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Video-Based Ergonomic Risk Assessment Among Transportation Maintenance Workers in Shoveling

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ABSTRACT

Shoveling is a physically demanding task that has resulted in various physical injuries, particularly affecting workers' lower backs and shoulders. Specifically, shoveling gravel has been identified as one of the primary activities leading to common ergonomic injuries among transportation maintenance workers. Previous research has focused on evaluating the risks of ergonomic injuries from shoveling through simulations in the construction industry and field experiments in the agricultural industry. However, there is a lack of studies about the ergonomic risks associated with shoveling activities by field experiments within the transportation industry. In addition, prior studies have proposed some ergonomic solutions to prevent injuries in shoveling activity, such as ergonomic handles and back exoskeletons (EXOs). However, no research has yet provided a direct comparison of ergonomic risk levels when workers utilize different ergonomic solutions while shoveling. To address these gaps, this research evaluated the ergonomic risk levels associated with shoveling activity using different ergonomic solutions among 26 transportation maintenance workers. The ergonomic risk evaluation was conducted using the Rapid Entire Body Assessment (REBA) and Rapid Upper Limb Assessment (RULA) methods based on videos of their shoveling activities. Videos were recorded from October 3rd to October 17th, 2022. Each participant completed four trials of shoveling gravel, averaging around 97 minutes, using a regular shovel, a back EXO, an ergonomic handle, and both the back EXO and the ergonomic handle. Between each two subsequent trials, a 15-minute break was provided for participants to recover from the previous trials. Moreover, participants finished the four trials of shoveling gravel following the Balanced Latin Square order, in order to avoid the carry-over and order effects. During each trial, participants first shoveled broken gravel from the ground to the skid steer loader and cleaned any residual gravel from the ground in Part 1. Then, they shoveled new gravel from the asphalt hot box machine to the ground and patched it in Part 2. A 5-minute break between Part 1 and Part 2 was also offered to simulate the real-life practice. Results found that wearing a back EXO did not significantly reduce ergonomic risks during shoveling gravel, whereas the use of ergonomic handles and the combined use of the back EXO and ergonomic handle significantly decreased ergonomic risk scores during shoveling gravel. This study not only fills the gaps of ergonomic risk evaluation in real-world transportation maintenance activities, but also provides valuable insights for enhancing worker safety and efficiency in such environments.

Keywords: Transportation maintenance, Ergonomic risk evaluation, Exoskeletons, Shoveling

INTRODUCTION

In the United States, 7.2 million construction workers face a 40% higher chance of developing work-related musculoskeletal disorders (WMSDs) compared to other industries, due to performing activities of substantial physical demands in their jobs (Arauz et al., 2024; Dong et al., 2015; Lette et al., 2018). Both the construction and transportation sectors report high fatalities, with 1,282 deaths in transportation and 976 in construction (BLS, 2021). More specially, in Indiana, construction leads with 31 fatalities, followed by transportation with 26 (IDOL, 2021). Shoveling gravel, a particularly high-risk activity in transportation maintenance, significantly contributes to WMSDs based on previous studies by Guo et al. (2022, 2024). These disorders of transportation maintenance workers performing shoveling activities can lead to severe health problems, such as disability and early retirement, to employee themselves, and economic burdens, such as treatment costs, to their employers that are state Department of Transportation. Ergonomic risks experienced by shoveling workers in physically demanding tasks is a major factor causing ergonomic injuries (Hartvigsen et al., 2018; Koopman et al., 2019). Ergonomic tools like back exoskeletons (EXOs) and ergonomic handles can eliminate some of the physical strain on workers. EXOs, available in passive types with elastic components and active types with motors or hydraulics, support the back and reduce the load to prevent WMSDs (Okunola et al., 2023). Ergonomic shovels, designed to redistribute physical load across various muscles, also help reduce injury risk during shoveling (Kotowski et al., 2009). Previous research has primarily evaluated the ergonomic injury risks from shoveling through simulations in the construction industry and field experiments in agriculture. However, there is a gap in studies examining these risks through field experiments in transportation maintenance activities when different ergonomic interventions are applied. Therefore, this paper aims to study how various ergonomic interventions impact ergonomic risks experienced by transportation maintenance workers by conducting evaluations using the Rapid Upper Limb Assessment (RULA) and the Rapid Entire Body Assessment (REBA) methods (Hignett and McAtamney, 2000; McAtamney and Nigel Corlett, 1993).

LITERATURE REVIEW

There is no lack of research evaluating the ergonomic injury risks from shoveling by using RULA and REBA in other fields. For example, Arendra et al. (2020) evaluated the ergonomic risks of salt evaporation field workers, focusing on five high-risk activities through ergonomic risk analysis using RULA and REBA. They redesigned tools and demonstrated that replacing shovels with pan hoes can reduce the REBA score from 11 to 5 for the highest-risk activity of picking up salt. Domingo et al. (2015) evaluated the ergonomic risks faced by over 2 million construction workers who shovel soil, finding that tasks, such as shoveling, pose significant risks with RULA scores around 7 and REBA scores around 9, highlighting the need for task redesign. Sirikasemsuk et al. (2024) compared RULA and REBA

for assessing ergonomic risks during shoveling tasks in the metal coating process. The average RULA score indicated high risk, while the average REBA score indicated moderate risk, showing RULA's greater sensitivity. Kotowski et al. (2014) qualitatively assessed ergonomic risks using RULA and REBA for South Korean farmers, focusing on activities like weeding, harvesting, and shoveling, revealing common issues such as severe flexion and highlighting unique risks such as deep knee flexion. There is still a gap in studies examining the ergonomic risks of shoveling through field experiments in transportation maintenance activities. Considering the differences in intensity, duration, and frequency of shoveling in transportation maintenance work, there is a need to use REBA and RULA to evaluate the ergonomic risks of shoveling activities when different ergonomic interventions are implemented in transportation maintenance activities.

METHOD

Shoveling activities were identified as the most frequent pulling/pushing activities in the transportation industry (Guo et al., 2023). To explore the ergonomic effect of different ergonomic interventions on transportation maintenance workers, field experiments were conducted with 26 transportation maintenance workers from October 3rd to October 17th, 2022. First, a demographic survey was distributed to collect participants' information, including age, gender, weight, etc. Then, each participant was requested to perform a four-trial shoveling activity using the Balanced Latin Square order, to prevent carry-over and order effects between the four trials (Sheehe and Irwin 1961). During the four trials, participants shoveled gravel under four conditions: (1) only a regular shovel, (2) a back EXO and a regular shovel, (3) only a shovel with ergonomic handle, and (4) both a back EXO and a shovel with ergonomic handle. A 15-minute break was provided between every two trials, because proper work-rest schedule can help workers recover from the previous trials (Seo et al., 2016). During each trial, participants shoveled gravel from the ground to a skid steer loader and cleaned any residual gravel as Part 1, followed by shoveling new gravel from an asphalt hot box machine to the ground and patched as Part 2. However, in Part 2, it was found that participants were unable to shovel gravel with the ergonomic handle due to the difficulty of shoveling from the asphalt hot box machine. Therefore, the following analyses will use a total of 105 videos of shoveling in Part 1 to compare the effects of back EXO and ergonomic handle on ergonomic risk levels. This study performed REBA and RULA analyses to conduct ergonomic risk evaluation by TuMeke (TuMeke 2024a, TuMeke 2024b), to present risk levels of entire body and upper body during shoveling, respectively. One-way analysis of variance (ANOVA) and post-hoc analyses were utilized to compare the difference in back EXO and ergonomic handle's effects on ergonomic risks during shoveling.

RESULTS AND DISCUSSION

As described in Table 1, this study gathered workers' demographic information such as age, height, and tenure years, and biometric information such as height, weight, body mass index (BMI). Most of the 26 participants

are male workers (24; 92.31%). First, workers had an average age of 35 years old and an average metabolic age of 38 years old, showing that their metabolic health is slightly older than their chronological age. This discrepancy between workers' metabolic age and their chronological age could indicate that transportation maintenance workers are experiencing an accelerated aging process or higher risk of age-related metabolic disorders. This result is consistent with previous studies, which have shown that transportation and construction workers have been identified as being at significantly high risk of metabolic syndrome (Davila et al., 2010; Hidaka et al., 2016; Naug et al., 2016). In addition, the discrepancy underscores the need for ergonomic solutions to delay human aging during shoveling activity in the transportation industry. Previous studies have shown that it is possible to delay human aging and promote healthy aging by integrating ergonomics in the workplace, especially for older workers (Rybnikár et al., 2023; Wang et al., 2017). Therefore, future studies can expand on the existing knowledge regarding the discrepancy between workers' metabolic age and their chronological age in the transportation industry to develop targeted interventions aimed at addressing accelerated aging processes and reducing the risk of age-related metabolic disorders.

Second, workers had an average BMI of 29.18, which fell in the overweight range (25< BMI< 30) defined by Centers for Disease Control and Prevention (CDC 2024). This result indicates that most transportation maintenance workers engaged in shoveling were at risk of health issues associated with excess weight, such as metabolic disorders and cardiovascular diseases. Studies have shown that overweight and obesity could lead to higher risk of lower back pain, cancer development, musculoskeletal disorders, and higher costs related to sick leave (Bonauto et al., 2014; Shiri et al., 2010). Hence, this study suggests a need for exploring interventions to address potential health risks during shoveling, particularly due to overweight and obesity.

Table 1. Demographics of participants.

Demographics	Mean	Standard Deviation
Age (year)	35.35	9.65
Height (inch)	70.35	3.50
Arm (inch)	27.54	2.21
Shoulder height (inch)	60.54	2.55
Waist height (inch)	37.88	2.76
Knee height (inch)	22.42	3.58
Waist size (inch)	39.27	6.48
Weight (lb)	206.17	51.24
Body mass index	29.18	6.11
Body fat percentage (%)	26.06	10.59
Fat free body weight (lb)	147.02	20.37
Subcutaneous fat (%)	22.31	8.87
Visceral fat	11.78	5.71
Body water percentage (%)	53.24	7.90
Skeletal muscle (%)	47.57	7.31
Muscle mass (lb)	139.58	19.51
Bone mass (lb)	7.45	0.88
Protein (%)	16.85	2.52
Basal metabolic rate (kcal)	1810.35	199.45
Metabolic age (year)	37.70	10.37
Tenure (year)	3.91	4.10

Table 2 presents the ergonomic risk levels of 26 transportation maintenance workers during shoveling, assessed by REBA and RULA. For REBA evaluation, the results indicate that none of the shoveling tasks were classified as Acceptable, reflecting a score of 1 (0%). A small proportion of tasks (2.9%) were categorized as Low risk, with REBA scores ranging from 2 to 3. The majority of workers performing shoveling tasks (71.4%) fell within the Medium risk category, with REBA scores between 4 and 7. High risk tasks, with scores of 8 to 10, accounted for 27 out of 105 tasks (25.7%). Results of REBA assessment reveal that most participants experienced Medium to High ergonomic risk levels of entire body during shoveling gravel. In addition, results of RULA assessment show that participants were most likely (89.50%) to have high ergonomic risk of upper body during shoveling gravel. These findings highlight the need for reducing potential ergonomic risks, particularly ergonomic risks of upper body faced by transportation maintenance workers during shoveling. Existing research supports the importance of reducing ergonomic risks during shoveling, as shoveling has been identified as a risky activity associated with frequent lower back and shoulder injuries (Guo et al. 2023, Huang and Paquet 2002, Oluwole 2018).

Table 2. Ergonomic risk levels during shoveling.

Assessment type		Acceptable	Low	Medium	High	Very High
REBA	Score range	1	2–3	4–7	8–10	11–15
	Number	0	3	75	27	0
	Percentage	0%	2.90%	71.40%	25.70%	0%
RULA	Score range	1–2	3–4	5–6	7	N/A
	Number	0	2	9	94	0
	Percentage	0%	1.90%	8.60%	89.50%	0%

Figure 1 presents the effects of using different ergonomic tools (back EXO, ergonomic handle, and both the back EXO and ergonomic handle) on ergonomic risk levels, evaluated by REBA and RULA during shoveling gravel. It was found that REBA evaluation is consistent with RULA evaluation in this study. First, compared to shoveling by the regular shovel or back EXO, ergonomic risk scores had been significantly reduced by using an ergonomic handle. The effectiveness of using ergonomic handle in reducing physical strain and risk of musculoskeletal disorders has been demonstrated by previous studies (Susan E. Kotowski et al., 2009; Lewinson et al., 2014). Second, it was surprisingly found that using a back EXO could not significantly decrease ergonomic risk score compared to using a regular shovel. Previous studies have devoted the surprising result in this study, by exploring the use of back EXOs during manual material lifting, shoveling, or tasks involving prolonged trunk bending to reduce musculoskeletal discomfort and perceived work intensity (Kim et al., 2021; Thamsuwan et al., 2020). The discrepancy between previous studies and this study could be the specific design of the back EXO used in this study. Different types of exoskeletons, whether soft or rigid, passive or active, may have varying effects

on ergonomic risk reduction based on their design features and how well they align with the biomechanical demands of the task (Mohamed Refai et al., 2024; Schwartz et al., 2021). Finally, the combination use of the back EXO and ergonomic handle significantly reduced ergonomic risk scores compared to using a regular shovel. One possible reason for this result could be that ergonomic handle provides better grip and leverage to reduce risk of upper body (Silva et al., 2013), while the back EXO combined with the handle could offer additional support to maintain proper posture during shoveling gravel.

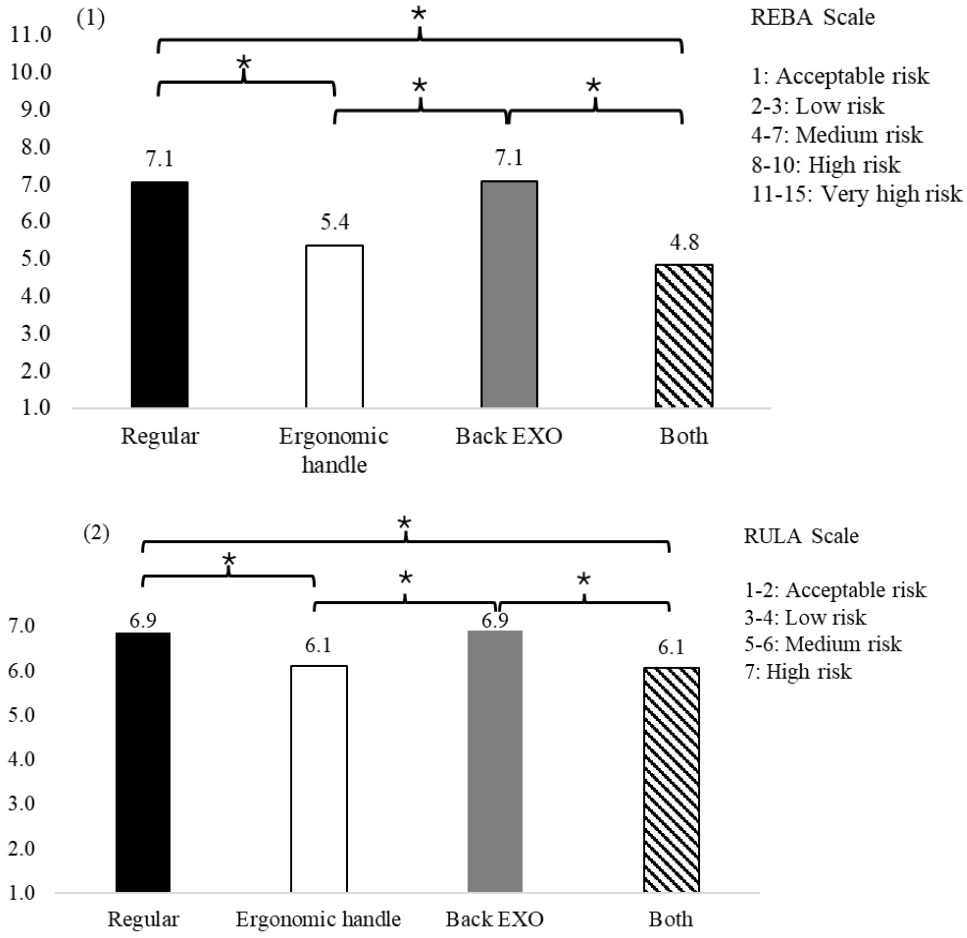

Figure 1: Ergonomic risk evaluation by (1) REBA and (2) RULA (* $p < 0.05$).

CONCLUSION

This study evaluated ergonomic risk levels during shoveling among 26 transportation maintenance workers and compared the effects of the back EXO and ergonomic handle on reducing ergonomic risks by video-based REBA and RULA analyses. Results show that (1) most transportation

maintenance workers had medium to high ergonomic risks in terms of whole body and high ergonomic risks of upper bodies during shoveling gravel; (2) using only ergonomic handle and both back EXO and ergonomic handle significantly decreased ergonomic risks, compared to shoveling by a regular shovel; and (3) the back EXO used in this study could not reduce ergonomic risks during shoveling. Research findings demonstrate the effectiveness of the ergonomic handle and its combined use with the back EXO in reducing ergonomic risks during shoveling. Additionally, the findings indicate the future need to address the high ergonomic risks to the upper body among transportation maintenance workers.

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