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Utilizing AI with Digital Human Modeling to Assess Risk of MSDs in Non-fireground Firefighter Activities

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ABSTRACT

The objective of this study is to examine ergonomic risk associated with routine, non-fireground activities performed by firefighters and to identify tasks most strongly associated with musculoskeletal disorders (MSDs). While prior research has largely focused on fireground operations, a substantial portion of firefighter injuries occur during daily station activities that involve repetitive motion, awkward postures, and manual material handling. This study employed a mixed-methods approach combining self-reported symptom data and AI-based ergonomic assessment to evaluate risk exposure during non-emergency tasks.

Within this study, a total of 10 routine, non-fireground activities were evaluated using Rapid Entire Body Assessment (REBA) implemented through AI-based digital human modeling software (TuMeke). Self-reported musculoskeletal symptoms were collected using the Nordic Musculoskeletal Questionnaire, along with demographic and work-history data. Multinomial logistic regression was used to examine relationships between reported symptoms and modeled ergonomic risk classifications.

Results demonstrated strong alignment between the most frequently identified REBA high-risk areas and the most commonly self-reported musculoskeletal symptoms, with upper arms and trunk most frequently associated with shoulder and lower back pain. Non-fireground activities pose a significant risk for MSDs among firefighters during routine station tasks (e.g., ladder access, fire engine inspection, etc.). These findings demonstrate that routine, non-fireground activities represent a significant source of musculoskeletal risk for firefighters and highlight the combined influence of task demands and fire apparatus design on injury risk.

KEY WORDS: *musculoskeletal disorders, occupational safety and health, ergonomics, firefighters, human modeling, artificial intelligence risk assessment*

1. INTRODUCTION

In 2022, the National Fire Protection Association (NFPA) identified musculoskeletal injuries, including strains, sprains, and muscular pain, as a leading cause of firefighter injuries, accounting for 57% of non-fireground injuries and 36% of fireground injuries (Campbell and Hall, 2023). According to the Bureau of Labor Statistics (BLS), in 2016, firefighters experienced musculoskeletal disorder (MSD) rates that far exceeded the national average. A study conducted on MSDs among California firefighters revealed a notably higher incidence of MSDs compared to other high-risk occupations (Dworsky, Seabury, and Broten, 2021). The researchers concluded MSDs constituted 47% of firefighter injuries, surpassing the rates of 38% for law enforcement and 42% for other public sector workers. Identifying specific musculoskeletal injury triggers and movements during training and other non-fireground tasks is crucial for minimizing MSDs. These MSD injury rates are clearly depicted in Fig. 1. These findings underscore the significant physical demands placed on firefighters and the persistent risk of injury associated with both emergency and routine occupational tasks.

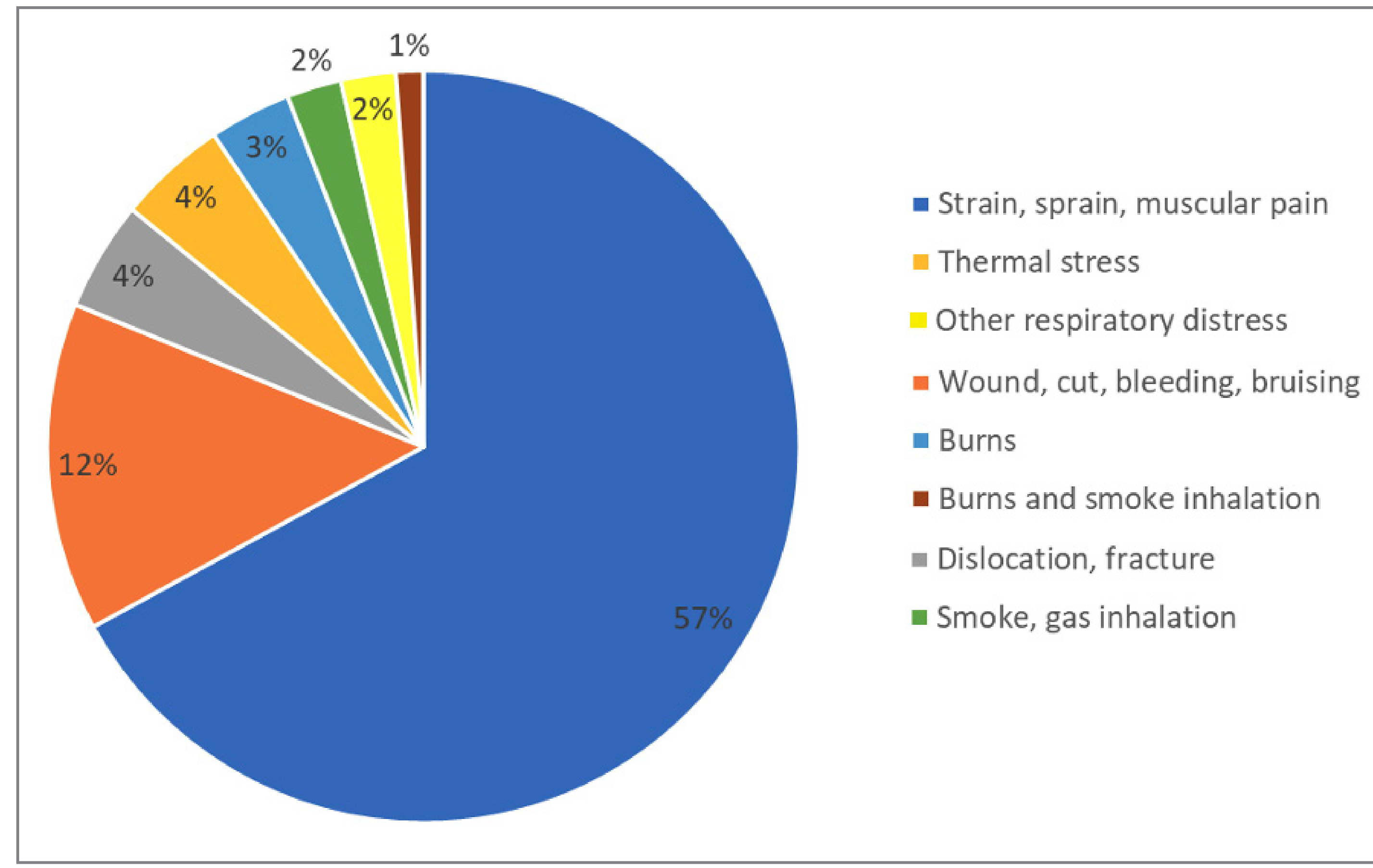


FIG. 1
Injuries During Non-fireground Activities (Training)

While much of the existing research has focused on fireground operations, a significant number of firefighter injuries occur during routine, non-fireground activities, such as equipment handling, apparatus access, inspections, and daily station tasks. Fireground operations are defined by the NFPA 1710 standard as "organized, safe, and effective deployment of resources for fire suppression, emergency medical services, and special operations to protect the public and ensure firefighter safety" (NFPA, 2020).

These activities are performed repeatedly throughout each shift, often under time constraints, and commonly involve awkward postures, repetitive movements, and the manual handling of heavy equipment (Tahernejad et al., 2024). Despite their frequency and physical demands, non-fireground tasks have received comparatively less ergonomic attention, even though their cumulative impact may play a substantial role in the development of MSDs.

Ergonomic assessment tools have long been used to evaluate risk factors associated with musculoskeletal injury. However, traditional observational methods can be time-intensive and subject to variability between evaluators. Advances in digital human modeling and artificial intelligence have introduced new opportunities to assess ergonomic risk in a more consistent and objective manner. These technologies allow for posture-based analysis and standardized risk scoring, offering an efficient approach for evaluating physically demanding tasks.

To evaluate ergonomic risk, several assessment tools have been developed and widely applied across occupational settings, including the Rapid Upper Limb Assessment (RULA), the Ovako Working Posture Analysis System (OWAS), and the Rapid Entire Body Assessment (REBA). These tools provide structured methods for evaluating postural load, movement patterns, force exertion, and task repetition. Among them, REBA is particularly well suited for assessing dynamic, whole-body tasks and has been widely validated for use in physically demanding work environments, including emergency response occupations (Middleworth, 2019; Sadeghi et al., 2019).

REBA was developed to "rapidly" evaluate MSDs associated with specific job tasks. The REBA tool (Fig. 2) uses a systematic process to evaluate both upper and lower parts of the musculoskeletal system for biomechanical and MSD risks associated with the job task being evaluated.

The single-page worksheet can be used to evaluate required or selected body posture, forceful exertions, type of movement or action, repetition, and coupling. The output of the tool is the final REBA score, a single value that represents the level of MSD risk for the job task being evaluated. The minimum REBA score = 1, and the maximum REBA score = 15. Table 1 outlines the REBA levels of MSD risk descriptions and cut points.

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

TABLE 1
Rapid Entire Body Assessment (REBA) Score Reference

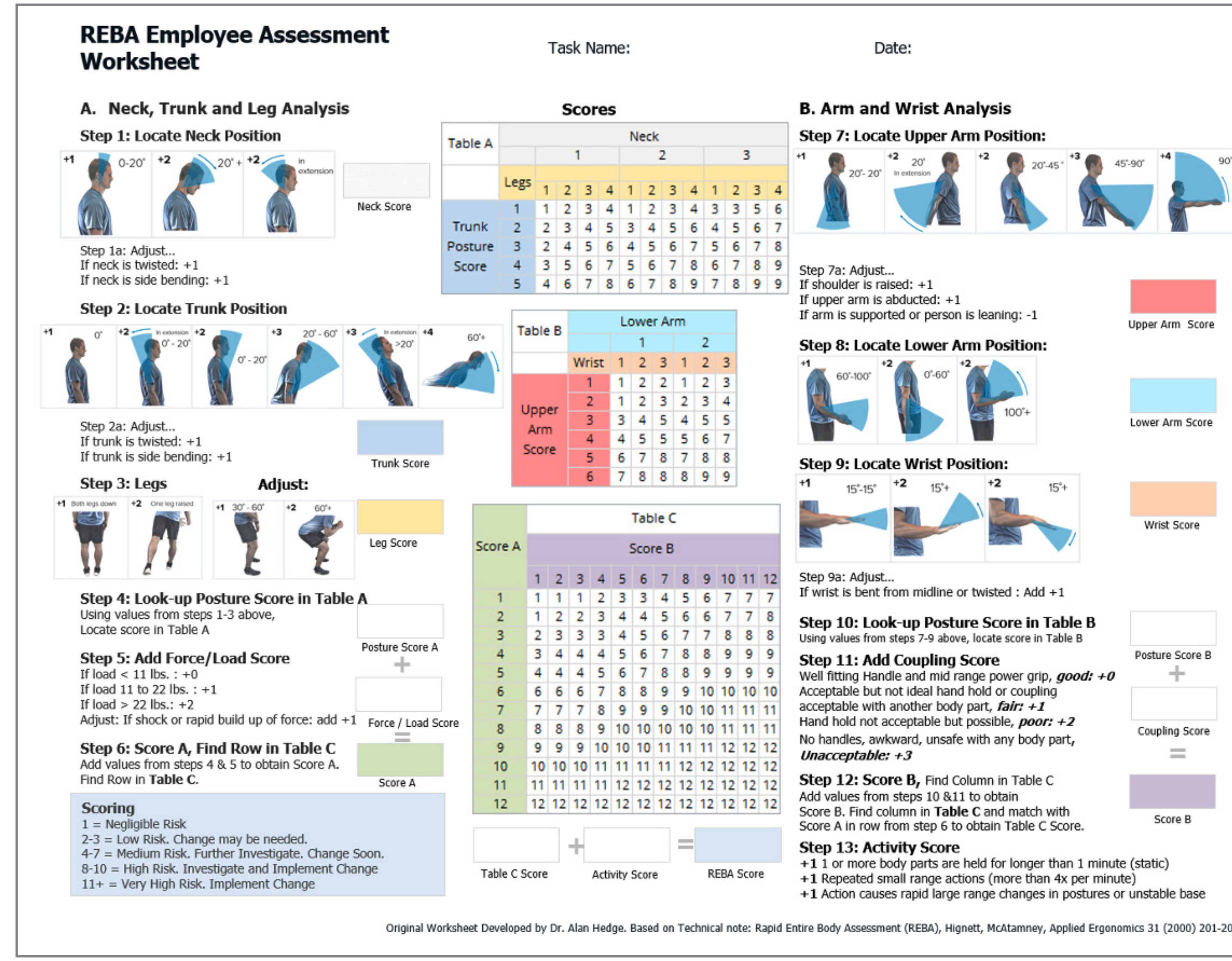


FIG. 2
Rapid Entire Body Assessment (REBA) Worksheet

Despite advances in ergonomic assessment methods, AI-based tools have rarely been applied to routine, non-fireground firefighter activities, and limited work has examined how objectively measured ergonomic risk aligns with firefighters' self-reported musculoskeletal symptoms. This gap restricts the ability to accurately characterize risk exposure and prioritize effective prevention strategies.

Accordingly, this study applies AI-based digital human modeling to evaluate ergonomic risk associated with routine, non-fireground firefighter tasks and examines its relationship with self-reported musculoskeletal symptoms. By integrating automated ergonomic assessment with standardized symptom reporting, this study provides a novel approach for identifying high-risk tasks and informing targeted ergonomic and injury-prevention efforts within the fire service.

2. LITERATURE REVIEW

The primary aim of this study is to examine ergonomic risk factors associated with routine, non-fireground activities that may contribute to MSDs among firefighters. Although fireground operations have traditionally received the greatest attention in injury research, a growing body of evidence indicates a substantial portion of firefighter injuries occur during non-emergency tasks performed as part of daily station operations. These activities often involve physical workload demands that, over time, may contribute to the development of both acute and chronic musculoskeletal conditions.

The researchers observed 10 everyday non-fireground tasks and analyzed each for factors that could lead to both short and long term MSDs. Understanding the ergonomic risks associated with these routing tasks is essential for guiding effective prevention strategies and work practices and improving long-term occupational health outcomes.

Work-related MSDs are defined by the Centers for Disease Control and Prevention (2023) as injuries to the body's musculoskeletal system, including the joints, ligaments, muscles, and tendons. These conditions often result from prolonged overuse, repetitive strain, or sudden exertion that causes wear and tear on muscles, tendons, and sensitive nerve tissues. Common occupational risk factors include prolonged or repeated manual handling, static or constrained postures, repetitive motion, vibration exposure, and contact stress. These risk factors are particularly relevant in firefighting, where workers frequently perform physically demanding tasks under time pressure and in environments that limit optimal body positioning. Ergonomic assessment tools have therefore been widely used to evaluate exposure to these risk factors and to identify tasks associated with elevated injury risk (NIOSH, 2019).

2.1 Prevalence of MSDs in Firefighters

Firefighters are consistently identified as one of the occupational groups at highest risk for MSDs. Systematic reviews and large-scale epidemiological studies demonstrate MSDs are common among firefighters. A recent meta-analysis reported an overall MSD prevalence of approximately 46% among firefighters, with the lower back, shoulders, knees, and lower extremities most frequently affected (Tahernejad et al., 2024). Similar findings have been reported across national and regional studies, which consistently show higher rates of musculoskeletal symptoms among firefighters compared to other occupational groups (Khoshakhlagh et al., 2024; Nazari, MacDermid, and Cramm, 2020; Negm et al., 2017). These conditions contribute to increased lost work days, restricted duty, and workers' compensation claims.

The high prevalence of MSDs in this population has been attributed to the physical demands inherent in firefighting, including repetitive lifting, manual handling of heavy equipment, awkward or constrained postures, and frequent transitions between tasks. Kodom-Wiredu (2019) reported a significant association between increasing work demands, task characteristics, and the occurrence of work-related MSDs among firefighters. As workload intensity increases, so does the likelihood of musculoskeletal symptoms, reflecting the cumulative nature of occupational exposure in this profession.

Over time, the cumulative effect of these physical demands can lead to persistent discomfort, reduced functional capacity, and increased absenteeism, further highlighting the importance of identifying and mitigating ergonomic risk factors within the fire service.

Large-scale injury surveillance data further underscore the magnitude of this issue. Quinn et al. (2023), in an analysis of more than 33,000 workers' compensation claims filed by Ohio firefighters over a 16-year period, identified overexertion and bodily reaction injuries, primarily involving lifting, pulling, and carrying, as the leading causes of injury. The majority of claimants were male firefighters aged 25 to 54, reflecting the demographic makeup of the firefighting workforce during the study period. The leading injury events were overexertion involving external sources, such as lifting, pulling, or carrying heavy objects. These events most frequently resulted in sprains to the back, lower extremities, and upper extremities, highlighting the cumulative physical strain associated with firefighting tasks. Overall, the findings point to key priority areas for injury-prevention initiatives, including improved ergonomic practices, safer handling techniques, and enhanced situational awareness.

Similar trends were reported by Anderson et al. (2023), who analyzed workers' compensation data from Washington state and found significantly higher injury and illness claim rates among firefighters compared to law enforcement and other occupational groups. Washington's workers' compensation data from 2006 to 2020 showed significantly higher compensable claim rates among firefighters than among law enforcement officers and all other workers. Nearly 40% of firefighters' claims were work-related MSDs, which occurred far more frequently than in comparison groups and often resulted from lifting and transporting patients, using firefighting tools and equipment, or performing physical training.

Claim patterns over time revealed overall declines in work-related MSD rates across all groups, although firefighters consistently had the highest rates. These findings underscore the physically demanding and hazardous nature of firefighting and emphasize the need for targeted prevention strategies, particularly those addressing WMSDs, within risk-management frameworks that support safer material handling, improved ergonomics, and broader hazard-control practices.

Collectively, these findings demonstrate MSDs remain a dominant source of injury among firefighters and are strongly associated with the physical demands of both emergency and routine work activities. The literature further suggests many of these injuries result from cumulative exposure rather than isolated events, underscoring the need to identify high-risk tasks and implement targeted ergonomic interventions. Despite this, relatively limited research has systematically evaluated non-fireground activities using objective ergonomic assessment methods capable of capturing posture, movement, and task demands in real-world settings.

2.2 Nordic Questionnaire

The Nordic Questionnaire is an indirect assessment tool designed to identify musculoskeletal symptoms through a standardized set of questions (López-Aragón et al., 2017). It is one of the most widely used ergonomic questionnaires globally and focuses on symptoms affecting the neck, back, shoulders, and extremities (López-Aragón et al., 2017). This tool is commonly applied across various occupational sectors, including manufacturing, agriculture, livestock, fishing, and forestry (López-Aragón et al., 2017).

The first section of the questionnaire evaluates symptoms in nine body regions—neck, shoulders, elbows, wrists/hands, upper back, lower back, hips/thighs, knees, and ankles/feet—both over the past seven days and in the past 12 months (López-Aragón et al., 2017). The second section targets the neck, shoulders, and lower back, addressing symptom history over the employee's work career as well as within the previous seven days (López-Aragón et al., 2017). All questions use a simple "yes" or "no" response format to streamline the interview process (Namwongsa et al., 2018).

The Nordic Questionnaire is frequently used in combination with other ergonomic assessment tools such as REBA (Koohpaei et al., 2017; López-Aragón et al., 2017).

ADVANTAGES:

- Simple, standardized response format
- Validated tool
- Increasingly used
- Widely applied worldwide

DISADVANTAGES:

- Does not consider demographic factors
- May underreport symptoms among physically fit individuals
- Does not identify sources of symptoms

2.3 Rapid Entire Body Assessment (REBA)

The REBA method evaluates the risk of MSDs by analyzing posture in the upper and lower bodies during work tasks (Middleworth, 2019). It was explicitly designed to assess whole-body postural demands in various job activities (Middleworth, 2019). REBA examines six body regions but also incorporates measures of grip and load coupling (Berlin and Adams, 2017). This method may be applied through direct observation, photographs, or video recordings (Middleworth, 2019). Entire body angles are evaluated and scored based on the degree of deviation observed in the area being assessed.

Its scoring system enables evaluators to assess both static and dynamic postures while accounting for coupling quality. Assessments can be conducted in real time or through photos and video recordings for later review (Berlin and Adams, 2017). The final score reflects the urgency with which ergonomic hazards should be addressed (Berlin and Adams, 2017). The scoring system is broken into five categories (Middleworth, 2019):

- **Score 1:** Negligible risk
- **Score 2-3:** Low risk, change may be needed
- **Score 4-7:** Medium risk, further investigate, change soon
- **Score 5-10:** High risk, investigate and implement change
- **Score 11+:** Very high risk, implement change

ADVANTAGES:

- User-friendly
- Straightforward to interpret
- Includes measures of grip and coupling
- More effective than RULA for evaluating tasks with moderate physical demands
- Measures effort intensity

DISADVANTAGES:

- May underestimate very high-risk tasks
- Must be performed twice because each side of the body is assessed separately
- Only measures individual postures, not a set of sequential postures during a task
- Task evaluations should be completed by occupational safety and health individuals familiar with the task at hand
- Duration of exposure and frequency of postures throughout the working day are not considered
- Does not take into account unfavorable conditions (temperature and/or relative humidity)

2.4 Overcoming Individual Assessment Disadvantages

The researchers overcame the disadvantages identified with each of the above assessment tools by utilizing a combination approach. By choosing a blend of the aforementioned qualitative, semi-qualitative, and quantitative methods, this allowed one assessment tool's strengths to offset another method's weaknesses.

3. METHODOLOGY

The population chosen for the study was a local municipality fire station. This study included 17 full-time firefighters of diverse demographics, including age, years of service, etc. The purpose of this study was to complete a thorough ergonomic assessment of firefighters. At the same time, they perform routine, daily non-fireground activities at the fire station during the shift to determine their likelihood of MSDs.

The research methodology incorporated a blend of qualitative and quantitative techniques to identify tasks within this process exhibiting characteristics associated with significant ergonomic risk.

The research methodology incorporated a blend of qualitative, semi-quantitative, and quantitative techniques to identify tasks within this process exhibiting characteristics associated with significant ergonomic risk. The qualitative aspect involves conducting standardized interviews with firefighters about musculoskeletal symptoms across various body regions.

This study protocol underwent extensive review by the Institutional Review Board (IRB) at Murray State University. The demographic questions, confidentiality, and any legal or liability concerns were addressed. Those involved with this study completed IRB training in relation to human subjects. The IRB approval number is 25-031.

3.1 Survey Questionnaire

The researchers administered the participant survey one-on-one to reduce potential bias introduced by the presence of other participants. The 17 full-time firefighters completed a demographic survey to support qualitative analysis, insights into participants' anthropometric wellness data, and work history. The survey data acquired provided additional information to better understand the correlations revealed by the statistical analysis of the quantitative data collected.

The demographic questions asked of the participants were the following:

1. What is your age demographic?
2. What was your sex at birth?
3. What is your current weight?
4. What is your height?
5. How much sleep do you get on average per night?
6. Do you exercise regularly? If so, how many hours/week?
7. Average number of hours you work per week?
8. Do you currently have back pain? If so, answer the following questions:
9. How long have you had back pain?
10. Do you feel this back pain is work-related?
11. Does this pain interfere with your work?
12. Does this pain interfere with your ability to sleep?

3.2 Nordic Questionnaire

The Nordic Questionnaire, a commonly employed ergonomic tool, consists of a series of questions addressing nine specific regions of the body. It comprises 28 multiple-choice questions with "yes" or "no" responses, inquiring about any pain experienced in these regions over the past 12 months or seven days (López-Aragón et al., 2017).

3.3 Digital Human Modeling Software

The researchers used a quantitative approach, applying REBA with the digital human modeling software TuMeke. This method was chosen based on scholarly evidence indicating its preference for assessing whole-body posture and ensuring consistent outcomes (Middleworth, 2019; Sadeghi et al., 2019). The quantitative approach selected uses the AI tool with digital human modeling, employing an advanced ergonomic risk assessment platform, as illustrated in Figs. 3 and 4. The researchers affirm that there are no funding issues or conflicts of interest associated with the chosen technology.

FIG. 3
Procedure of recording task for AI-human modeling assessment

FIG. 4
Biomodeling software conducting REBA from uploaded video

The population chosen for the study was a local municipality fire station. This study included 17 full-time firefighters of diverse demographics, including age, years of service, etc. The purpose of this study is to complete a thorough ergonomic assessment of firefighters. At the same time, they performed routine, daily non-fireground activities at the fire station during the shift to determine their likelihood of MSDs. The 10 activities observed and assessed on the 17 firefighters were:

1. Climb into the fire engine cab.
2. Climb out of the fire engine cab.
3. Remove the fire extinguisher (25 pounds) from the compartment on the fire engine.
4. Remove extrication equipment (50 pounds) from the compartment on the fire engine.
5. Remove ladder (40 pounds) from the compartment on the fire engine.
6. Climb to the top of the fire engine and inspect the water level.
7. Remove SCBA air pack from fire engine cab for daily inspection.
8. Don SCBA air pack for daily inspection.
9. Walk ladder truck ladder for inspection.
10. Remove high-rise hose packs from the compartment on the fire engine.

4. DISCUSSION

4.1 Demographic Survey Results

According to the demographic survey, participants ranged in age from 19 to 50 years old. The age distribution was as follows: 29.41% were between 18 to 25 years old, 47.06% were 26 to 35 years old, 17.76% were 36 to 45 years old, and 5.88% were over 45 years old. The mean age was 31.06 years. The average participant weight was 208.82 pounds, with an average BMI of 29.29. All participants were male. On average, participants reported sleeping 6.88 hours per day, exercising 4.53 hours per week, and working 60.35 hours per week—some of which included second jobs to supplement income. Firefighting experience ranged from one month to 18 years, with an average of 4.25 years.

4.2 Nordic Questionnaire Results

Body Part	Participants Reporting Pain
Lower Back	9 (28.125%)
Shoulder	7 (21.875%)
Knee	5 (15.625%)
Wrist/Hand	4 (12.5%)
Hip/Thigh	3 (9.375%)
Neck	2 (6.25%)
Ankle/Feet	1 (3.125%)
Upper Back	1 (3.125%)
Elbow	0 (0%)

TABLE 2
Participants Reporting Pain Via Nordic Questionnaire

Using the Nordic Questionnaire, 70.58% of participants reported experiencing musculoskeletal symptoms in one or more areas, including the neck, shoulders, elbows, wrists/hands, back, hips, knees, or ankles. Of those reporting MSD symptoms, 35.29% were within the 26 to 35 age range. The most commonly affected area was the lower back, with 28.125% of participants reporting pain in the past 12 months. The second most frequently reported area was the shoulder, with 21.875% indicating shoulder pain during the same time period. Table 2 summarizes the participants' reports of body areas affected by pain within the past year.

4.3 Statistical Analysis

A binomial logistic regression was conducted to determine the influence of age, weight, BMI, and years of firefighting experience on the likelihood of participants reporting musculoskeletal symptoms. The overall model was statistically significant, $X^2(4) = 15.188$, $p < .0005$, indicating that the predictors reliably distinguished between those with and without symptoms. All four variables, age, weight, BMI, and years of firefighting experience were statistically significant contributors to the model. Results showed that increased age, greater weight, and more years in the firefighting profession were associated with a higher likelihood of reporting musculoskeletal symptoms. In contrast, a lower BMI was associated with a lower likelihood of experiencing such symptoms.

4.4 Biomodeling Software REBA Results

Figure 5 presents a visual comparison of the REBA scores across all tasks. A comparison of REBA scores for the 10 pre-selected, non-fireground activities indicated that Task 4, removing extrication equipment (Fig. 6), had the highest overall score at 9.06.

This task, along with Task 9, walking the ladder truck ladder (Fig. 7), with a score of 8.76, and Task 6, climbing to the top of the fire engine to inspect the water level (Fig. 8), with a score of 8.12, were classified as "high risk," falling within the REBA high-risk range of 8 to 10. These activities warrant further investigation and ergonomic interventions to reduce risk levels.

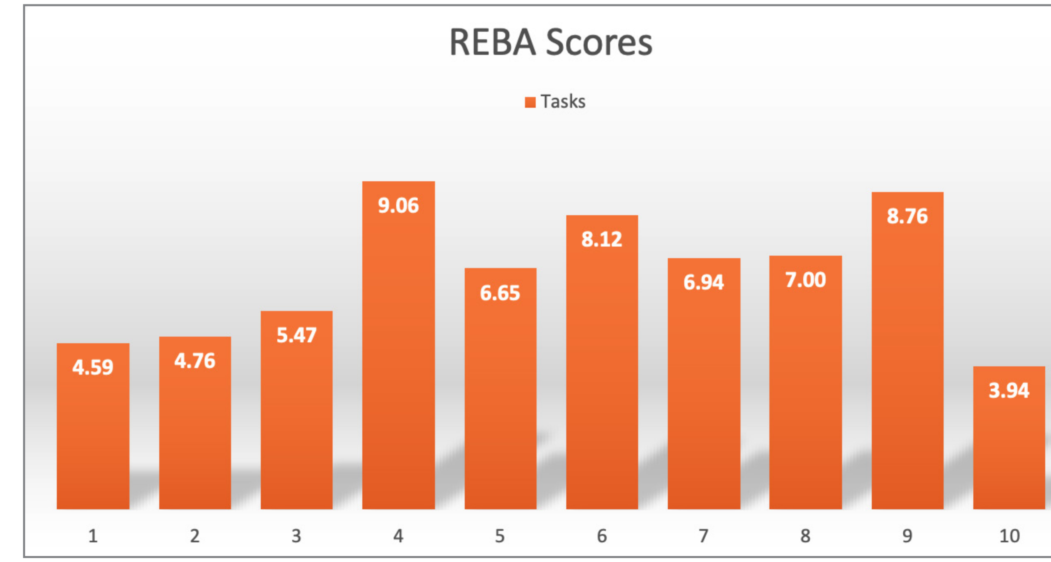


FIG. 5
REBA scores for 10 non-fireground activities

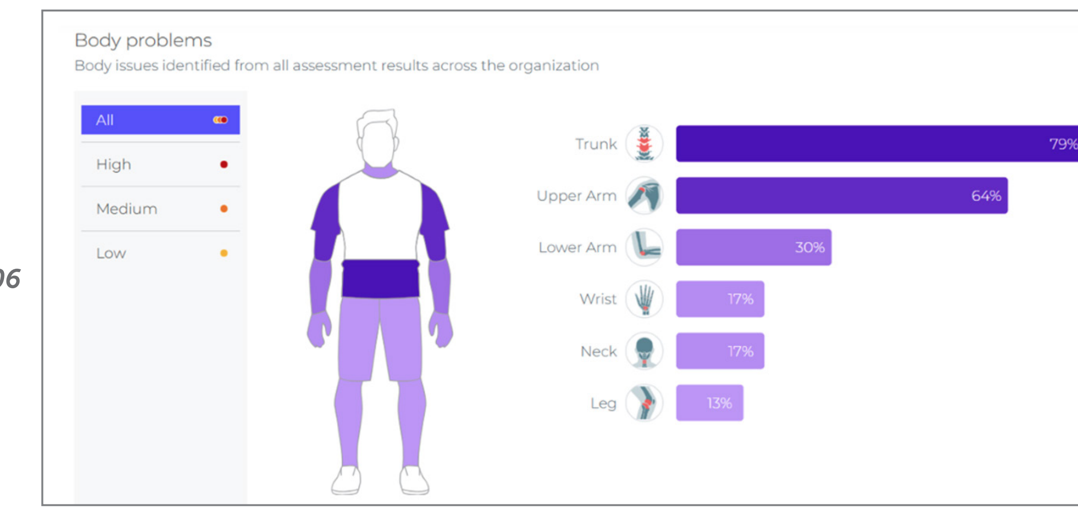


FIG. 6
Task 4 (Remove Extrication Equipment) Overall Body Problems, REBA Score = 9.06

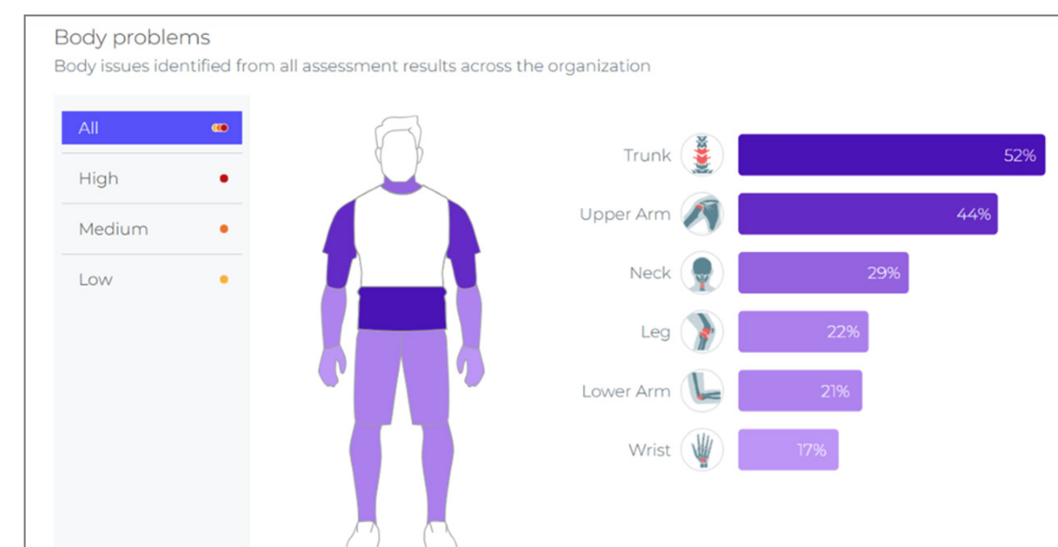
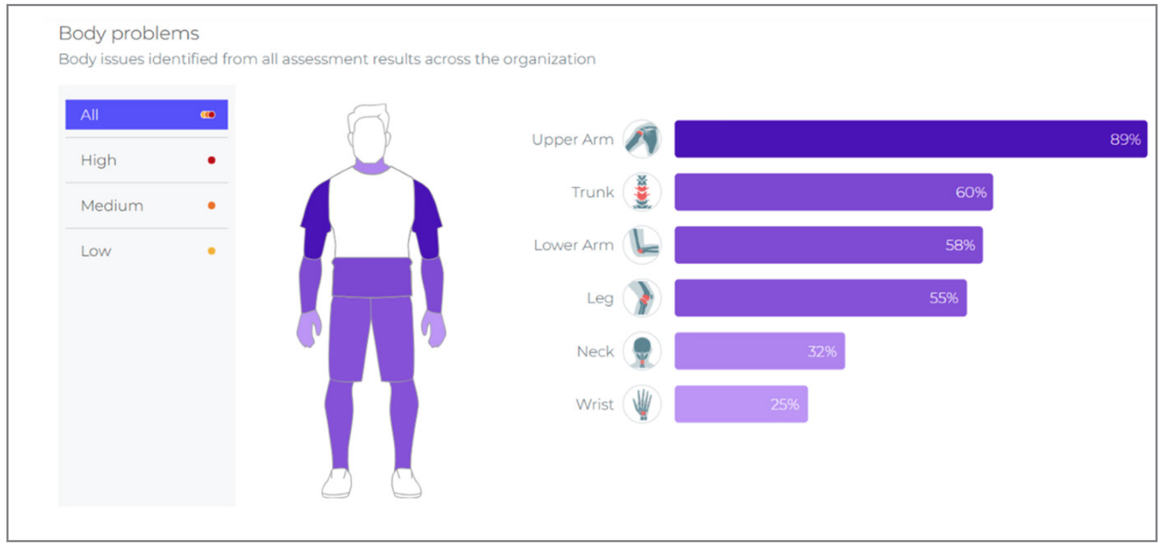


FIG. 7
Task 9 (Walk Ladder Truck Ladder) Overall Body Problems, REBA Score = 8.76

FIG. 8
Task 6 (Climb/Inspect Water Level) Overall Body Problems, REBA Score = 8.12



Most of the other tasks were categorized as "medium risk," with REBA scores ranging from 4 to 7. Specifically, Task 8, putting on the SCBA air pack (Fig. 9), scored 7.00, and Task 7, removing the SCBA air pack (Fig. 10), scored 6.94. Task 5, removing a ladder (Fig. 11), scored 6.65, and Task 3, removing a fire extinguisher from a compartment (Fig. 12), scored 5.47. Task 2, climbing out of the fire engine cab (Fig. 13), scored 4.76. Finally, Task 1, climbing into the fire engine cab (Fig. 14), scored 4.59. These medium-risk activities warrant further investigation and changes soon.

FIG. 9
Task 8 (Don SCBA Air Pack) Overall Body Problems, REBA Score = 7.00

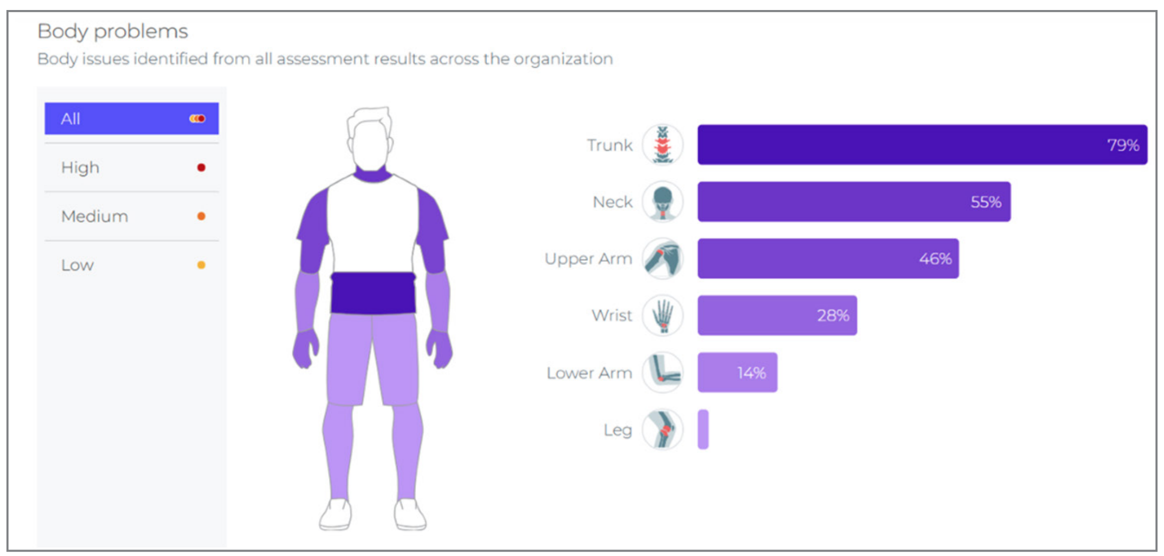


FIG. 10
Task 7 (Remove SCBA Air Pack from Fire Engine Cab) Overall Body Problems REBA Score = 6.94

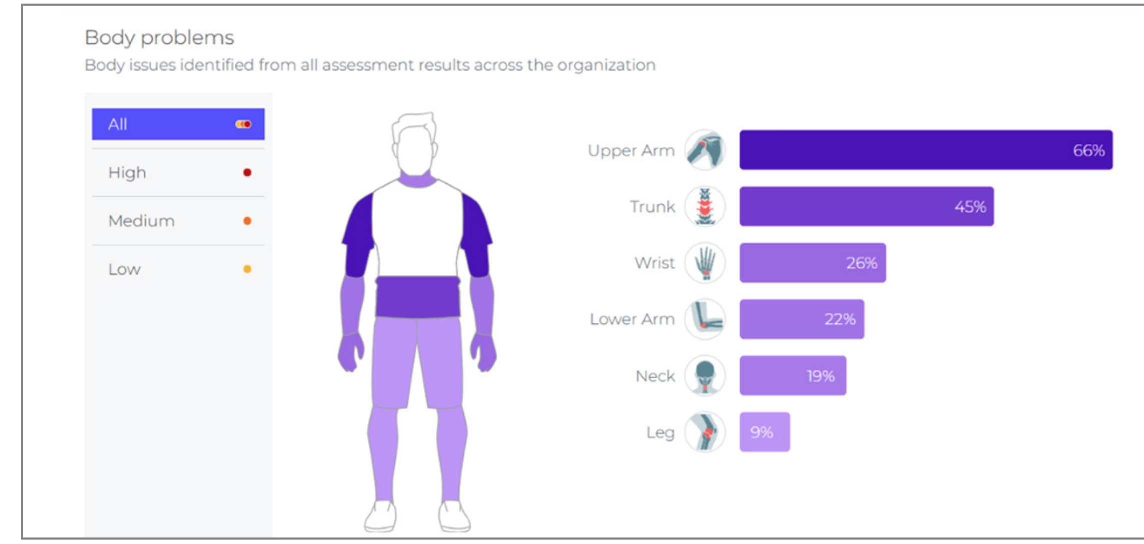


FIG. 11
Task 5 (Remove ladder) Overall Body Problems, REBA Score = 6.65

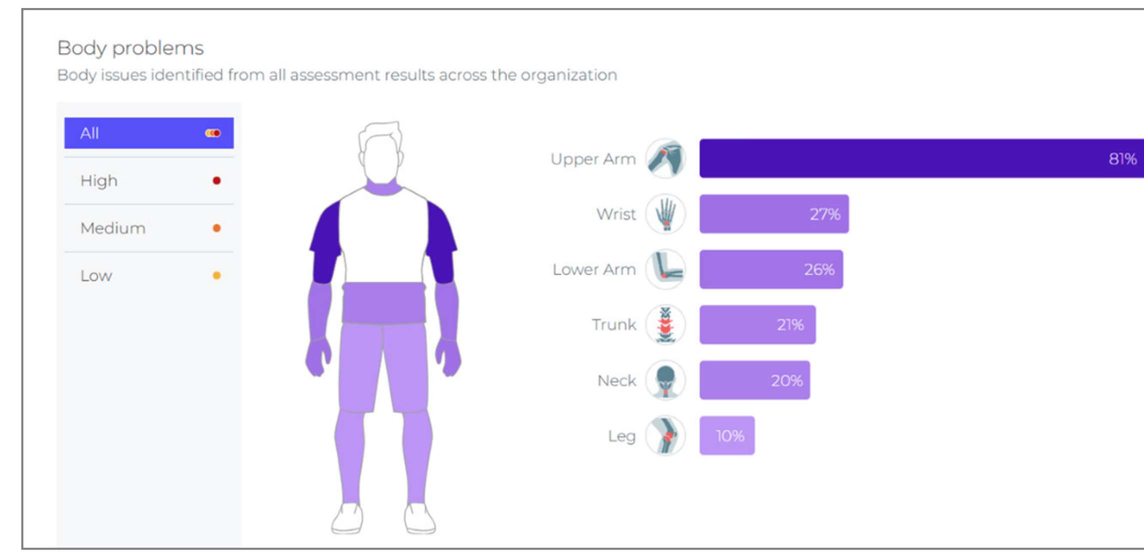
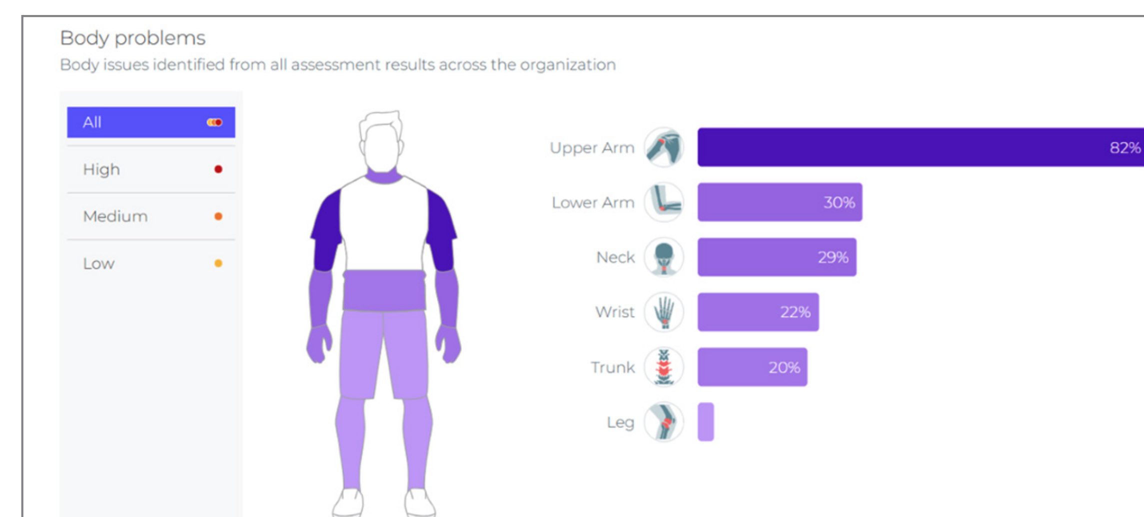


FIG. 12
Task 3 (Remove Fire Extinguisher) Overall Body Problems, REBA Score = 5.47



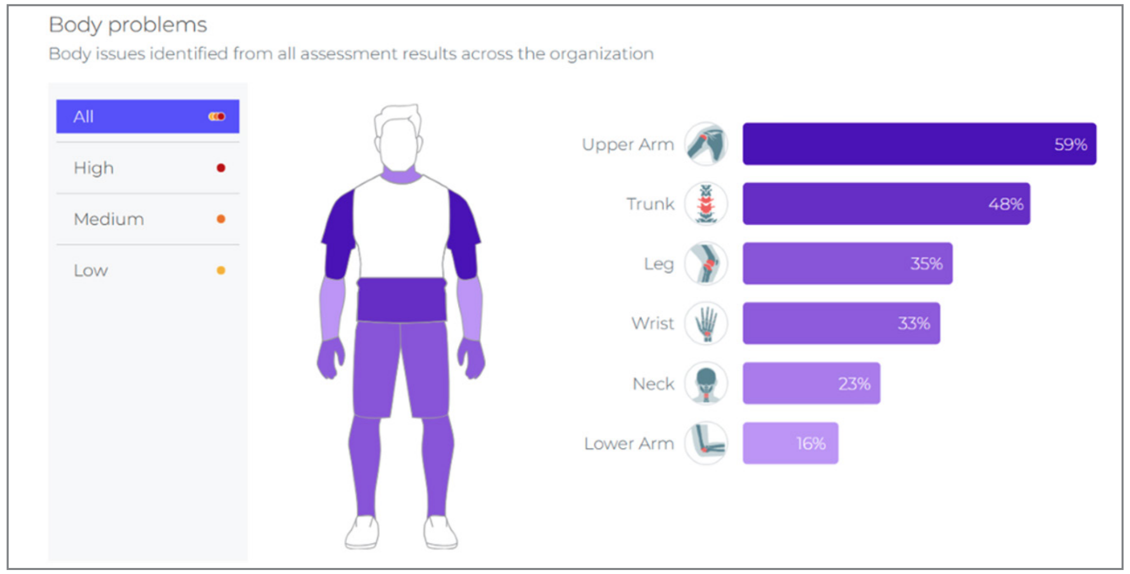


FIG. 13
Task 2 (Climb Out of Fire Engine) Overall Body Problems, REBA Score = 4.76

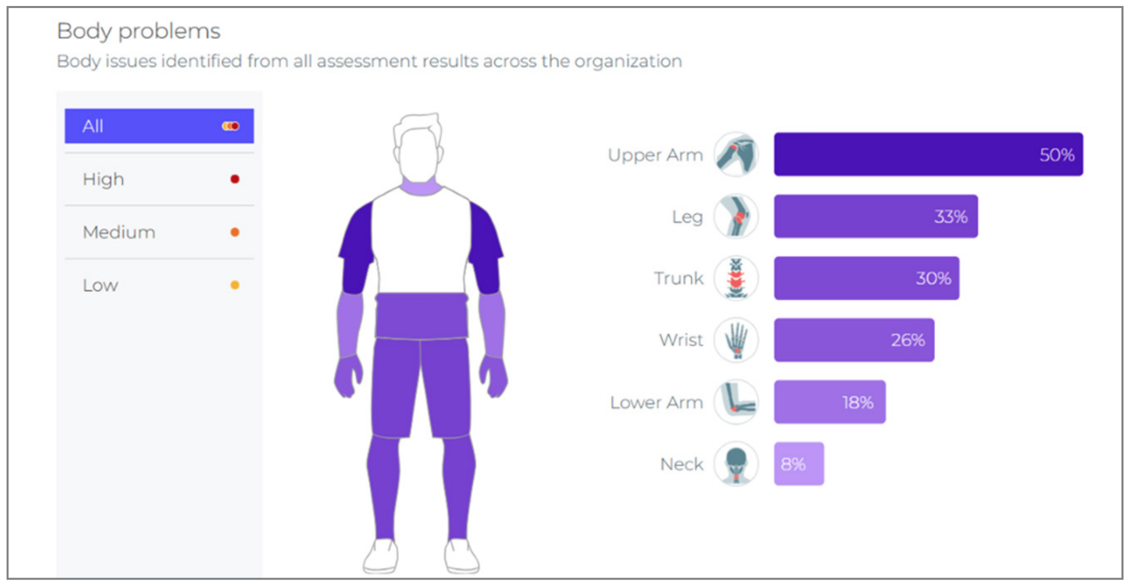


FIG. 14
Task 1 (Climb into Fire Engine) Overall Body Problems, REBA Score = 4.59

The only task categorized as "low risk," with a REBA score between 2 and 3, was Task 10, removing high-rise hose packs (Fig. 15), which scored 3.94. Low-risk REBA scores such as this task indicate that change may be needed.

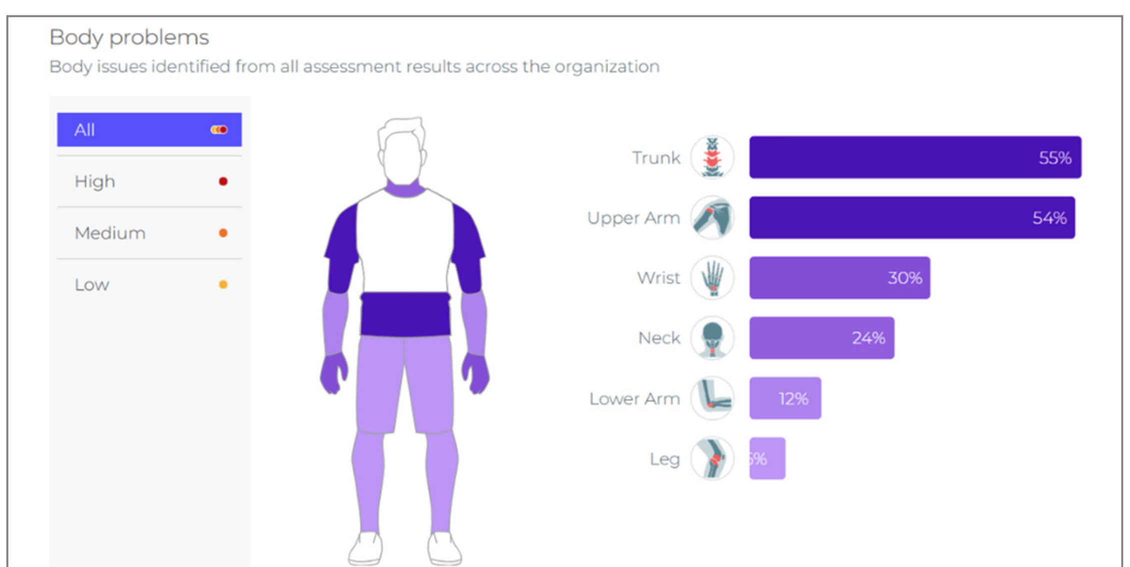


FIG. 15
Task 10 (Remove High Rise Hoses) Overall Body Problems, REBA Score = 3.94

The researchers then analyzed how frequently each body part was identified as a high-risk area based on the REBA scores. As shown in Table 3, the upper arms were flagged most often, accounting for 42.59% of high-risk identifications, followed by the trunk at 30.04%. When compared with the self-reported painful body part areas in Table 2, the researchers found a strong alignment: the most frequently identified REBA risk areas, the upper arms and trunk, closely corresponded to the most commonly reported pain sites among firefighters in the Nordic Questionnaire, specifically the shoulders and lower back.

Body Part	Percentage of Problem Area Focus
Upper Arm	42.59%
Trunk	30.04%
Lower Arm	9.67%
Neck	7.58%
Wrist	5.57%
Leg	4.55%

TABLE 3
Percentage of Times Body Parts Identified as Problem Areas

Biomodeling software also generated recommendations to help address identified problem areas. For Task 4, with the highest REBA score of 9.06, remove extrication equipment, the top suggestion was to minimize forward trunk bending, which could lower the risk score by 30%. Additionally, reducing forward upper arm movement and limiting shoulder abduction could decrease the risk score by 20%. These recommendations are illustrated in Fig. 16.

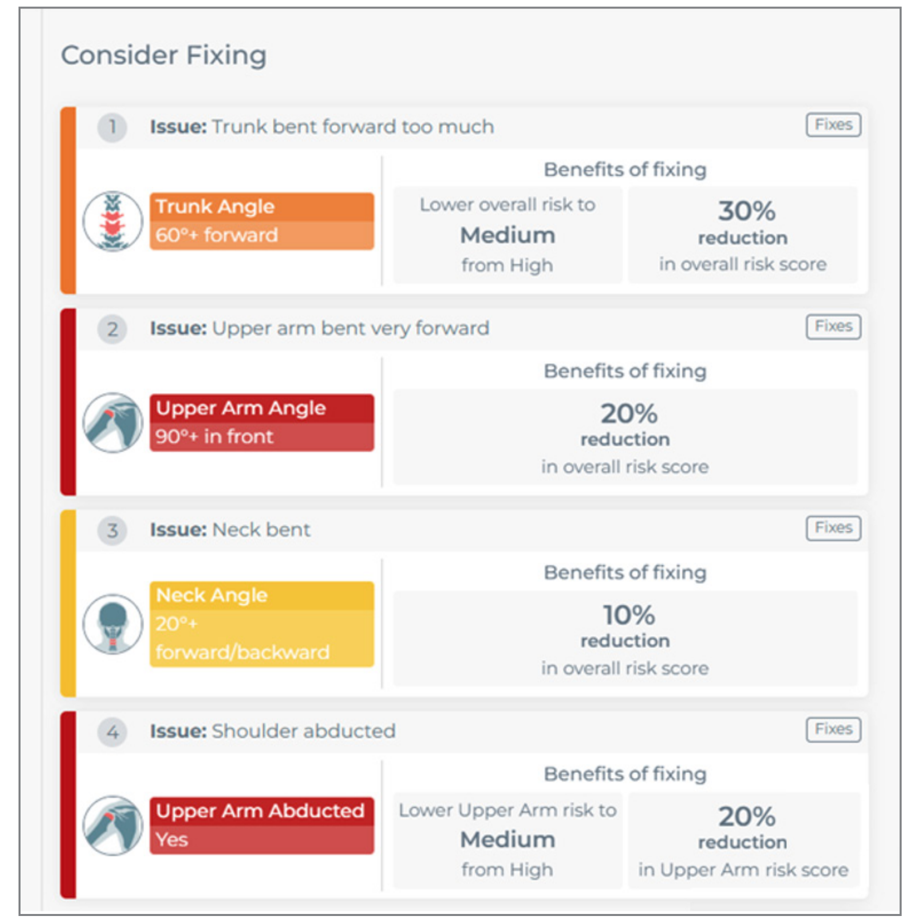


FIG. 16
Recommended Corrective Actions for Task 4, Remove Extrication Equipment

The task with the next highest REBA score was Task 9, walk ladder truck ladder for inspection, with a score of 8.76. As shown in Fig. 17, biomodeling software recommended that a 33% reduction in the overall risk score could be achieved by decreasing the upper-arm angle while climbing onto the fire engine to access the ladder truck. Additionally, the trunk was excessively bent forward during the ladder inspection. This issue could be mitigated by moving the ladder truck out from under the low ceiling inside the fire station, allowing firefighters to stand upright while performing the inspection.

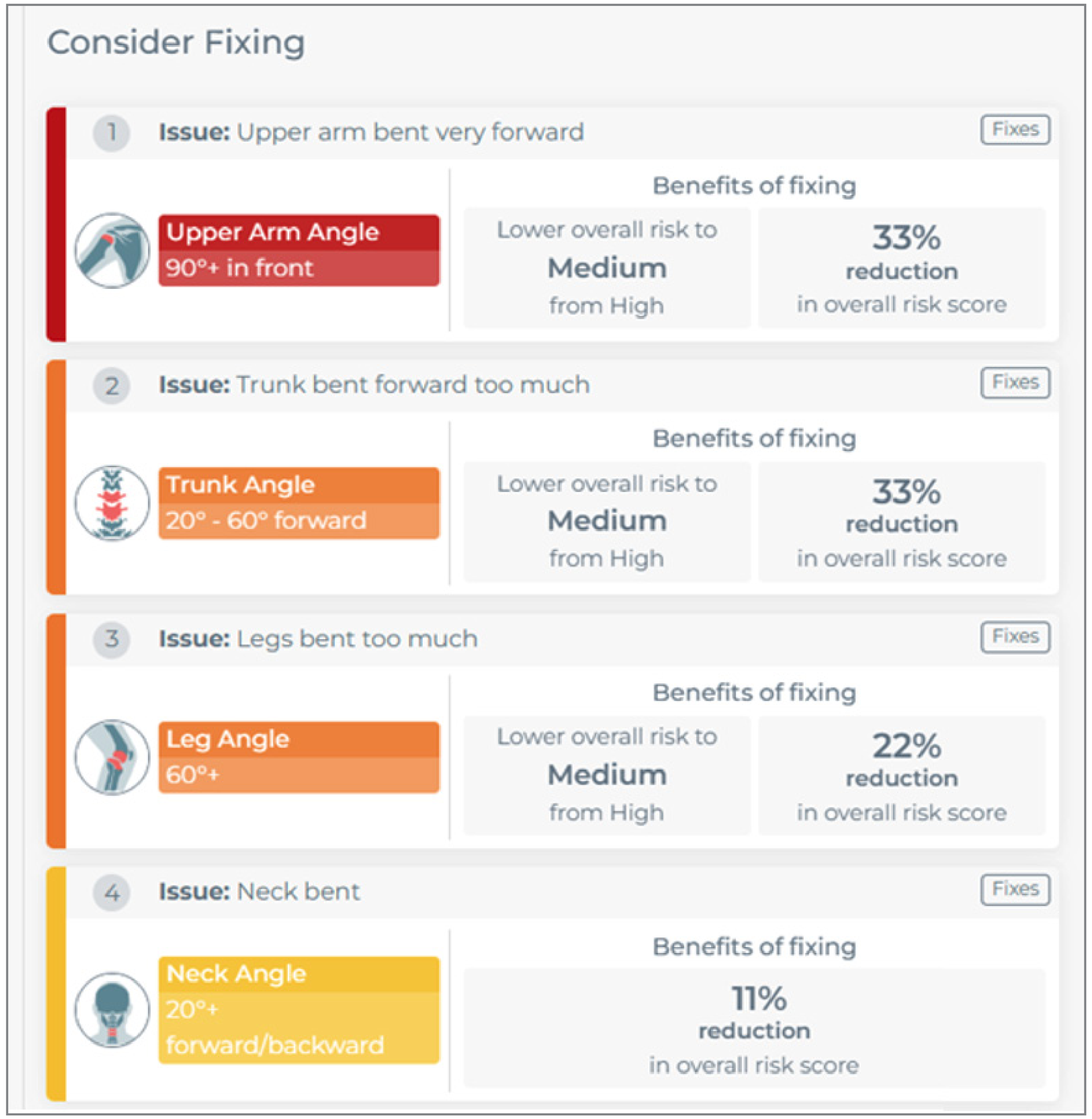


FIG. 17
Recommended Corrective Actions for Task 9, Walk Ladder Truck Ladder

Finally, Task 6, climbing to the top of the fire engine to inspect the water level, had the third-highest overall REBA score at 8.12. As shown in Fig. 18, biomodeling software estimated that a 50% reduction in risk score could be achieved by minimizing trunk flexion and reducing leg bending. However, this may be challenging to implement, as the existing rungs used to climb the fire engine are fixed. To address this, the fire truck would need to be reconfigured with rungs placed closer together and the water level viewing area repositioned, allowing firefighters to inspect it without excessive leaning.

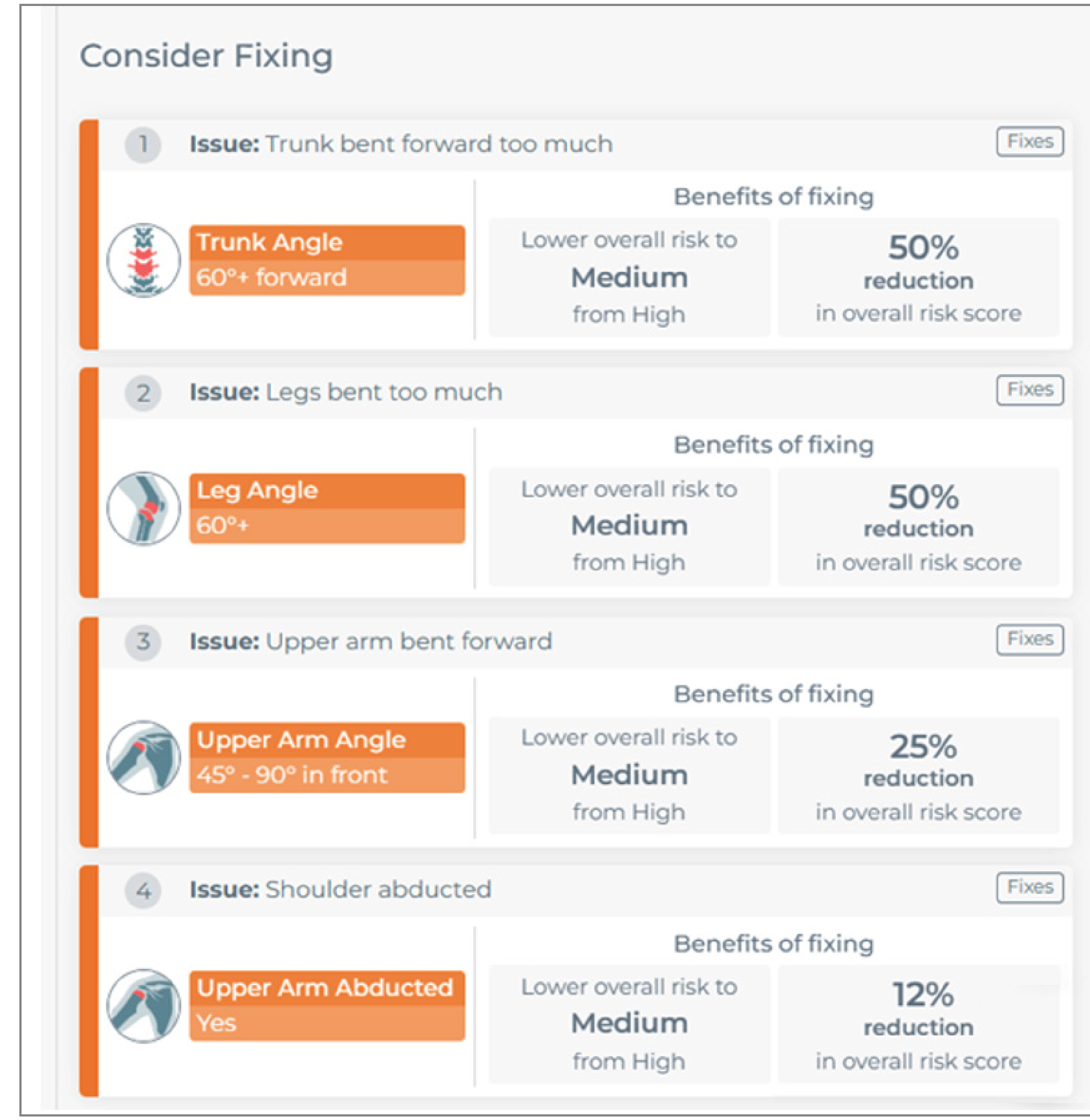


FIG. 18
Recommended Corrective Actions for Task 6, Climb/ Inspect Water Level

4.5 Limitations and Future Directions

This study focused on one fire department that provided a letter of support. Future studies can be broadened to include more fire departments to further validate findings.

The results of this study can be used to develop in-service training for firefighters, industrial hygienists, and safety professionals.

Some participants have second jobs to supplement their income, which could not be considered a major confounding factor; rather, it was addressed in the qualitative survey. That survey examined total work hours, sleep, and exercise, which could possibly contribute to fatigue.

5. CONCLUSIONS

The study involved male firefighters aged 19 to 50, with a mean age of 31.06; most participants were between 26 and 35 years old. Participants averaged 208.82 pounds in weight, a BMI of 29.29, slept 6.88 hours/day, exercised 4.53 hours/week, and worked 60.35 hours/week. Firefighting experience ranged from one month to 18 years, with an average of 4.25 years.

According to the Nordic Questionnaire, 70.58% reported musculoskeletal symptoms, most commonly in the lower back (28.13%) and shoulders (21.88%). A logistic regression showed that age, weight, BMI, and years of firefighting experience significantly influenced the likelihood of reporting symptoms.

This study aimed to examine the movements most commonly used in non-fireground training activities that pose the most significant risk of MSDs to firefighters. REBA assessments conducted by the biomodeling software of 10 non-fireground tasks identified three tasks as "high risk": removing extrication equipment (REBA score: 9.06), walking the ladder truck ladder (8.76), and inspecting the water level on the fire engine (8.12). Most of the remaining tasks were identified as "medium risk": don SCBA air pack (REBA score: 7.00), remove SCBA air pack (6.94), remove ladder (6.65), remove fire extinguisher (5.47), climb out of fire engine cab (4.76), and climb into fire engine cab (4.59). Moreover, one task, removing high-rise hose packs, was "low risk" (REBA score: 3.94).

The researchers found that the upper arms (42.59%) and trunk (30.04%) were the most frequently identified high-risk areas based on biomodeling software REBA scores. These findings closely aligned with the self-reported pain areas from the Nordic Questionnaire, with firefighters most commonly reporting shoulder and lower back pain.

Another specific aim of this study was to determine the most effective corrective actions for each high-risk, non-fireground ergonomic task for firefighters. Biomodeling software provided recommendations to reduce ergonomic risks for the top three highest-scoring tasks. For Task 4 (remove extrication equipment, REBA score 9.06), reducing trunk bending and upper arm movement could lower the risk score by up to 50%. For Task 9 (walk ladder truck ladder for inspection, score 8.76), minimizing upper arm angles and trunk flexion could reduce risk by 33%, with further improvement possible by relocating the truck to allow an upright posture.

Task 6 (inspect water level on fire engine, score 8.12) could see a 50% risk reduction by decreasing trunk and leg bending, though this would require structural changes to the fire engine's rungs and water level viewing area.

6. RECOMMENDATIONS

Based on the study's findings, several recommendations are proposed for organizations, policymakers, and future research efforts. The ergonomic risk treatment hierarchy was applied when developing the following recommendations.

1. Firefighting vehicles need engineering modifications to reduce the stretch required by firefighters to use the vehicle and its apparatus, as well as overall improvements in ergonomic design and layout. Modifications to improve the design of the firefighting vehicles and tools should be considered to reduce these MSD risks.
2. What other specific non-fireground tasks (e.g., equipment cleaning, training drills, patient lifting) pose the highest ergonomic risks for MSDs among firefighters?
3. How do the physical demands of training activities compare to actual emergency responses in terms of musculoskeletal strain?
4. What is the cumulative effect of repetitive, low-intensity tasks on the development of MSDs over a firefighter's career?
5. What is the effectiveness of ergonomics combining engineering and administrative controls to intervene (e.g., lifting techniques, redesigned tools, adjustable equipment) in reducing MSDs during training and maintenance activities?
6. Can wearable technologies or exoskeletons reduce strain and injury risk during physically demanding non-fireground tasks?
7. Do firefighters downplay or ignore early MSD symptoms due to cultural norms, and how does this impact injury progression?

The Ergonomics Risk Assessment Tool (ERAT) could be an additional risk assessment checklist used alongside other methods in this study. The ERAT would address the limitations previously mentioned for the REBA as well. The ERAT can be used to analyze tasks with limited training. Also, the ERAT addresses multiple ergonomic risks, including awkward postures, high repetition, force, mechanical compression, vibration, and environmental factors such as lighting and temperature (American National Standards Institute, 2000).

Acknowledgement

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Effectiveness of the NU'care Participatory Ergonomics Program on Musculoskeletal Discomfort, Postural Risk, and Mental Workload among Operating Room Nurses

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ABSTRACT

Operating room (OR) nurses are exposed to high ergonomic and psychological demands that increase the risk of musculoskeletal disorders (MSDs) and mental workload. This quasi-experimental study evaluated the effectiveness of the NU'care (Nurses' care) participatory ergonomics program on musculoskeletal discomfort, postural risk, body posture angles, visual fatigue, and mental workload among OR nurses.

A one-group, pretest-posttest design was conducted among 38 OR nurses at a tertiary hospital in northeastern Thailand. The 10-week NU'care program was developed based on participatory ergonomics principles. Data were collected using an online musculoskeletal discomfort questionnaire, the Rapid Entire Body Assessment (REBA), the Subjective Workload Index (SWI), a visual fatigue assessment using critical flicker fusion frequency, and direct measurements of body posture angles. Paired t-tests and Wilcoxon signed-rank tests were used to compare pre- and post-intervention outcomes.

After the intervention, participants reported significantly reduced musculoskeletal pain in the shoulders, upper back, and lower back ($p < .05$). REBA scores demonstrated significant reductions in applied force, lower arm posture, and coupling ($p < .05$). Mental workload scores significantly decreased following the program ($p < .001$). In addition, significant reductions were observed in shoulder flexion, arm crossing, wrist deviation, wrist flexion, and wrist extension angles during work tasks ($p < .001$).

The NU'care participatory ergonomics program effectively reduced musculoskeletal discomfort, ergonomic risk, awkward postures, and mental workload among OR nurses. The findings suggest that this participatory-based program can be adapted for other occupational settings with similar ergonomic risks.

KEY WORDS: *musculoskeletal disorders, operating room nurses, participatory ergonomics, risk assessment*

1. INTRODUCTION

Musculoskeletal disorders (MSDs) are a major global public health concern. According to the Global Burden of Disease report, approximately 1.71 billion individuals worldwide are affected by musculoskeletal conditions, including lower back pain, neck pain, and joint disorders (World Health Organization, 2019). Healthcare workers experience a disproportionately high burden of MSDs, with work-related injuries occurring at a significantly higher rate, in some cases seven times higher than that observed in other industrial sectors (BLS, 2018; Mohanty et al., 2019). Nurses, in particular, frequently report musculoskeletal pain involving the shoulders, lower back, calves, and hands, which contributes to absenteeism and early departure from the profession.

Operating room (OR) nurses face unique ergonomic challenges due to prolonged standing, repetitive instrument handling, and extended surgical procedures that vary in duration and complexity. These occupational demands significantly increase the risk of developing MSDs (Watkhoksoong and Chaiklieng, 2024). In addition to physical strain, work-related stress has been associated with neck and shoulder pain among nurses, further compounding the risk of injury (Chaiklieng et al., 2022).

Some previous studies reported that participatory ergonomics (PE) is an approach that emphasizes active worker involvement in identifying ergonomic hazards, developing solutions, and implementing workplace improvements. In addition, Laowanich et al. (2022) showed that PE interventions can effectively reduce ergonomic risk, musculoskeletal symptoms, and muscle fatigue among healthcare workers. By engaging employees in problem-solving and decision-making processes, PE promotes sustainable ergonomic improvements and enhances workers' ownership of health interventions (Copsey et al., 2025).

Concerning OR nurses who are at risk of MSDs from physical and psychosocial workload, there were no reports of previously implemented ergonomics programs. Therefore, this study aimed to evaluate the effectiveness of the NU'care (Nurses' care) participatory ergonomics program, based on a seven-step PE framework on visual fatigue, musculoskeletal discomfort, ergonomic risk, body posture angles, and mental workload among operating room nurses.

2. MATERIALS AND METHODS

2.1 Research Design

A quasi-experimental, one-group pretest-posttest design was used. The intervention was based on participatory ergonomics principles following the framework proposed by Mijatovic (2008) and implemented through the NU'care occupational health ergonomics program (Watkhoksoong and Chaiklieng, 2025).

2.2 Ethical Considerations

Ethical approval was obtained from the Khon Kaen University Ethics Committee, Thailand (No. HE672223). Participation was voluntary, and informed consent was obtained from all participants.

2.3 Participants and Sampling

The study population consisted of nurses working in the OR of a tertiary hospital in northeastern Thailand. Sample size was calculated using G*Power software based on the criteria set by Cohen (1988), yielding a minimum requirement of 33 participants. To account for potential attrition, 38 nurses were recruited using purposive sampling.

Inclusion criteria were: (a) working as a scrub nurse in an OR for at least one hour per day, (b) having at least three months of OR experience, and (c) willingness to participate. Exclusion criteria included: having congenital MSDs, having experienced a musculoskeletal injury within the last six months leading to time off work, having undergone previous musculoskeletal surgery, and being pregnant at the time of the study.

2.4 The NU'care Participatory Ergonomics Program

The NU'care program was conducted over 10 weeks and consisted of seven participatory steps: (a) baseline data collection, (b) program preparation, (c) ergonomic knowledge-building activities, (d) design of preventive strategies, (e) establishment of ergonomic management methods, (f) joint implementation, and (g) monitoring and evaluation, as shown in Fig. 1.

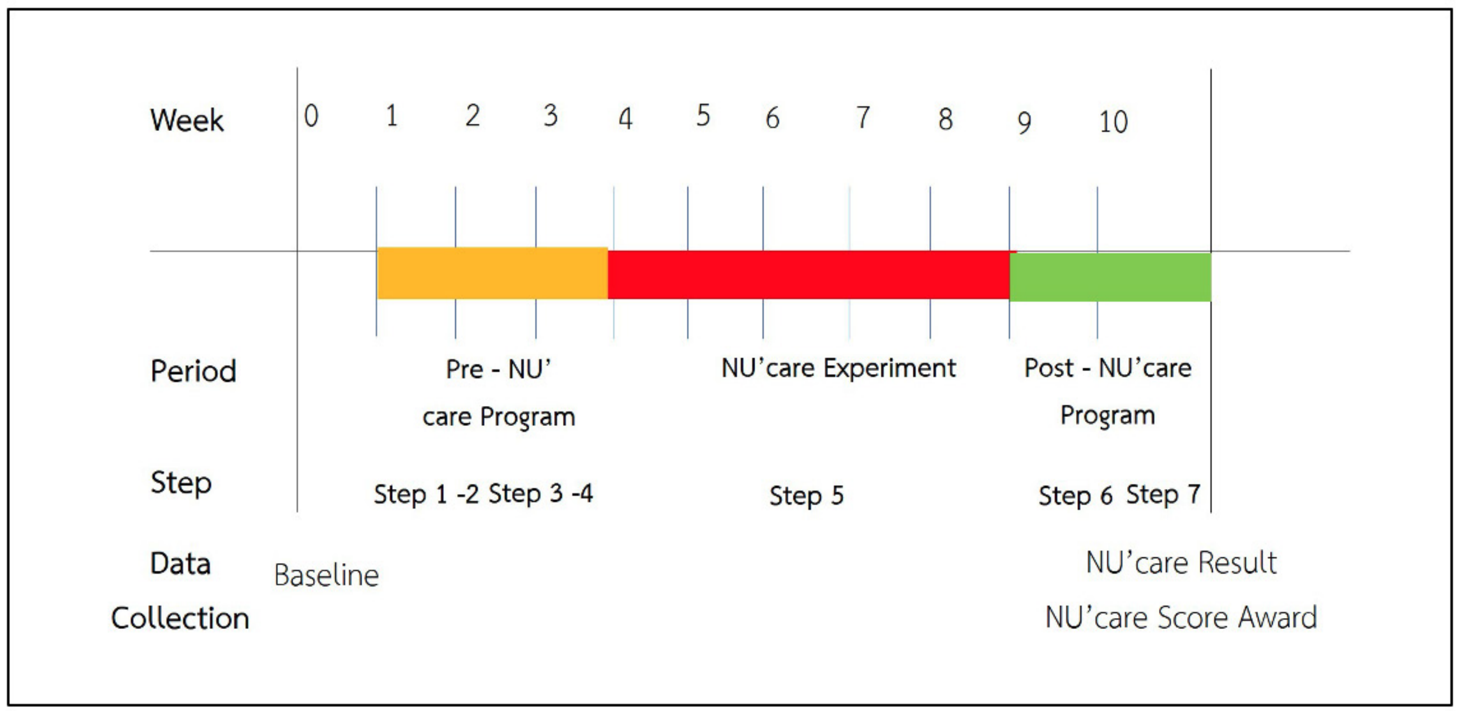

FIG. 1
Execution of the NU'care Occupational Health and Ergonomics Program

2.5 Pre-NU'care Program Phase

WEEK 1: STEP 1

Risk Communication and Participatory Ergonomic Risk Analysis. The results from the baseline phase, collected from ergonomic risk data for each participant during week 1 (refer to outcome measures below) were summarized and communicated to participants to analyze ergonomic problems and jointly identify appropriate preventive measures.

WEEK 2: STEP 2

Educational Activity on Ergonomic Principles. Study participants attended a lecture titled "Prevention and Reduction of Work-Related Discomfort in the Operating Room: Stretch and Strong," which covered topics including ergonomic working postures and basic self-stress management techniques. The content was adapted from the chapter on MSD surveillance in the Occupational Ergonomics book (Chaiklieng, 2023).

WEEK 3: STEPS 3 AND 4

Step 3: Designing Ergonomic Risk Prevention Strategies. Based on the ergonomic risks identified in Step 1, participants and researchers collaboratively designed preventive strategies.

Step 4: Ergonomic Intervention Planning and Goal Setting. Through collaborative decision-making, researchers and participants agreed on specific ergonomic management measures. The consensus included the following: patient handling must involve an assistant for procedures lasting longer than one hour, scheduled breaks should be taken to alleviate physical fatigue, and stretching and eye relaxation exercises, consisting of eight stretching exercises for musculoskeletal relief and five eye relaxation techniques, were to be integrated into the daily routine. The exercises were scheduled during three key time periods: morning (8:20-8:35 AM), lunch break (12-12:15 PM), and before finishing work (4:15-4:30 PM). To support the implementation and consistency of these activities, the researcher sent reminders and infographic materials (illustrating the eight stretching exercises and five eye techniques) to participants via the LINE OA. Additionally, to encourage compliance and motivation, participants were invited to record their participation in each stretching session through the LINE OA system. Each completed session was worth five points, and those with the highest scores at the end of the intervention period were eligible for rewards, referred to as the NU'care Score Award.

2.6 NU'care Program Experimental Phase

WEEKS 4-8: STEP 5 - Intervention Period

Collaborative Implementation of the Program. Participants engaged in the NU'care occupational health ergonomics program for five weeks, following the ergonomic management approach co-designed in Step 4.

2.7 Post-NU'care Program Phase

WEEK 9: STEP 6

Post-Program Follow-Up and Data Collection. Post-intervention ergonomic risk data were collected using the same procedures and tools as in the baseline phase, including online questionnaires and measurements.

WEEK 10: STEP 7

Risk Communication and Summary of Program Outcomes. The findings from the post-intervention data (Step 6) were summarized and shared with participants. Additionally, the individual with the highest NU'care Score (accumulated from stretching sessions) received recognition through the NU'care Score Award.

Educational activities included ergonomic posture training, stretching exercises, eye relaxation techniques, and stress management strategies. Stretching and eye exercises were performed three times daily and reinforced through reminders and self-monitoring using a LINE OA. Participant engagement was encouraged through a point-based reward system (NU'care Score Award).

The LINE OA NU'care Program is a platform that facilitates self-assessment of ergonomic risk. The researchers developed online questionnaires using Google Forms, which were embedded within the LINE OA system. Participants were invited to add the LINE OA account as a friend, complete the self-assessments online, and receive their individual risk analysis via the same platform, as shown in Fig. 2.

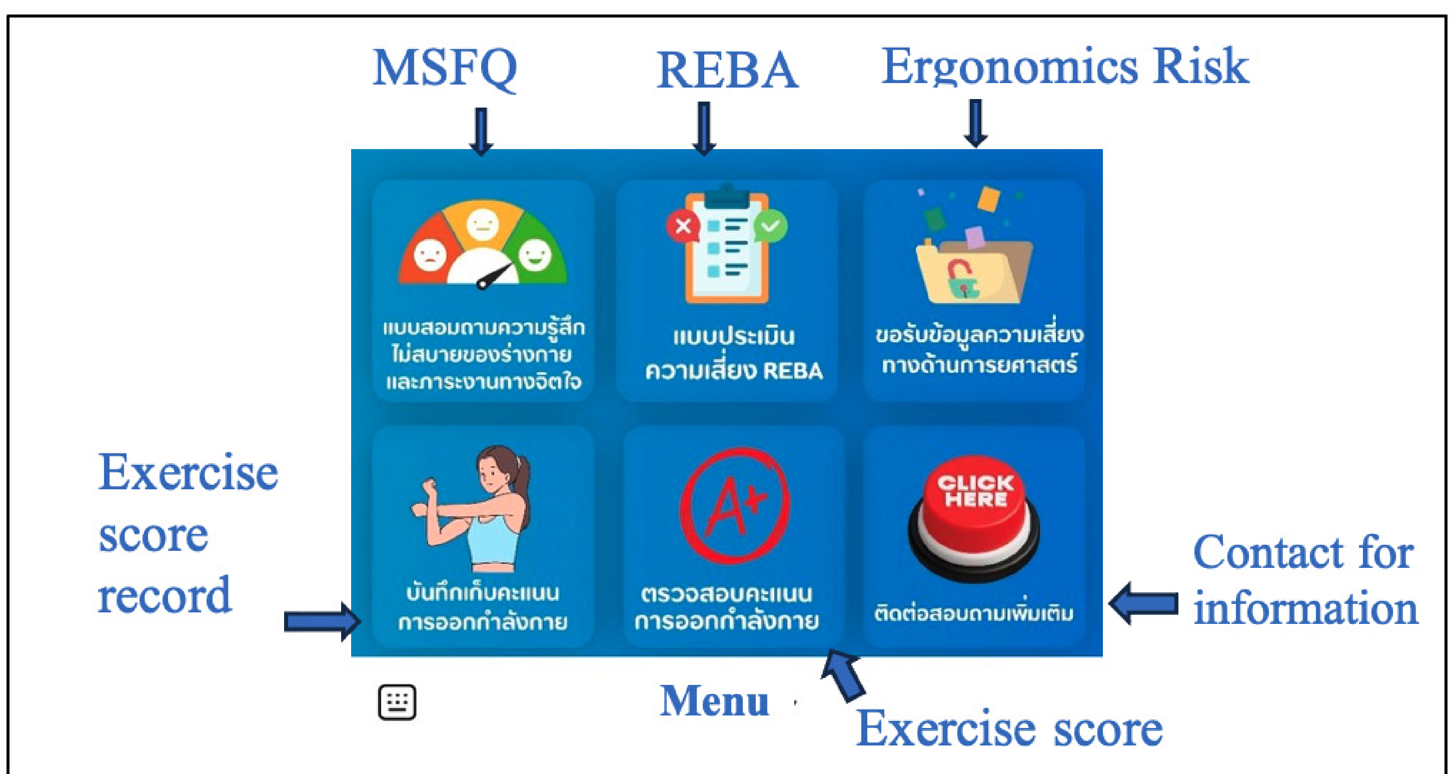

FIG. 2
Menu of the NU'care Online System via LINE Official Account

2.8 Instruments and Data Collection

Data were collected through online questionnaires and objective measurements using various instruments, as detailed below.

Musculoskeletal discomfort was assessed using the Musculoskeletal Severity and Frequency Questionnaire (MSFQ) adapted from Chaiklieng (2019). Questions concerning musculoskeletal complaints elicited information on self-reported musculoskeletal complaints during the previous month for 10 body regions: neck, shoulders, upper back, lower back, upper arms, lower arms, wrists and hands, hips and thighs, knees and lower legs, and feet/ankles. Musculoskeletal complaints were defined as "aches, pain, or discomfort caused or made worse by your work." In addition to the affected body part, participants were asked to rate the severity and frequency of these symptoms. The severity of complaints was rated and scored according to four categories (mild (score = 1), moderate (score = 2), severe (score = 3), and very severe (score = 4)), as was the frequency of complaints (1-2 times per week (score = 1), 3-4 times per week (score = 2), once daily (score = 3), and several times per day (score = 4)). Scores for the severity and frequency of complaints were multiplied and classified into five categories based on the MSFQ: Level 0 (MSFQ Score = 0), no discomfort; Level 1 (MSFQ Score 1-2), mild discomfort; Level 2 (MSFQ Score 3-4), moderate discomfort; Level 3 (Score 5-8), severe discomfort; and Level 4 (MSFQ Score 9-16), extremely severe discomfort (Chaiklieng, 2019; Poochada and Chaiklieng et al., 2022).

Ergonomic risk was evaluated using the REBA tool. The REBA tool is used to evaluate working postures, particularly in standing positions. REBA scores were classified into five risk levels [9]: Level 1 (Score = 1), negligible risk; Level 2 (Score 2-3), low risk, may require changes; Level 3 (Score 4-7), medium risk, needs improvement; Level 4 (Score 8-10), high risk, corrective action needed; Level 5 (Score $\geq$ 11), very high risk, immediate correction required. Risk assessment was conducted for each body region: neck, trunk, legs, upper arm, lower arm, wrist, grip, and applied force. The maximum REBA score (max score) was compared with the composite max REBA score, derived from summing risk scores across all body positions.

Mental workload was measured using the Subjective Workload Index (SWI), which assesses fatigue, stress, workload complexity, and job satisfaction (Chaiklieng et al., 2022). SWI scores were calculated using the following formula:

$$SWI = \frac{[(\sum Negative\ factors) - (\sum Positive\ Factors)]}{8}$$

Scores were interpreted as follows: SWI ≥ 3 indicates a high stress level, and SWI < 3 indicates a low stress level. This tool consists of eight items assessing mental workload, including: 1) fatigue, 2) risk of hazards or accidents, 3) work-related stress, 4) task difficulty and complexity, 5) work pace, 6) responsibility, 7) job satisfaction, and 8) autonomy at work. Items 1-6 represent negative factors, while items 7-8 represent positive factors. Responses are rated on a visual analog scale from 1 to 10.

Visual fatigue was measured using the critical flicker fusion frequency, with measurements taken both before starting work and after 2 hours of work on the same day. Eye fatigue analysis was assessed by comparing critical fusion frequency (CFF) before and after work. A difference of more than 1 SD of an individual's pre-work CFF indicated significant fatigue. CFF scores were interpreted as follows [9,10]: $30 \leq$ CFF < 40 indicates normal, $40 \leq$ CFF < 45 indicates mild visual fatigue, $45 \leq$ CFF < 50 indicates moderate visual fatigue, and CFF ≥ 50 indicates severe visual fatigue.

The body posture angles were assessed using a digital inclinometer in accordance with Thai ergonomic standards (Thailand Institute of Occupational Safety and Health, 2021). Body movement angles during work tasks were evaluated using inclinometer data and categorized as either acceptable risk or high risk. This classification followed the ergonomic risk assessment standards for static working postures issued by the Thai Institute for the Promotion of Occupational Safety, Health and Environment (IPOSH).

3. DATA ANALYSIS

Descriptive statistics were used to summarize participant characteristics. Wilcoxon signed-rank tests were applied to compare pre- and post-intervention scores for musculoskeletal discomfort, REBA scores, visual fatigue, and posture angles. Paired t-tests were used to analyze mental workload. Statistical significance was set at $p < .05$. All statistical analyses were performed using STATA version 10. Data were entered into an Excel program (Chaiklieng, 2019) to compute descriptive statistics (mean, standard deviation, percentage), which were used to analyze general and musculoskeletal health-related participant characteristics. Musculoskeletal disorders, levels of discomfort, and ergonomics risk were then automatically analyzed by that platform.

4. RESULTS

Most participants were female (84.21%), consistent with the general distribution of professional nurses in Thailand, and were aged 26-30 years or 41-50 years. Approximately one-third had 5-10 years of OR experience, and the majority reported limited engagement in regular physical exercise (63.16%), while 31.58% exercised 1-3 days per week. Regarding body mass index (BMI), 41.03% were within the normal range, and 23.08% were classified as obese.

Before the intervention, 50% of participants reported severe discomfort, 28.95% reported moderate discomfort, and 15.79% reported extreme discomfort. After the intervention, the severity of discomfort was lower (MSFQ score of 5.16 (after) compared to 6.58 (before)), with severe discomfort falling to 7.9%, while moderate discomfort was reported at 26.32%. Conversely, mild discomfort increased to 39.5%, as the MSFQ score reduction (21.58%) is shown in Fig. 3a.

Following the NU'care program, musculoskeletal pain in the shoulders (reduction from 34.21% to 7.89%), upper back (26.06% to 18.42%), and lower back (34.21% to 5.26%) significantly decreased ($p < .05$), as shown in Fig. 3b.

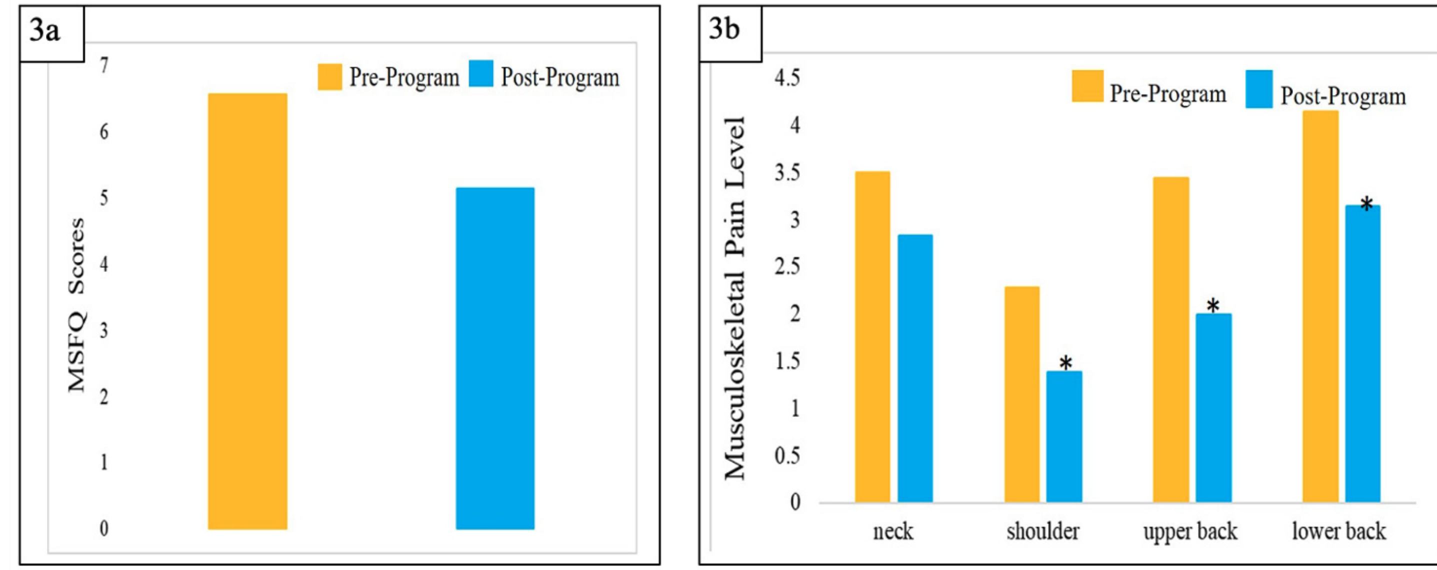

FIG. 3

Comparison of total musculoskeletal discomfort score (3a) and musculoskeletal pain level (3b) before and after the NU'care Occupational Health Ergonomics Program (*p < .05)

Although visual fatigue scores declined after the intervention, the change was not statistically significant ($p = .14$). REBA results showed significant reductions in applied force, lower arm posture, and coupling scores ($p < .05$). The reduction in the REBA score was attributed to holding or push-pull-carrying the patient with two nurses after the intervention, compared to only one nurse before the intervention.

Prior to implementing the NU'care occupational health ergonomics program, the largest proportion of OR nurses was categorized as being at high ergonomic risk (44.74%), followed by medium risk (39.47%), and low risk (10.53%). After completing the program, the largest proportion fell into the medium-risk category (42.11%), followed by low-risk (23.68%), and the high-risk category accounted for 21.05%.

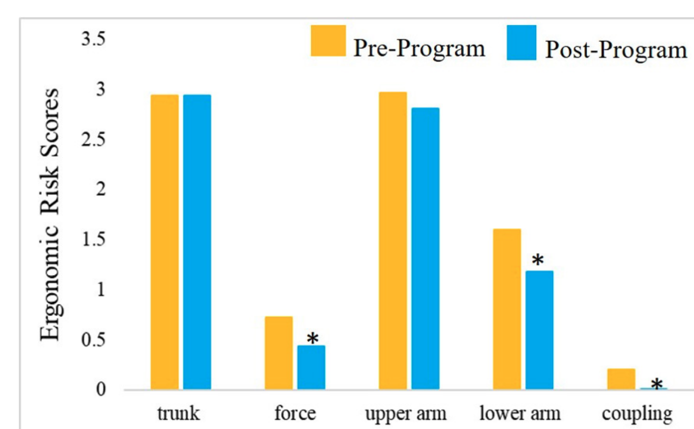

FIG. 4

Comparison of Ergonomic Risk Scores Based on Standing Work Postures (REBA) Before and After the NU'care Occupational Health Ergonomics Program (*p <.05)

Prior to the intervention, the REBA assessment indicated that the average trunk posture score was 2.95 (max score = 5), and the average lower arm posture score was 1.60 (max score = 2). After the program, the trunk posture score remained unchanged at 2.95, while the lower arm posture score decreased to 1.18. Statistical analysis revealed that the mean scores for force, lower arm posture, and coupling significantly decreased after the program, with differences significant at the 0.05 level, as shown in Fig. 4. The percentage of OR nurses in the high-risk group of REBA was reduced by 47.05%.

In addition, mental workload levels decreased significantly after the intervention (p < .001). Before the intervention, 92.11% of OR nurses experienced high mental workload fatigue related to stress, and 7.89% experienced low fatigue. After completing the NU'care program, the proportion of those with high stress-related mental workload fatigue decreased to 60.53%, while the proportion with low fatigue increased to 39.47%. The comparison of pre- and post-intervention mental workload fatigue scores showed a statistically significant reduction in average fatigue scores (p < 0.001), as shown in Fig. 5.

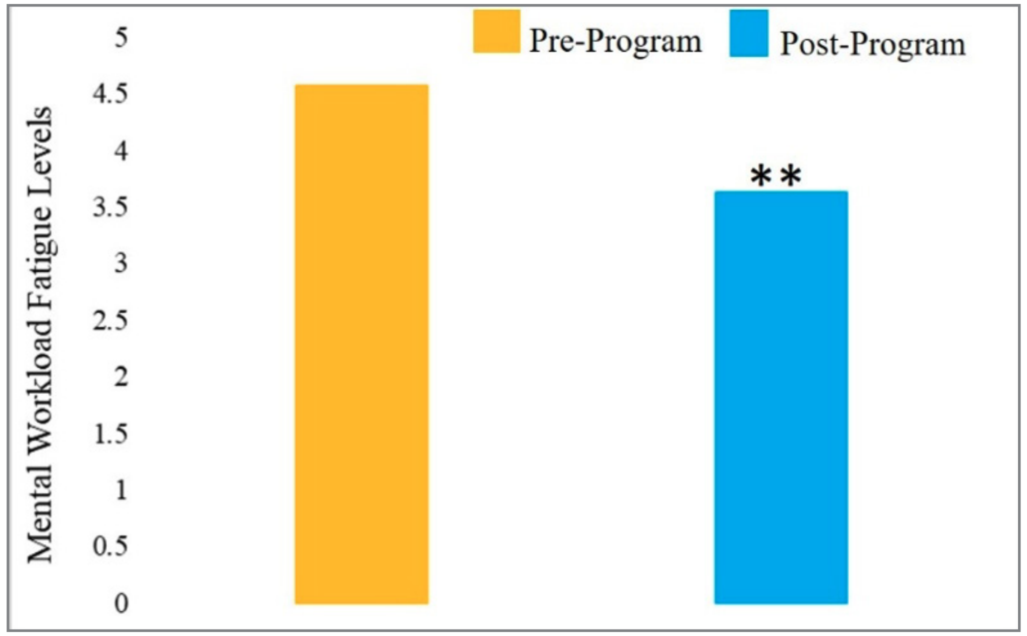

FIG. 5

Comparison of Mental Workload Fatigue Levels (SWI) Before and After the NU'care Occupational Health Ergonomics Program (**p <.001)

Additionally, body posture analysis revealed significant reductions in shoulder flexion, arm crossing beyond the body midline, wrist deviation, wrist flexion, and wrist extension angles during work tasks (p < .001). Before the intervention, the most frequently observed abnormal body posture angles were arm crossing the midline of the body (89.47%), followed by shoulder flexion (84.21%), and wrist deviation (71.05%). After participating in the program, the proportion of postural angles exceeding standard values decreased as follows: arm crossing the midline reduced to 65.79%, shoulder flexion to 23.68%, and wrist deviation to 21.05%. The program revealed significant reductions in the average angles of shoulder flexion, arm crossing the midline of the body, wrist flexion, wrist deviation, and wrist extension at the 0.05 significance level, as shown in Fig. 6.

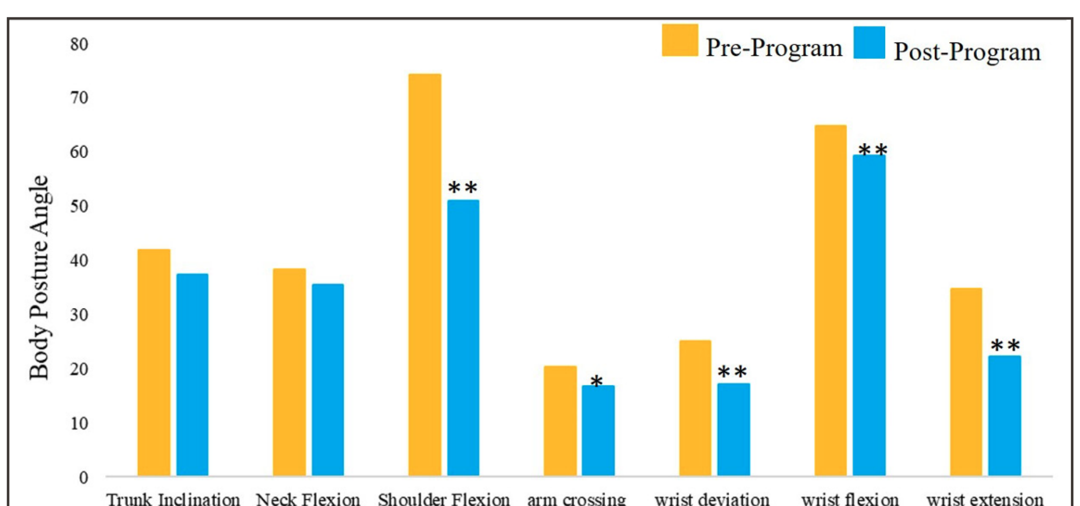

FIG. 6

Comparison of Body Posture Angle Before and After the NU'care Occupational Health Ergonomics Program (*p < .05, **p < .001)

5. DISCUSSION

The findings indicate that the NU'care participatory ergonomics program effectively reduced musculoskeletal discomfort, ergonomic risk, and mental workload among operating room nurses. The reduction in shoulder and back pain is consistent with previous studies demonstrating the effectiveness of ergonomic education, scheduled breaks, and stretching exercises in preventing MSDs (Sangthong et al., 2020).

It is evident that the program's implementation produced significant decreases in REBA scores in some areas. Risk reduction was achieved for force, coupling, and the upper and lower arms. The only part that did not produce ergonomic risk reduction was the trunk. The trunk ergonomics risk scores could not be reduced in the short period of ergonomics training and awareness of risk postures without the support of engineering controls and design for appropriate standing-station work for the OR nurse. To further reduce the risk of ergonomic issues, a higher level of ergonomic risk treatment is required.

Furthermore, the observed reduction in mental workload aligns with evidence that physical activity and relaxation exercises can mitigate work-related stress by promoting physiological and psychological recovery (Makphin, 2014). Relaxation exercises work by deregulating the sympathetic nervous system and activating the parasympathetic nervous system, thereby promoting physiological relaxation. Additionally, after participating in the NU'care program, participants reported a significant reduction in shoulder, upper back, and lower back pain. This supports the notion that stretching exercises can effectively alleviate musculoskeletal discomfort, potentially leading to improved mental well-being.

Improvements in body posture angles further support the effectiveness of participatory ergonomics, as workers actively applied ergonomic principles learned during the program. These improvements are likely due to the knowledge-sharing activities in the NU'care program, which provided demonstrations of proper working postures and instructed participants on how to achieve ergonomic joint angles in accordance with established best practices. These results reinforce the value of worker involvement in the design and implementation of ergonomic interventions.

A reduction in eye fatigue after participating in the NU'care occupational health ergonomics program may be attributed to scheduled rest breaks throughout the workday and to designated eye-relaxation exercises included in the intervention. The results are consistent with the study by Prasopkittikun and Suranathawatchawong (2024), which found that visual relaxation exercises during work significantly reduced eye fatigue.

This outcome may be attributed to the program's educational components, which emphasized proper ergonomic postures and movements. The significant decrease in REBA scores suggests improved postural behavior and reduced physical strain, likely resulting from increased ergonomic awareness and application of correct working postures. It is plausible that participants applied the ergonomic principles learned in training to their daily work routines. These findings are consistent with a previous study (Laowanich et al., 2022), which demonstrated that integrating workplace improvement programs with ergonomics education significantly reduced ergonomic risks.

The authors determined that to further reduce the ergonomic risk scores for the trunk, a higher level of ergonomic risk treatment will have to be implemented, as shown in Fig. 7 (Lyon et al., 2022). Engineering controls could be implemented to reduce trunk MSD risk by changes to workplace design, tools, equipment, fixtures, adjustability, and layout.

METHOD	PHASE/APPLICATION	EXAMPLES	EFFECTIVENESS
Avoidance	Conceptual Stage – Design/Redesign	Prevent entry of hazard into workplace by design through selection of technology and work methods	High
Elimination	Existing Process – Redesign	Eliminate hazard by changes in design, equipment and methods	High
Substitution	Existing Process – Redesign	Substitute materials, sizes, weights and other aspects to a lower hazard severity or likelihood	Moderately High
Engineering Controls	Existing Process – Redesign	Reduce hazard by changes to workplace, tools, equipment, fixtures, adjustability, layout, lighting, work environment	Moderate
Administrative Controls	Existing Process – Practice and Procedures	Reduce exposure to hazard by changes in work practices, training, job enlargement, job rotation, rest breaks, work pace	Moderately Low
Personal Protective Equipment	Existing Process – Workers	Reduce impact of hazard to employee by use of protective equipment and materials such as vibration attenuation gloves	Low

Note. Adapted from "Improving Ergo IQ: A Practical Risk Assessment Model," by B.K. Lyon, G. Popov and K. Hanes, 2013, Professional Safety, 58(12), 26-34.

FIG. 7
Hierarchy of Ergonomic Risk Treatment

The overall cost of the NU'care program was 15,000 Thai Bahts (approximately $460 USD). However, the program achieved great productivity improvements. It also resulted in a significant reduction in absenteeism rates. In addition, the organization's reputation improved significantly due to management's commitment and employee involvement.

It could be concluded that risk reduction could lead to improved non-financial benefits, such as employee morale, employee performance, lower turnover rate, and confidence in the ergonomics program.

In addition, the NU'care ergonomic program and implementation of higher levels of controls would reduce absenteeism among operational nurses. Absenteeism is a critical issue driven by high burnout, job dissatisfaction, and physical/mental health issues. It leads to significantly increased workload, low morale, and reduced quality of patient care. NU'care occupational health ergonomics program shows ergonomics risk reduction and improves the work environment.

6. LIMITATIONS AND RECOMMENDATIONS

This study relied in part on online monitoring via the LINE OA system, which may have limited direct observation of participants' compliance. Additionally, high workloads and operational constraints may have influenced full participation in the program. Future studies should consider longer intervention periods and alternative monitoring strategies to enhance engagement and sustainability.

The authors plan to conduct additional risk assessments and a full financial and non-financial benefits analysis for longer study periods (12-week intervention).

7. CONCLUSION

The NU'care occupational ergonomics program, grounded in participatory ergonomics principles, significantly reduced musculoskeletal pain, ergonomic risk, awkward working postures, and mental workload among operating room nurses. By actively involving nurses in program design and implementation, the intervention demonstrated strong potential for adaptation across other occupational settings with similar ergonomic challenges. The program could help organizations achieve great productivity improvements. Implementation of such programs leads to improved organizational reputation. To further reduce ergonomic risks, higher levels of control should be implemented. However, a comprehensive financial analysis should be conducted and presented to management to justify the investment. Ergonomics risk reduction contributed to improved non-financial benefits, such as employee morale, employee performance, and confidence in the overall health and safety management system.

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