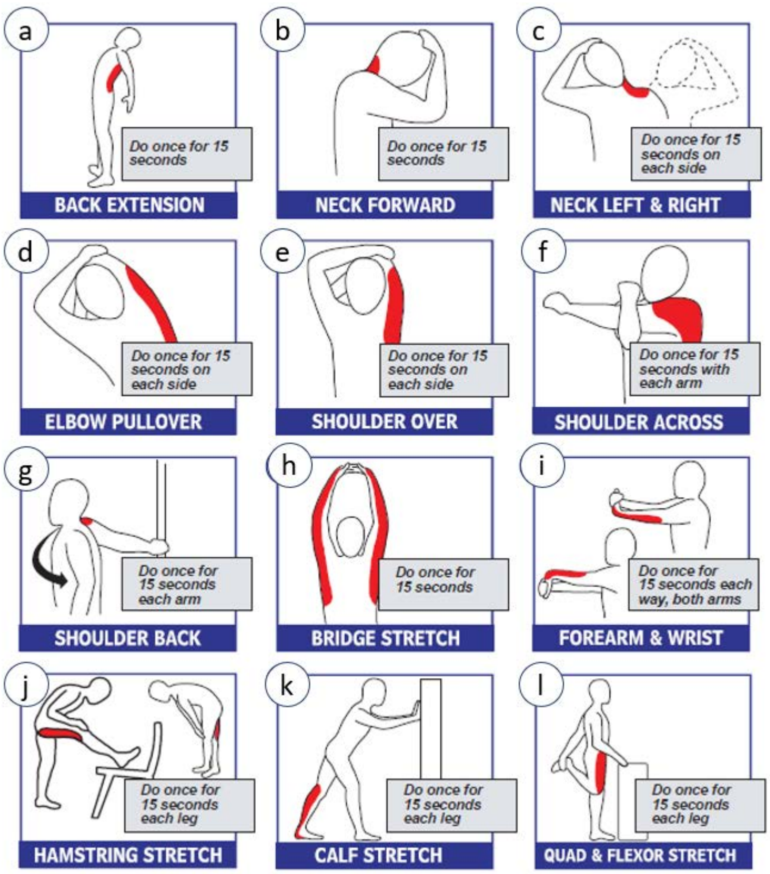
61. Do you usually feel any symptom (fatigue, pain, etc.) after performing the installing/repairing/replacing activities for a period of time?
    a. Yes, please specify ___ minutes after performing the installing/repairing/replacing activities.
    b. No
62. What tools do you usually use to *install/repair/replace*?
    a. Wrench
    b. Others, please specify
63. What installing/repairing/replacing technique do you usually use to *install/repair/replace*?
    a. Hold the equipment to install/repair/replace with both hands
    b. Hold the equipment to install/repair/replace with one hand
    c. Others, please specify
64. How often do you usually need to *install/repair/replace*?
    a. 1 to 5 times a day
    b. 6 to 10 times a day
    c. 11 to 15 times a day
    d. Others, please specify
65. How long do you usually need to *install/repair/replace* per time?
    a. 1 to 10 mins per time
    b. 11 to 20 mins per time
    c. 21 to 30 mins per time
    d. Others, please specify
66. Is there any assistance (co-worker, tools, etc.) available to you on site when you perform **installing/repairing/replacing** activities?
    a. Yes
    b. No
67. What kind of assistance is used on site when you perform **installing/repairing/replacing** activities? Please select all that apply
    a. Other certified co-workers are available to help.
    b. Tools or equipment are available, please specify
    c. Others, please specify
68. Is there any other assistance you wish to apply to improve the safety of **installing/repairing/replacing** activities?
    a. No
    b. Yes, please specify

Stretching Exercises Experience

69. Do you do any stretching exercises, such as the picture shown?
    a. Yes
    b. No



70. When do you do the stretching exercises?
    a. Before the shift
    b. During the shift
    c. After the shift
    d. Others, please specify
71. Why do you do the stretching exercises?
    a. Do it as a routine or a habit.
    b. Do it because of feeling pain on the body.
    c. Others, please specify
72. **How long** and **how often** do you do the stretching exercises you just selected?



a. Back extension ___ mins per time, and ___ times per day
b. Neck forward ___ mins per time, and ___ times per day
c. Neck left & right ___ mins per time, and ___ times per day
d. Elbow pullover ___ mins per time, and ___ times per day
e. Shoulder over ___ mins per time, and ___ times per day
f. Shoulder across ___ mins per time, and ___ times per day
g. Shoulder back ___ mins per time, and ___ times per day
h. Bridge stretch ___ mins per time, and ___ times per day
i. Forearm & wrist ___ mins per time, and ___ times per day
j. Hamstring stretch ___ mins per time, and ___ times per day
k. Calf stretch ___ mins per time, and ___ times per day
l. Quad & flexor stretch ___ mins per time, and ___ times per day
m. Others, please specify____ mins per time, and ___ times per day

Protection

73. Do you wear any PPE when you are on site to perform activities?
    a. Yes, I do.
    b. No, I do not. But PPE is available.
    c. N/A. PPE is not available.
    d. Others, please specify
74. Which one(s) of the following activities do you wear PPE for? Please select all that apply.

a. Lifting
b. Pulling/pushing
c. Cutting
d. Cleaning
e. Installing/repairing/replacing

75. What PPE do you wear on site when you perform the selected activities? Please select all that apply.
    a. Gloves
    b. Rain coats
    c. Face shields
    d. Masks
    e. Eye protection
    f. Boots
    g. Hard Hat
    h. Others, please specify
76. Is there any medical protection available to you on site when you perform activities?
    a. Yes
    b. No
77. What kind of medical protection is provided on site when you perform activities? Please select all that apply
    a. First aid is easily available.
    b. CPR trained workers are available.
    c. AED trained workers are available.
    d. Others, please specify
78. Is there any other medical protection you wish to apply to improve the safety of activities?
    e. No
    f. Yes, please specify
79. Please comment on any safety concerns or ideas that you would like to see addressed.

APPENDIX C. POTENTIAL PARAMETERS OF LIFTING ACTIVITY

Independent variables	**Number of values**	**Value 1**	**Value 2**	**Value 3**
Techniques of lifting	1	Bend leg to lift and turn around to lift		
Lifting stuff	2	Bags of dry concrete mix	Sign stands	
Weights of lifting load (pounds for bags only)	3	30	40	50
Loads of lifting	2	signs without sign stands	sign stands without signs	
Vertical distance for bags	1	36’’ (material on pallet)/36’’ (truck with tailgate)/0’’ (material on ground)		
Vertical distance for sign stands	1	36’’ (signs/sign stands on pallet)/36’’ (truck with tailgate)/0’’ (signs/sign stands on ground)		
Horizontal distance	1	10 feet		
Frequency (times per hour)	1	5		
Exoskeleton	2	Yes	No	
Stretching exercises	2	Yes	No	
Total number of trials for each participant when lifting	Lifting bags: 12 trials = 3 (weights) × 2 (exoskeleton) × 2 (exercises) Lifting sign/sign stands: 8 trials = 2 (signs & sign stands) × 2 (exoskeleton) × 2 (exercises)			

APPENDIX D. POTENTIAL PARAMETERS OF PUSHING/PULLING ACTIVITY

Independent variables	**Number of values**	**Value 1**	**Value 2**
Techniques of pushing/pulling	1	Two hand push/pull	
Pushing/pulling stuff	2	White-tailed deer	Shovel
Loads of pushing/pulling (pounds)	2	125 lbs. for deer (pull only)	Flat shovel (asphalt)/ Digging shovel (dirt)
Tools	2	Flat shovel	Digging shovel
Typical deer pulling distance	1	6-12 feet	
Typical shovel duration and frequency	1	5 minutes per time/3 times per hour	
Moving distance for shoveling materials	1	3 feet	
Exoskeleton	2	Yes	No
Stretching exercises	2	Yes	No
Total number of trials for each participant when pushing/pulling	Shoveling: 8 trials = 2 (types of shovels) × 2 (exoskeleton) × 2 (exercises) Pulling deer: 4 trials = 2 (exoskeleton) × 2 (exercises)		

APPENDIX E. COMPARISON BETWEEN VALUES OF LIFTING BAGS

Activity: Lifting Bags of Materials					
	Current Value				
Parameters	Value 1	Value 2	Value 3	Observed Value	Final Value Through Discussion
Approach to lift	Directly lift to the truck	Lift to the liftgate, then to the truck		Approach #1 (Lift to liftgate first, and then to truck) or Approach #2 (directly to the truck)	Lift directly to the truck.
Loads of lifting	30	40	50	Observed value is different from prior knowledge. 80-pound bags are more common because of its lower unit price.	Recommended lifting limit is 50 pounds. 80 pounds, 50 pounds, and 31.5 pounds will be tested.
Height of materials	26’’	46’’		Observed value is different from prior knowledge. Height is 28″ (Note: 6 layers per pallet and 7 bags per layer).	28″ height will be used.
Dimension of a typical bag	17″ in length, 10-1/2″ in width, and 4″ in height			Dimension is correct for the 80-pound concrete mix bag. Dimension may change based on weights.	
Dimension of a typical pallet	4″ * 48″ * 40″ to decide how many bags can be put there.			Dimension is confirmed.	
Stretching exercises	Yes			Observed value is different from prior knowledge. Know the program, but do not do it.	
Techniques of lifting	Bend leg to lift and turn around to lift.			Observed value is different from prior knowledge. Bending back to lift is more common.	Workers use their normal ways to lift.
Lifting stuff	Bags of concrete mix			Dry concrete mix	
Vertical distance	material on pallet/42″ (truck)/0″ (ground)			Observed value is different from prior knowledge.	42″

		Truck with liftgate (42″ if loading from back).	
Horizontal distance	10 feet	Observed value is different from prior knowledge. 7.5 feet will be used.	7.5′
Other tools or help used	No	No other tools are used.	
Frequency (times per hour)	5	Observed value is different from prior knowledge. 10–15 bags will be lifted per day.	12 bags will be used in the experiment.

APPENDIX F. COMPARISON BETWEEN VALUES OF LIFTING SIGN STANDS

Activity: Lifting Sign Stands			
Parameters	**Current Value**	**Observed Value**	**Final Value Through Discussion**
Techniques of lifting	Bend leg to lift and turn around to lift.	Observed value is different from prior knowledge. Bend back a little to lift.	
Loads of lifting	2 stands at a time (30–40 pounds per sign stands): Sign stands with aluminum legs are 32 pounds. Sign stands with orange powder coated steel legs are 40 pounds	Workers lift 2 sign stands at a time and 6 sign stands in total for a day. Sign stands with aluminum legs are more commonly used.	
Vertical distance for frames	Material on pallet/36″ (truck)/0″ (ground)	Observed value is different from prior knowledge. It is more common to use the truck with liftgate. Height will be 42″ if loading from back or 46″ if loading from side.	Loading sign stands from side (46) of a truck is more common.
How is frame stored (height)	Typically sign stands are stored folded up and standing upright on the floor.	On the ground	
Horizontal distance	15 feet	Observed value is different from prior knowledge. The distance should be 5–10 feet as the truck can move into storage. 7.5 feet will be used.	7.5 feet will be used.
Frequency (times per day)	Four times. Once to load up in the morning, once to remove from the truck and place in the field, once to take down in the field and put back in the truck, and once to offload from the	Frequency is confirmed.	

	truck and place back in the shop.	
Other tools or help used	No	No other tool is needed.
Stretching exercises	Yes	Observed value is different from prior knowledge. Know the program, but do not do it.

APPENDIX G. COMPARISON BETWEEN VALUES OF PULLING DEER FROM ROAD TO TRUCK

Activity: Pulling Deer to Truck			
Parameters	**Current value**	**Observed value**	**Final Value through Discussion**
Techniques of pulling	Two hand pull	Two-hand pulling is correct.	
Loads of pushing/pulling (pounds)	Deer is 125 pounds for deer.	The actual weight may be about 200 pounds.	It may feel heavier due to friction. The adoption of 125 pounds is reasonable.
Horizontal distance (to drag deer to the truck)	6 feet	18 feet (center of the two-lane road to side of the road).	
Height of the lift gate when on the ground	3″–4″	4″	
Number of employees if it is average sized deer	One employee, no other tools or help is needed except for liftgate	Two employees are required. One employee is for stopping the traffic. The other one is for pulling the deer from road to roadside. Two workers are needed for pulling the deer to liftgate of the truck. One employee is for pulling the deer from the liftgate into the truck.	Two employees
Besides the lift gate, other tools used?	No	No other tool is used.	
Stretching exercises	Yes	Workers know the program, but do not actually do it.	

APPENDIX H. COMPARISON BETWEEN VALUES OF PULLING DEER FROM TRUCK TO BURNER

Activity: Pulling/Dragging Deer to Burner			
Parameters	**Current Value**	**Observed Value**	**Final Value Through Discussion**
Techniques of pulling	Two hand pull	Two-hand pulling is correct.	
Loads of pulling (pounds)	125 pounds for deer	Actual weight may be about 200 pounds.	125 pounds
Height of the burner	40″	40″	
Number of employees needed	One employee is needed. No other tool or help is used, besides liftgate	Two employees are required. One employee stops the traffic. One employee pulls the deer from road to side. Two employees pull the deer to the liftgate of the truck. One employee pulls the deer from the liftgate into the truck.	Two employees are needed.
Besides the lift gate, other tools used?	No	Only liftgate is used.	
How to dump deer to the burner?	Drag deer out of truck, across the lift gate and into the burner.	Two employees need to drag the deer to the burner from the same side.	Two employees need to drag the deer to the burner from the same side.
Stretching exercises	Yes	Workers know the program, but do not do it.	

APPENDIX I. EXAMPLE OF EXPERIMENT ORDER FOR LIFTING BAGS OF DRY CONCRETE MIX

#	Sub#	Order Balanced Latin Square Order					
1	1	A	B	F	C	E	D
2	2	B	C	A	D	F	E
3	3	C	D	B	E	A	F
4	4	D	E	C	F	B	A
5	5	E	F	D	A	C	B
6	6	F	A	E	B	D	C
7	1	A	B	F	C	E	D
8	2	B	C	A	D	F	E
9	3	C	D	B	E	A	F
10	4	D	E	C	F	B	A
11	5	E	F	D	A	C	B
12	6	F	A	E	B	D	C
13	1	A	B	F	C	E	D
14	2	B	C	A	D	F	E
15	3	C	D	B	E	A	F
16	4	D	E	C	F	B	A
17	5	E	F	D	A	C	B
18	6	F	A	E	B	D	C
19	1	A	B	F	C	E	D
20	2	B	C	A	D	F	E
21	3	C	D	B	E	A	F
22	4	D	E	C	F	B	A
23	5	E	F	D	A	C	B
24	6	F	A	E	B	D	C
25	1	A	B	F	C	E	D
26	2	B	C	A	D	F	E
27	3	C	D	B	E	A	F
28	4	D	E	C	F	B	A
29	5	E	F	D	A	C	B
30	6	F	A	E	B	D	C

Notes:

Trail A: Lifting 31.5-pound bags without back exoskeleton.
Trial B: Lifting 31.5-pound bags with back exoskeleton.
Trial C: Lifting 50-pounds bags without back exoskeleton.
Trail D: Lifting 50-pound bags with back exoskeleton.
Trail E: Lifting 80-pound bags without back exoskeleton.
Trail F: Lifting 80-pound bags with back exoskeleton.

APPENDIX J. EXAMPLE OF PRE-SURVEY IN FIELD EXPERIMENTS

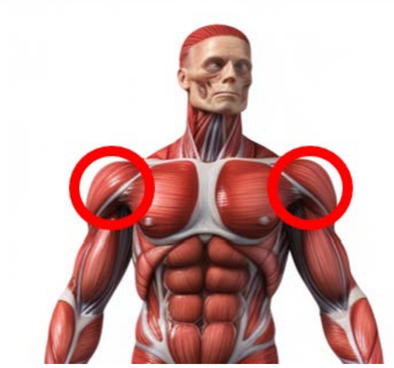
1. What is your age?
2. What is your gender?
    a. Female
    b. Male
    c. Others, please specify
3. What is your height?
4. What is your arm length?
5. What is your leg length?
6. What is your knee height?
7. What is your shoulder height?
8. What is your abdominal circumference?
9. What is your weight?
10. What is your body fat percentage?
11. What is your body water percentage?
12. What is your Body Mass Index (BMI)?
13. What is your bone percentage?
14. What is your highest education level?
    a. Primary school
    b. Junior high
    c. Senior high
    d. Undergraduate
    e. Graduate, master's
    f. Graduate, doctoral
    g. Others, please specify
15. What is your ethnicity?
    a. White
    b. Hispanic or Latino
    c. Black or African American
    d. Native American or American Indian
    e. Asian
    f. Pacific Islander
    g. Other, please specify
16. What is your current position at INDOT?
17. How long have you worked in this position?
18. Do you do any lifting work in your daily job?
    a. Yes
    b. No
    c. Others, please specify
19. If yes to the above question, what lifting work do you do?
20. If yes to the above question, how often do you do that lifting work?
21. If yes to the above question, how long do you lift?
22. What is the typical height of the platform from which you need to lift (pick up) the material?
23. What is the typical height of the platform to which you need to place (drop off) the material?

24. What is the typical weight of the material that you need to lift? Pounds
25. Do you use any assistance when lifting?
    a. Yes
    b. No
    c. Others, please specify
26. If yes to the above question, what assistance do you use?
27. Have you ever been injured before?
    a. Yes
    b. No
    c. Others, please specify
28. If yes to the above question, what injury is it?
29. If yes to the above question, when is that injury happened?
30. If yes to the above question, are you fully recovered now?
31. Have you ever had any pain/symptom before?
    a. Yes
    b. No
    c. Others, please specify
32. If yes to the above question, what pain/symptom is it?
33. If yes to the above question, when is that pain/symptom happened?
34. If yes to the above question, are you fully recovered now?
35. What is your dominant hand (which hand you normally write with)?
    a. Left hand
    b. Right hand
    c. Others, please specify
36. What is your dominant foot (which foot you would kick a ball with)?
    a. Left foot
    b. Right foot
    c. Others, please specify
37. Have you ever used any exoskeleton?
    a. Yes
    b. No
    c. Others, please specify
38. If yes to the above question, what exoskeleton did you use before?
39. Do you smoke?
    a. Yes
    b. No
    c. Others, please specify
40. If yes to the above question, how often do you smoke?
41. Did you smoke before today's experiment?
    a. Yes
    b. No
    c. Others, please specify
42. If yes to the above question, how many times did you smoke?
43. If yes to the above question, when did you smoke?
44. If yes to the above question, how many cigarettes did you smoke each time?

45. Do you have smokeless tobacco or chewing tobacco?
    a. Yes
    b. No
    c. Others, please specify
46. If yes to the above question, how often do you use smokeless tobacco or chewing tobacco?
47. Did you have smokeless tobacco or chewing tobacco before today's experiment?
    a. Yes
    b. No
    c. Others, please specify
48. If yes to the above question, how many times did you have smokeless tobacco or chewing tobacco?
49. If yes to the above question, when did you have smokeless tobacco or chewing tobacco?
50. If yes to the above question, how much did you have smokeless tobacco or chewing tobacco each time?
51. Do you drink alcohol?
    a. Yes
    b. No
    c. Others, please specify
52. If yes to the above question, how often do you drink?
53. Did you just drink alcohol before today's experiment?
    a. Yes
    b. No
    c. Others, please specify
54. If yes to the above question, when did you drink?
55. If yes to the above question, how much did you drink?
56. Do you do stretching exercises at work?
    a. Yes
    b. No
    c. Others, please specify
57. If yes to the above question, when do you do stretching exercises?
58. If yes to the above question, how often do you do stretching exercises?
59. If yes to the above question, how long do you do stretching exercises?
60. Do you work out in your daily life?
    a. Yes
    b. No
    c. Others, please specify
61. If yes to the above question, how often do you work out?
62. If yes to the above question, how long do you work out?

APPENDIX K. EXAMPLE OF POST-SURVEY IN FIELD EXPERIMENTS

1. Please **circle** a number to indicate your **perceived level of exertion** for **shoulder** muscle as indicated below (Aryal et al., 2017; Borg, 1998).



For your **left shoulder** muscle

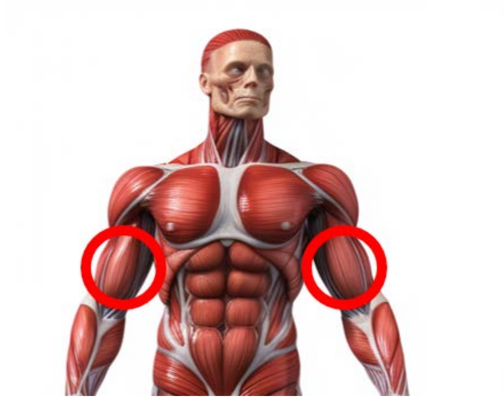
RPE	Level of Exertion
6	No exertion
7	
7.5	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

For your **right shoulder** muscle

RPE	Level of Exertion
6	No exertion
7	
7.5	Extremely light
8	
9	Very light

10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

2. Please **circle** a number to indicate your **perceived level of exertion** for **arm** muscle indicated below (Aryal et al., 2017; Borg, 1998).



For your **left arm** muscle

RPE	Level of Exertion
6	No exertion
7	
7.5	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard

18	
19	Extremely hard
20	Maximal exertion

For your **right arm** muscle

RPE	**Level of Exertion**
6	No exertion
7	
7.5	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

3. Please **circle** a number to indicate your **perceived level of exertion** for **back** muscle indicated below (Aryal et al., 2017; Borg, 1998).

For your **left back** muscle

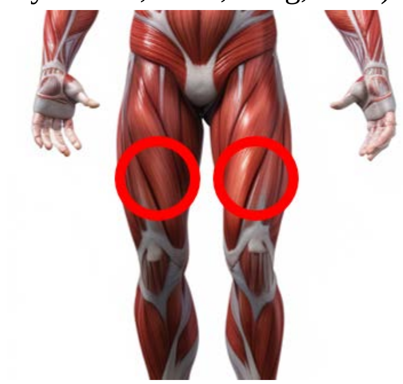
RPE	Level of Exertion
6	No exertion
7	
7.5	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

For your **right back** muscle

RPE	Level of Exertion
6	No exertion
7	
7.5	Extremely light
8	
9	Very light
10	

11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

4. Please **circle** a number to indicate your **perceived level of exertion** for **upper leg** muscle as indicated below (Aryal et al., 2017; Borg, 1998).



For your **left upper leg** muscle

RPE	Level of Exertion
6	No exertion
7	
7.5	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

For your **right upper leg** muscle

RPE	Level of Exertion
6	No exertion
7	
7.5	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

5. Please **circle** a number to indicate your **perceived level of exertion** for **lower leg** muscle as indicated below (Aryal et al., 2017; Borg, 1998).

For your **left lower leg** muscle

RPE	Level of Exertion
6	No exertion
7	
7.5	Extremely light
8	
9	Very light
10	

11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

For your **right lower leg** muscle

RPE	**Level of Exertion**
6	No exertion
7	
7.5	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

6. Please **circle** the number that reflects your immediate response to each statement about the product (exoskeleton) you just worn (Bangor et al., 2008).

	Strongly Disagree 1	**2**	**3**	**4**	**Strongly Agree 5**
1. I think that I would like to use this product frequently					
2. I found the product unnecessarily complex					
3. I thought the product was easy to use					
4. I think that I would need the support of a technical person to be able to use this product					
5. I found that the various functions in this product were well integrated					
6. I thought that there was too much inconsistency in this product					
7. I would image that most people would learn to use this product very quickly					
8. I found the product very awkward to use					
9. I felt very confident using the product					
10. I needed to learn a lot of things before I could get going with this product					

7. Please **circle** the number to indicate your perceived musculoskeletal pressure (Antwi-Afari et al., 2021).

	No Pressure at All 0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Extremely Strong Pressure 10**
Shoulder muscle											
Arm muscle											
Back muscle											
Upper leg muscle											
Lower leg muscle											

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at http://docs.lib.purdue.edu/jtrp.

Further information about JTRP and its current research program is available at http://www.purdue.edu/jtrp.

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