Jurnal Kejuruteraan 38(3) 2026: 1003-1015
https://doi.org/10.17576/jkukm-2026-38(3)-01

Integrating Quick Exposure Checklist (QEC) for Ergonomic Risk Management in the Food Manufacturing Sector

Melor Amran, Dayana Hazwani Mohd Suadi Nata*, Ismarulyusda Ishak & Putri Anis Syahira Mohamad Jamil

Center of Toxicology and Health Risk Studies (CORE), Faculty of Health Sciences,
Universiti Kebangsaan Malaysia, Jalan Raja Muda Abdul Aziz, 50300 Kuala Lumpur, Federal Territory of Kuala Lumpur

**Corresponding author: dayanahazwani@ukm.edu.my*

Received 15 September 2025, Received in revised form 8 February 2026
Accepted 8 March 2026, Available online 30 May 2026

ABSTRACT

Small and medium-sized enterprises (SMEs) are pivotal in Malaysia's food manufacturing sector. However, they often lack robust ergonomic practices, leading to a high risk of work-related musculoskeletal disorders (WRMSDs). This study aimed to evaluate ergonomic risk exposures using the Quick Exposure Checklist (QEC) in selected SME food processing environments. A cross-sectional study involving 151 participants was conducted through walkthrough observations, video recordings and QEC assessments. The results revealed substantial ergonomic risk exposures particularly in the shoulders/arms (64.2% very high exposure), static back posture (46.4%), and neck (38.4%). These results highlight the urgent need for engineering-based interventions, such as adjustable workstations, ergonomic tool adoption, and job task redesign. The integration of ergonomic risk assessment into SME practices is recommended as a practical and cost-effective strategy to enhance occupational health, boost productivity and support sustainable industrial performance.

Keywords: Quick Exposure Checklist (QEC), small and medium enterprises (SMEs), workstation design, ergonomic risk; food manufacturing; workstation redesign

INTRODUCTION

Work-related musculoskeletal disorders (WRMSDs) represent one of the most prevalent occupational health problems globally, especially in labor-intensive sectors such as food manufacturing. In Malaysia, small and medium-sized enterprises (SMEs) dominate this sector, contributing significantly to national economic growth and employment opportunities. However, these SMEs often face systemic challenges in implementing effective occupational safety and health (OSH) practices due to limited financial resources, technical know-how, and weak regulatory enforcement (Marzuki et al. 2023; Ismaila et al. 2020). These limitations result in workers being frequently exposed to adverse ergonomic conditions—such as repetitive movements, awkward postures, and prolonged static work—which significantly heighten the risk of WRMSDs (Bernard 1997; da Costa & Vieira 2010; Peter 2023).

Despite the widespread nature of these risks, many SMEs lack structured ergonomic assessments or engineering-based interventions to proactively identify and mitigate such hazards. Existing literature and field evidence suggest that the absence of ergonomic integration in work system design exacerbates the physical burden on workers and may lead to productivity losses, increased absenteeism, and higher injury rates (Domínguez-Alfaro et al. 2023; Hasanain 2024). This gap underscores the need for accessible and cost-effective ergonomic assessment tools tailored to the resource constraints of SMEs. The Quick Exposure Checklist (QEC) is a semi-quantitative assessment tool that provides a practical and systematic approach for evaluating biomechanical stressors associated with routine occupational tasks. Due to its simplicity, cost-effectiveness, and ease of implementation, the QEC is particularly well-suited for application within small and medium-sized enterprises (SMEs), where resources for comprehensive ergonomic assessments may be limited. Its use facilitates evidence-based decision-making concerning

workstation redesign and task modifications without imposing significant financial constraints (Cook et al. 2001; Cunha et al. 2021; Hawari et al. 2023).

This study adopts an engineering-based ergonomic risk assessment approach using the QEC across selected food manufacturing SMEs in Malaysia. The primary objectives are: (i) to identify the main ergonomic hazards encountered by workers, (ii) to evaluate and classify the level of risk across different body regions, and (iii) to recommend feasible engineering and administrative interventions aimed at optimizing workstation design and improving worker safety. The results are expected to offer practical insights into how ergonomic risks can be effectively managed in resource-limited SME environments supporting both occupational health and sustainable productivity.

METHODS

This study employed a cross-sectional research design to assess ergonomic risk factors among employees in selected small and medium-sized enterprise (SME) food manufacturing facilities located in Johor Darul Takzim, Malaysia. A total of 151 employees were recruited from various production roles, providing a heterogeneous sample reflective of the diverse job functions and ergonomic exposures common in labour-intensive food processing environments. The selection of Johor state as the study site was based on its strategic position as one of Malaysia's most active industrial zones for food manufacturing where SMEs play a pivotal role in both domestic and export-oriented production. Its accessibility and concentration of SMEs allowed for efficient coordination of data collection across multiple facilities while capturing representative ergonomic challenges faced within the sector.

To minimize selection bias and ensure the generalizability of findings, the participating SMEs were chosen based on similar operational characteristics including workforce size, type of food products handled, production processes and layout configurations. This approach allowed for valid cross-comparison of ergonomic risk factors while controlling for potential confounders that could arise from variability in company size or production type. Moreover, the sample included companies of varying ownership structures and management systems to reflect the broader spectrum of SME operations in the region. Ethical approval for the study was obtained from National University of Malaysia Research Ethics Secretariat (JEP-2024-864) and informed consent was secured from all participants prior to data collection. Participation was voluntary and anonymity and confidentiality were strictly maintained to ensure ethical integrity.

WALKTHROUGH SURVEY

The first phase of the study involved structured walkthrough surveys at each facility. This survey allowed for systematic, on-site observation of workplace conditions focusing on physical layout, workflow patterns, employee-task interactions and existing ergonomic arrangements such as workstation height, posture requirements, and equipment use. Structured field notes and photographic documentation were used to capture relevant data which guided the identification of high-risk activities and informed the subsequent in-depth assessments. This phase was essential in ensuring that the ergonomic evaluations were grounded in the real work context of each facility, thereby enhancing the validity of the findings.

VIDEO-BASED TASK ANALYSIS

Following the walkthrough, video-based observations were conducted to capture detailed information on employee movements, body mechanics, and task execution in real-time. This method provided an objective and dynamic representation of postural and biomechanical loading during routine work activities, which may not be adequately detected through direct observation alone (Moen 2014; Pehkonen et al. 2009). Video recordings were taken with participant consent and were later reviewed by trained assessors to ensure accurate ergonomic risk evaluation.

ERGONOMIC RISK ASSESSMENT USING QEC

The Quick Exposure Checklist (QEC) was employed as the main instrument for the quantitative evaluation of physical ergonomic risks (Davied et al.2008). The QEC is a semi-quantitative observational technique intended to assess exposure to various biomechanical stressors, such as repetitive movements, uncomfortable postures, static loads, and force exertion in critical body areas (Cook et al. 2001). The evaluated regions comprised the back (focussing on static postures), shoulders/arms, wrists/hands, and neck, as these areas are frequently linked to work-related musculoskeletal diseases (WRMSDs) in industrial environments (Colim et al. 2020).

All assessors participated in a rigorous training session before data collection started to make the QEC evaluations more objective. This included a two (2) hours theoretical briefing that explained the QEC, made the scoring criteria and indicator definitions clearer and pointed out common scoring mistakes. After that, the assessors took part in practical calibration sessions where they watched sample films of food manufacturing jobs and gave QEC scores on their own. After these sessions, there were agreement

discussions lead by an ergonomics specialist to make sure that all the assessors understood posture angles, repetition thresholds, force levels and worker–assessor inputs in the same way. Only individuals who consistently and accurately scored during these calibration activities moved on to onsite assessments. This made sure that all study locations had a high level of standardisation.

To ensure uniformity and strengthen the reliability of the scoring method, two trained observers separately assessed the identical video recordings and field notes for each activity. To check inter-rater reliability, the scores for each body part was compared. Using standardized QEC scoring criteria, each task was categorized into one of four risk levels: low, moderate, high, or very high. This classification system enabled the identification of both individual-level and task-specific ergonomic hazards. If any discrepancies existed, the discussion conducted to achieve agreement adhered to the QEC regulations for solution. This systematic approach to reconciliation increased trust in the reproducibility and validity of the exposure classifications produced in the study.

In addition, all QEC observations were carried out during typical work cycles representing normal production hours rather than periods of peak demand or unusually high workload. Conducting the assessments under routine operating conditions allowed the study to capture ergonomic exposures that most accurately reflect workers' everyday tasks, ensuring that the findings are both representative and applicable to standard industry practices.

To enhance the objectivity and reproducibility of scoring, the study incorporated the Occupational Health Clinics for Ontario Workers (OHCOW) QEC Calculator (OHCOW 2024), a digital spreadsheet tool that computes exposure scores and assigns risk levels automatically based on observer input and worker feedback. This calculator automatically converted raw input into risk level classifications (low, moderate, high, and very high) for each body region and overall task exposure. The use of this calculator helped standardize scoring, minimize subjectivity, and ensure consistent application across multiple sites and observers.In addition, workers were briefly interviewed post-observation to obtain self-reported information on perceived force, task repetition, and rest breaks. These responses were incorporated into the calculator to reflect the QEC's design as a joint-assessor-and-worker tool, improving the robustness of exposure classification (OHCOW, 2024).

DATA ANALYSIS

Quantitative data generated from the OHCOW-adapted Quick Exposure Checklist (QEC) were analyzed using IBM Statistical Package for the Social Sciences (SPSS) Version 30.0. The QEC scores, derived from both observer evaluations and worker-reported inputs were first compiled using the official QEC Excel calculator which automatically computes exposure scores for each body region and classifies them into four standardized risk levels: Low, Moderate, High, and Very High.Once exposure scores were computed and verified, data were exported into SPSS for statistical analysis. Descriptive statistics were reported as means and standard deviations (mean ± SD) for all QEC scores. Risk exposure levels were reported by anatomical regions (e.g., shoulders/arms, back, neck, wrists/hands), enabling the identification of ergonomic hotspots within the observed SME food manufacturing tasks. The analysis also allowed for the profiling of ergonomic burden across the sample and supported the prioritization of intervention needs based on severity and frequency of exposure. Cross tabulations were conducted to explore potential associations between job roles and QEC risk levels, though no inferential statistics were applied as the primary aim was exposure profiling rather than hypothesis testing.

RESULTS & DISCUSSION

A total of 151 employees from SME food manufacturing facilities in Johor participated in this study. Table 1 outlines the demographic distribution of the participants, including gender, age group, job position, work experience and body mass index (BMI) classification.

Understanding the demographic profile of this workforce is essential, as these attributes markedly affect ergonomic exposure, workplace stress levels, and vulnerability to musculoskeletal disorders (MSDs). The population studied was primarily male (56.3%), suggestive of a growing pattern in industrial environments where physically strenuous positions are frequently occupied by men. The gender distribution is significant, as men had higher risk exposures for shoulders/arms and back, especially in raw material handling and packing tasks that aligned with their physical work assignments (Kim & Jeong 2024).

The age distribution indicated that most participants were young to middle-aged, with 41.1% aged 30–39 years and 31.8% aged 18–29 years. This group is generally linked to greater physical labour capability, however may exhibit poor knowledge of cumulative ergonomic risks and safe postural practices. Workers aged 40 and above (27.2%) may possess greater employment experience and established coping mechanisms; still they are typically more susceptible to biomechanical damage, increasing the risk of chronic musculoskeletal disorders (Ariyanto et al. 2022; Darvishi et al. 2024).

Anthropometric data indicated that 53.6% of participants were within the normal BMI range, 34.4% were categorised as overweight, and 11.9% were categorised as obese. High body mass index (BMI) is a recognised risk factor for musculoskeletal disorders due to increased mechanical stress on joints and decreased physical flexibility. Research has established a correlation between high body mass index (BMI) and increased rates of work-related injuries and absenteeism (Darvishi et al. 2024; Ibrahim & Gaafar 2024; Hultén et al. 023). Poor physical health might worsen ergonomic stress when coupled with occupational demands and psychosocial elements, including perceived job pressure, diminished control, and insufficient rest periods (Li et al. 2021; Nestorova & Mircheva 2018).

The demographic and ergonomic risk factors present in food manufacturing roles significantly influence the health and well-being of employees. In this context, the roles of packaging (35.8%) and raw material handling (30.5%) represent the highest proportions among participants, underscoring their fundamental importance in small and medium-sized enterprise (SME) food production. These functions are intrinsically linked to distinct ergonomic demands characterized by a high frequency of physical activities such as lifting, twisting, and repetitive upper limb movements. Such biomechanical tasks directly correlate with the highest risk scores reported for shoulder, arm, and static back postures within ergonomic assessments, highlighting a pressing need for targeted ergonomic interventions (Ismaila et al. 2020; Teixeira et al. 2022).

The constraint of postural variation and task rotation due to the repetitive nature of jobs in packaging and handling intensifies biomechanical stressors, potentially leading to work-related musculoskeletal disorders (WRMSDs) (Colim et al.,2020). Specifically, these job categories inherently impose limitations on employees' ability to modify their working postures, exacerbating the risk of cumulative trauma in the shoulders and back over time. The implications of static postures are well-documented, showing that prolonged fixed positions can result in fatigue and discomfort, thereby heightening the likelihood of developing chronic conditions (Patil & Patil 2023; Harun et al. 2025).

In this study, packing roles represented the highest percentage of workers at 35.8%, followed by raw material handling at 30.5%, quality inspection and labelling at 19.2%, and machine operation at 14.6%. These functional categories delineate the principal operational tasks in SME-based food production, each characterised by unique ergonomic exposure profiles. In terms of job experience, around 47.0% of participants had been working for 1 to 5 years, 36.4% possessed over 5 years of experience, and 16.6% were newcomers to the industry with less than 1 year of service. This distribution reflects a balanced workforce for exposure duration and task familiarity. Quality inspection and labelling roles while less physically intensive are associated with prolonged visual concentration, sustained neck flexion, and constrained posture due to close-up work surfaces. This explaining the high-risk scores recorded for the neck region. These role-specific exposures align with findings from previous research which shows that repetitive and static tasks are common contributors to WRMSDs in food processing jobs (Peter 2023; Domínguez-Alfaro et al. 2023). Therefore, ergonomic solutions must be tailored not only by job function but also by the specific anatomical demands imposed by those functions.

Work experience ranged from less than 1 year (16.6%) to over 5 years (36.4%). Notably, workers with less than 1 year of experience reported the highest rates of very high exposure risk, particularly in the shoulders/arms and back. This trend highlights a critical adaptation gap among new employees who may lack the task familiarity, ergonomic training, or conditioning to manage physical loads effectively. It underscores the importance of ergonomic onboarding programs that provide early education on safe lifting, posture awareness, and micro-break strategies (Ismaila et al. 2020). Conversely, workers with more than five years of experience, while possibly more adapted to repetitive tasks, may still be vulnerable due to cumulative wear and tear. Long-term exposure to suboptimal ergonomic conditions can lead to chronic musculoskeletal degeneration (Teixeira et al. 2022). As such, both short- and long-tenured employees require tailored ergonomic support, including refresher training and periodic workstation re-evaluations (Robertson et al. 2008).

TABLE 1. Demographic characteristics of study participants (N = 151)

Variables	Cateogry	n (%)	Mean ± SD)
Gender	Male	85 (56.3)	
	Female	66 (43.7)	
Age Group (years)			34.74 ± 13.13
	18–29	48 (31.8)	
	30–39	62 (41.1)	
	≥ 40	41 (27.2)	
Job Position	Packaging	54 (35.8)	
	Handling Raw Materials	46 (30.5)	
	Quality Inspection/ Labelling	29 (19.2)	
	Machine Operation	22 (14.6)	

BMI Category (kg/m^2)			25.19 ± 5.64
	Normal (18.5–24.9)	81 (53.6)	
	Overweight (25.0–29.9)	52 (34.4)	
	Obese (≥30.0)	18 (11.9)	
Work Experience	< 1 year	25 (16.6)	
	1–5 years	71(47)	
	> 5 years	55 (36.4)	

ERGONOMIC RISK DISTRIBUTION BY BODY REGION

Ergonomic risk exposure among workers was assessed using the OHCOW-adapted Quick Exposure Checklist (QEC) calculator, which integrates observer-based and worker-reported data to generate cumulative scores for major body regions. Risk levels were computed using the official QEC Excel calculator provided by the Occupational Health Clinics for Ontario Workers (OHCOW) ensuring standardised and reproducible scoring. The assessment included exposure to awkward postures, repetitive movements, force exertion, and vibration, and the risk was categorised into four levels: Low (Level 1), Moderate (Level 2), High (Level 3), and Very High (Level 4). The data highlight a significant burden of biomechanical stress, particularly affecting the upper limbs and spine, and reveal the widespread presence of very high-risk exposures among workers. Table 2 summarizes QEC Risk Levels by Body Region Based on OHCOW Calculator (N = 151).

The shoulders and arms emerged as the most affected anatomical regions, with 64.2% of workers falling into the very high-risk category (Level 4). The mean cumulative QEC score for this region was 33.23 ± 7.4, indicating the prevalence of tasks involving prolonged reaching, heavy lifting, and repetitive upper limb movements. These high-exertion activities were particularly common in packaging and raw material handling roles. This finding is consistent with Sardar and Lee (2024), who reported hazardous upper limb postures during repetitive industrial tasks in smart manufacturing settings, where frequent reaching and lifting significantly increased ergonomic risk. The high score in the present study underscores the considerable physical demand placed on the upper limbs in these job functions, often exacerbated by the absence of mechanical aids and suboptimal workstation design.

In the static back posture category, 46.4% of participants were classified as very high risk (27.77±7.4). This reflected prolonged standing and forward bending, often without sufficient breaks or support tools. This reflects chronic exposure to prolonged standing and forward bending without adequate ergonomic interventions. Similar postural stress patterns have been documented in pharmaceutical manufacturing, where repetitive tasks led to elevated REBA scores and high WRMSD risk for the lower back and spine (Jose et al.2018).

Risk exposure for the neck also warranted concern with 38.4% of workers experiencing very high risk (12.58± 4.1). Tasks that required constant visual attention to small details, such as labeling or inspection, contributed significantly to neck strain. his aligns with previous reports in small-scale and manual-intensive industries, where fine inspection tasks require sustained visual focus, leading to chronic neck strain (Agre et al. 2022; Mohd Suadi nata et al. 2025).

Interestingly, wrists/hands showed the highest average QEC score (33.99 ± 8.6), but only 17.2% were classified as very high risk. This suggests that although hand activity was intense, periodic variation or task cycling may have reduced continuous strain, echoing findings by Chiasson et al. (2015), who found that subjective pain perception and rest intervals could modulate perceived risk levels in repetitive hand tasks.

This suggests intense repetitive hand use, though some variability or rest periods were present. Vibration and driving-related scores were excluded from analysis due to their low prevalence across the sample (<5%), consistent with the absence of vibration-intensive machinery or vehicle operation in the observed work environments.

TABLE 2. Exposure to ergonomic risk factors among individuals (N = 151)

Body Region	Mean ± SD	Low (%)	Moderate (%)	High (%)	Very High (%)
Shoulders/ Arms	33.23 ± 7.4	4.6	13.9	17.2	64.2
Back (Static)	27.77 ± 7.4	4.6	25.2	23.8	46.4
Wrists/ Hands	33.99 ± 8.6	9.3	23.8	49.7	17.2
Neck	12.58 ± 4.1	9.3	20.5	31.8	38.4

Note: Scoring and risk categories are based on the OHCOW QEC calculator's exposure algorithms, which integrate both observational and self-reported data.

Among all participants, 42.4% were classified under the "Very High" overall exposure risk based on total QEC scores, 27.2% were in the "High" category, 22.5% fell into the "Moderate" category, and only 7.9% were classified as having "Low" overall ergonomic risk. These findings indicate that nearly 70% of the workforce operates under

high or very high ergonomic risk conditions, pointing to widespread exposure to biomechanical stressors across SME food manufacturing environments.

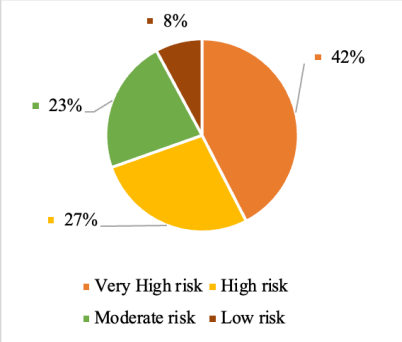

FIGURE 1. Overall QEC risk level distribution (N=151)

ERGONOMIC RISK PROFILE ACROSS GENDER, JOB ROLES, AND WORK EXPERIENCE

As presented in Table 3 and Figure 2, packaging workers exhibited the highest proportion of very high risk in the shoulder/arm (70.4%) and wrist/hand (59.3%) regions. These findings suggest that high-speed, repetitive tasks such as folding, sealing, cutting, and taping are principal contributors to upper limb strain. This aligns with prior studies showing that forceful repetition and static upper limb postures are central risk factors for musculoskeletal injuries in packing operations (Onofrejovaet al. 2024; Ismaila et al. 2020). Raw material handlers also demonstrated substantial ergonomic risk, with 60.9% reporting very high exposure in the shoulders/arms and 56.5% in static back positions. These high-risk ratings are likely due to frequent lifting, carrying, and torso bending associated with handling bulky or heavy materials (Teixeira et al. 2022).

In contrast, inspection and labelling workers presented a distinct risk pattern, with 58.6% experiencing very high neck strain, likely due to sustained neck flexion during close-up visual inspection. This is consistent with ergonomic literature that identifies neck flexion and static head postures as risk factors in quality control and labelling tasks (Chaiklieng & Suggaravetsiri 2020).Although machine operators had comparatively lower reported risks, their rates of very high exposure in the shoulders (40.9%) and back (40.9%) are still notable, suggesting biomechanical stress related to seated or awkward standing postures near fixed machinery.

TABLE 3. Cross-tabulated ergonomic risk classification by job role (N = 151)

Job Role	Shoulders/ Arms - Very High (%)	Back (Static) - Very High (%)	Wrists/ Hands - High (%)	Neck - Very High (%)
Packaging	70.4	51.9	59.3	31.5
Raw Materials	60.9	56.5	45.7	26.1
Inspection	48.3	34.5	34.5	58.6
Machine Operation	40.9	40.9	31.8	27.3

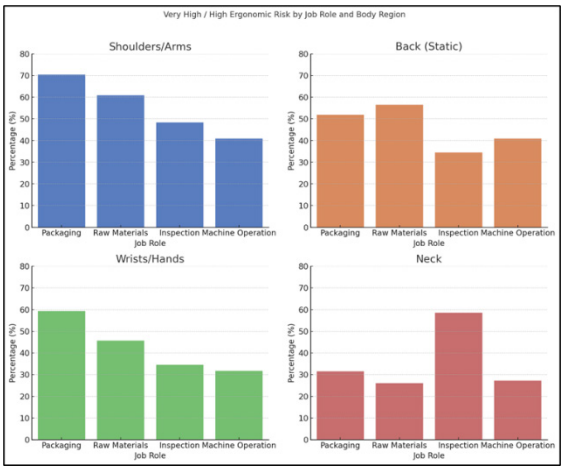

FIGURE 2. Distribution of high and very high ergonomic risks across different job roles and anatomical regions

Figure 3 illustrates the distribution of participants experiencing significant ergonomic risk differentiated by work experience (left panel) and gender (right panel). The evaluated body regions involve the shoulders and arms, back (in static postures), and neck, all of which can frequently be related to repetitive and static work requirements in food manufacturing environments.

Employees with less than one year of employment demonstrated the highest incidence of extremely high risk, especially in the shoulders/arms (72%) and back (60%). This is likely due to task unfamiliarity, insufficient ergonomic training, and underdeveloped muscle conditioning. Previous studies have confirmed that newer employees often exhibit higher prevalence of postural strain and WRMSDs due to improper technique and limited exposure (Chaiklieng & Suggaravetsiri 2020; Guerreiro et al. 2020). In contrast, employees with longer tenures (1–5 years and >5 years) reported progressively lower exposure, potentially reflecting task adaptation, ergonomic conditioning, or movement efficiency gained with experience.

Gender differences in ergonomic exposure further highlight occupational role-based segregation and its impact on musculoskeletal health. Male workers were more likely to be exposed to very high risk in the shoulder/arm (67.1%) and back (51.8%) regions, likely due to involvement in physically demanding roles such as material handling. Female workers, on the other hand, reported significantly higher neck strain (42.4%), likely because of frequent assignment to inspection and labelling tasks that involve prolonged static visual work. This pattern supports extensive ergonomic research indicating that men typically engage in force-heavy roles, whereas women are frequently assigned visually intensive or repetitive fine motor tasks, each presenting unique musculoskeletal risks (Ercan et al. 2022; Laberge et al. 2019).

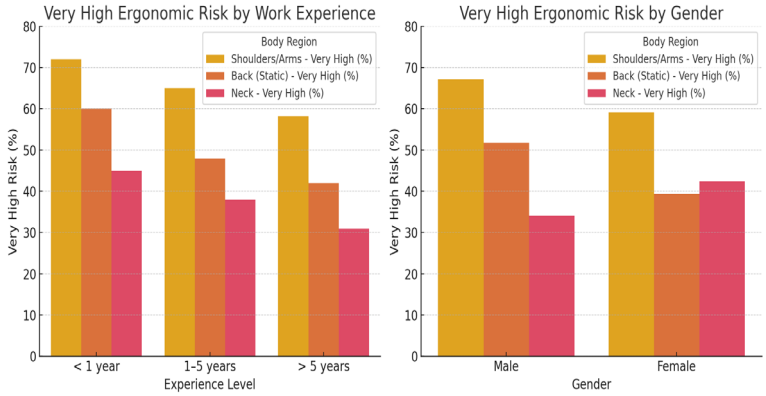

FIGURE 3. Distribution of very high ergonomic risk by work experience and gender across body regions (shoulders/arms, back, and neck)

Crucially, as illustrated in Figure 4, 65% of participants experienced very high ergonomic risk in two or more anatomical regions, suggesting the presence of cumulative biomechanical load. This overlap of stressors significantly amplifies the risk of developing WRMSDs and indicates that isolated interventions may be inadequate. These findings are echoed in manufacturing studies emphasizing the dangers of multi-region ergonomic strain (Bernard 1997; Sun et al. 2023).

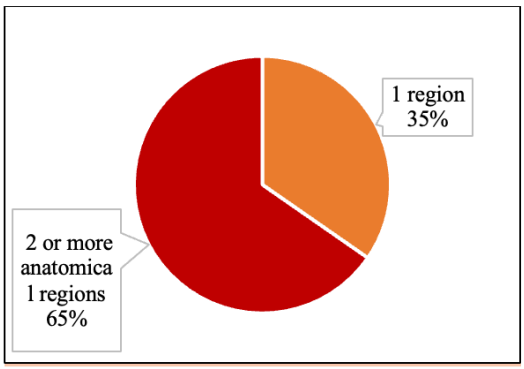

FIGURE 4. Proportion of participants with very high ergonomic risk across multiple body regions

Recent ergonomic studies in other developing countries report similar patterns of high physical workload and limited intervention capacity, reinforcing the global relevance of the present findings. For example, manufacturing workers in Vietnam and Indonesia demonstrated elevated shoulder and lower-back risks linked to repetitive manual tasks, prompting low-cost interventions such as adjustable platforms, job rotation schedules, and participatory ergonomics programmes (Nguyen 2009; Pramitasari et al. 2015). Likewise, interventions implemented in India's small-scale food processing sector such as workstation height adjustments and tool redesign resulted in measurable reductions in WRMSD symptoms (Pawar & Anandh 2020). The alignment between these international findings and our Malaysian context underscores that ergonomic challenges in SME environments are not isolated but part of a broader regional trend affecting developing economies with labour-intensive production systems.

WORKER AWARENESS, SELF-EFFICACY, AND SAFETY CULTURE: IMPLICATIONS FOR ERGONOMIC INTERVENTIONS

In addition to physical risk assessments, behavioral observations revealed key gaps in ergonomic awareness and safety practices among SME workers which may affect intervention uptake. These insights are discussed below as part of a broader interpretation of the findings.

Informal post-task interviews and observational data during the QEC assessments reveal critical behavioural gaps that likely exacerbate the already high ergonomic risk

levels observed across job roles. A prominent theme emerging from these interviews is the limited ergonomic literacy among workers and low self-efficacy in recognizing and mitigating biomechanical stressors. Many workers demonstrated hesitation in articulating discomfort origins, and few were able to suggest adjustments or preventive actions. Additionally, supervisors were largely reactive, rarely enacting ergonomic changes unless prompted, indicating weak institutional enforcement of preventive safety measures. These trends suggest a passive safety culture, which is consistent with prior findings on SMEs, where ergonomic risk is often underreported due to lack of awareness, training, or empowerment (Fasanya & Shofoluwe 2018).

Interestingly, a small subset of workers was proactive in identifying cumulative fatigue, suggesting isolated instances of ergonomic awareness. Nonetheless, this was atypical and further indicates the lack of organised training or early intervention systems. Similar deficiencies in self-awareness and symptom disclosure have been observed in other high-risk industrial environments, where insufficient ergonomic training has been associated with an increased prevalence of musculoskeletal disorders (MSDs) (Mahboobi et al. 2020).

In addition to physical exposures, psychosocial and organisational factors may further modulate the severity of ergonomic risks in SME environments. Many food manufacturing facilities operate under time-sensitive production cycles, where work pressure, tight deadlines, and minimal rest breaks can increase muscle fatigue and reduce the likelihood of posture variation. Studies from Thailand and Bangladesh have shown that shift work, monotonous tasks, and production quotas significantly elevate the risk of WRMSDs by reducing workers' ability to recover between cycles (Chuppawa et al. 2025; Hossain et al. 2018; Sombatsawat et al. 2025). Similar dynamics may be present in the current study, particularly among packaging workers who often work at high speed to meet daily output targets. These organisational stressors can amplify biomechanical load, highlighting the importance of integrating workload management, micro-break scheduling, and psychosocial support into ergonomic interventions.

These behavioral observations strongly support the need for a structured intervention model specifically, the Health Belief Model (HBM) to enhance worker engagement with ergonomic principles. The HBM framework can guide efforts to raise workers' perceived susceptibility by illustrating how ergonomic risks are directly linked to real injury cases, and to enhance perceived severity by emphasizing the long-term consequences of work-related musculoskeletal disorders (WRMSDs). It also encourages recognition of the benefits of early symptom reporting and proactive workstation adjustments, while helping to reduce barriers to action through the provision of simple, actionable strategies. Additionally, the model can trigger cues to action via visual reminders and peer-led safety briefings. Although this study did not formally assess knowledge, attitudes, and practices (KAP), the observed gaps highlight the value of incorporating a structured KAP assessment in future phases to ensure that interventions are effectively aligned with workers' existing beliefs and behaviors.

IMPLICATIONS FOR WORKSTATION DESIGN AND ERGONOMIC CONTROL STRATEGIES

This study's findings indicate a high prevalence of ergonomic risks among employees in small and medium-sized enterprise food manufacturing, especially affecting the shoulders/arms, back, neck, and wrists/hands. Over 70% of packaging workers and more than 56% of raw material handlers were classified as experiencing very high ergonomic risk across multiple anatomical regions. These observations reinforce the urgent need for targeted and cost-effective interventions to improve workstation layout and task design based on ergonomic principles.

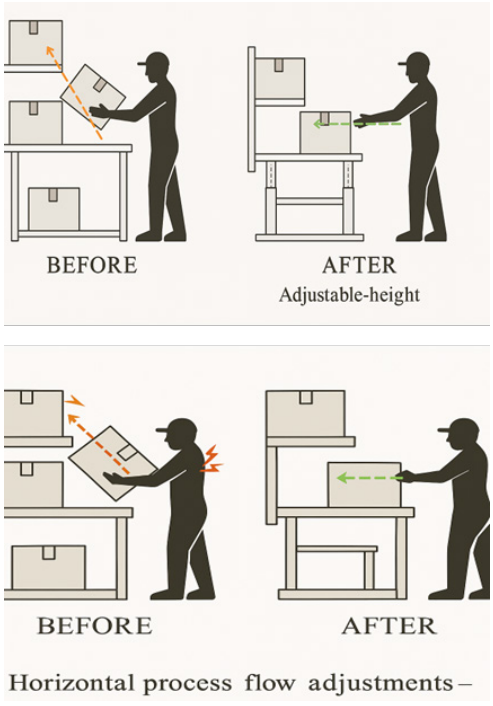

FIGURE 5. Comparison of work posture before and after implementing adjustable-height workbenches (top) and horizontal process flow adjustments (bottom)

One of the most prominent risk areas identified was the shoulder and arm region, especially among packaging

workers. This is largely attributed to repetitive arm lifting above shoulder level and awkward reaching. A practical and scalable solution for SMEs is the introduction of adjustable-height workbenches, which allow employees to perform tasks within optimal reach zones regardless of their height or arm span. This reduces muscular effort and promotes neutral shoulder postures. As shown in Figure 5, ergonomic modifications such as adjustable-height workbenches (top) and horizontal process flow adjustments (bottom) can significantly reduce biomechanical strain and improve posture without requiring major investment. Studies have shown that proper working height adjustments can lead to measurable reductions in musculoskeletal complaints and fatigue (Kalkis et al. 2021).

Neck strain particularly common among inspection and labelling personnel, is primarily caused by prolonged forward neck flexion and sustained visual focus on flat or low-lying work surfaces. Affordable solutions such as tilted work surfaces, document holders or angled trays can help align the line of sight with neutral cervical posture. These aids minimize neck flexion and enhance visual ergonomics. Figure 6 illustrates how a simple redesign of the workstation angle supports upright posture and reduces cervical stress during detailed inspection tasks. This approach is supported by recent findings from Mohd Suadi Nata et al. (2025), who suggest the improvements in neck posture and task endurance through low-cost workstation redesign.

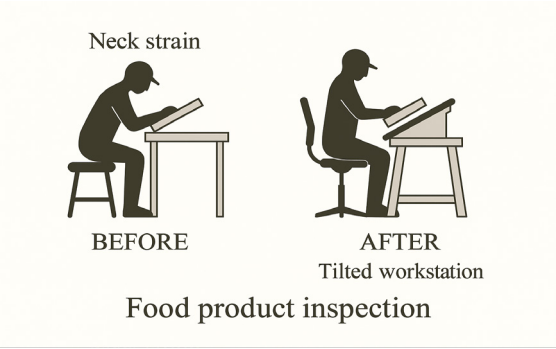

FIGURE 6. Comparison of neck posture before and after implementing a tilted workstation for inspection tasks. The angled surface supports neutral cervical alignment and minimizes forward head posture during prolonged visual activities.

Despite wrist and hand risks being mostly classified as high rather than very high, these areas require attention due to their involvement in manual, repetitive activities such as folding, cutting, and sealing. SMEs may minimise strain in these regions by utilising ergonomically designed equipment featuring appropriate grip dimensions, non-slip materials, and minimal activation force. These tools are economical, high-impact investments that markedly improve comfort and diminish the risk of tendinitis and carpal tunnel syndrome (Fasanya & Shofoluwe 2018). Where possible, simple mechanical jigs or fixtures can partially automate repetitive manual activities without requiring complete automation.

The cumulative load of multi-region ergonomic exposure, with over 65% of participants categorised as very high risk in two or more body regions, highlights the necessity for an extensive ergonomic strategy. Solutions should encompass not just equipment enhancements but also job rotation, work reconfiguration, and fundamental ergonomic training initiatives. These tactics are both economical and sustainable, especially when applied along with behavioural interventions.

FUTURE DIRECTION

Building upon these observational insights, future work will focus on the development of a structured intervention module to address the evident gaps in ergonomic knowledge, attitude, and practice (KAP) among SME workers and supervisors. The observed deficiencies in ergonomic awareness, symptom reporting, and risk mitigation behaviors underscore the need for a behavioral change framework tailored to the SME context. The Health Belief Model (HBM) offers an appropriate theoretical foundation for this intervention, as it addresses core psychosocial drivers such as perceived susceptibility to WRMSDs, perceived severity of ergonomic risks, and perceived benefits of adopting safe practices. The intervention will be designed to strengthen ergonomic self-efficacy, overcome perceived barriers like cost and time, and foster positive safety attitudes.

The integration of findings from the OHCOW-adapted Quick Exposure Checklist (QEC) reinforces the evidence-based nature of this intervention. The tool's simplicity, cost-effectiveness, and adaptability make it an ideal component for identifying ergonomic priorities and guiding worker education. Embedding QEC into the intervention will support regular ergonomic self-assessments and empower frontline personnel to recognize, report, and act on risk factors proactively. Ultimately, this future intervention aims to foster a culture of safety, where ergonomic risks are not only identified but actively managed through improved knowledge, more positive attitudes, and the consistent application of safe practices. This approach holds promise as a scalable, low-cost solution to improve occupational health outcomes and operational sustainability in resource-constrained SME environments.

STUDY LIMITATION

Despite offering practical insights, this study has several limitations that should be acknowledged. First, the cross-sectional design precludes any causal inference between ergonomic exposures and musculoskeletal health outcomes. Second, data collection was limited to a single work shift per facility which may not capture daily or weekly variations in workload and task diversity. Third, while the Quick Exposure Checklist (QEC) is a validated and user-friendly assessment tool, it does not account for psychosocial stressors, environmental influences (e.g., lighting, noise, temperature) or organizational dynamics that may also contribute to ergonomic risk. Furthermore, the integration of observational data with self-reported inputs, although methodologically beneficial may still be susceptible to response bias, especially with thought strain and fatigue. These factors may influence the accuracy of exposure assessment. Future research should utilise longitudinal research designs, multi-day task sampling, and additional ergonomic assessment techniques, including wearable biomechanical sensors or motion capture devices, to enhance the accuracy and comprehensiveness of ergonomic risk profiles.

CONCLUSION

This study provides strong empirical evidence of widespread ergonomic risk exposure among workers in Malaysian small and medium-sized enterprise (SME) food manufacturing settings. The Quick Exposure Checklist (QEC) assessment revealed particularly high risk classifications in the shoulders/arms (64.2%), static back postures (46.4%) and neck (38.4%), highlighting the biomechanical strain associated with repetitive tasks, awkward postures and static loading. Among job roles, packaging and raw material handling emerged as the most ergonomically demanding, with risk levels further influenced by gender and work experience, suggesting that both task design and individual factors contribute to risk distribution. These findings support the urgent need for engineering-based ergonomic interventions such as adjustable-height workstations, process layout redesign and the adoption of ergonomically appropriate tools. Addressing these physical risks must also be accompanied by a systemic approach that includes worker training, job rotation and routine ergonomic evaluations to foster sustainable risk reduction.The use of the OHCOW-adapted QEC tool demonstrated that ergonomic risks can be effectively assessed and prioritized even in resource-constrained environments, making it a practical solution for SMEs with limited access to specialized expertise. By embedding such tools within SME operations, organizations can promote safer work practices, reduce the incidence of work-related musculoskeletal disorders (WRMSDs), and enhance productivity. As SMEs continue to play a pivotal role in economic development, integrating ergonomics into daily operations, equipment design, and organizational policy is not only beneficial for worker health but also essential for maintaining a resilient and efficient industrial workforce.

ACKNOWLEDGMENT

The authors would like to acknowledge the invaluable support and cooperation of the management and employees of the participating small and medium-sized food manufacturing enterprises in Johor Darul Takzim. Their willingness to engage in this study, accommodate observational assessments, and share practical insights greatly contributed to the success of the research. Special thanks are also extended to the supervisors and safety coordinators for facilitating access to the worksites and ensuring a safe and conducive environment for data collection. The authors are grateful for their time, openness, and commitment to improving workplace ergonomics.

DECLARATION OF COMPETING INTEREST

None.

REFERENCES

Agre, S., Qutubuddin, S. M., Shabadi, S. & Hiremath, R. 2022. Identification of ergonomic risks and postural analysis in small scale industries – a case study of oil mill and dal mill (pulse processing) industries. *Proceedings of the International Conference on Industrial Engineering and Operations Management*.

Ariyanto, J., Palutturi, S., Russeng, S., Birawida, A., Denny, H., Daud, A. et al. 2022. Prediction and control model of musculoskeletal disorders in the instant noodle company in Makassar 2020–2050. *Open Access Macedonian Journal of Medical Sciences* 10(E): 12–17. https://doi.org/10.3889/oamjms.2022.7897

Bagheri, S. & Ghaljahi, M. 2019. Ergonomic evaluation of musculoskeletal disorders with rapid office strain assessment and its association with occupational burnout among computer users at Zabol University of Medical Sciences in 2017. *Asian Journal of Water*

Environment and Pollution 16(1): 91–96. https://doi.org/10.3233/ajw190010

Bernard, B. P. 1997. *Musculoskeletal disorders and workplace factors: A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back*. Cincinnati: NIOSH.

Birinci, T., Aydın, G., Üçgül, M. & Yeldan, İ. 2019. Genç akademisyenlerde muskuloskeletal ağrı, aleksitimi ve psikososyal faktörler arasındaki ilişki. *Türk Fizyoterapi ve Rehabilitasyon Dergisi*. https://doi.org/10.21653/tfrd.413491

Bulduk, E. 2019. Work-related stress levels and musculoskeletal disorders among municipal solid waste collectors in Ankara. *Work* 63(3): 427–433. https://doi.org/10.3233/wor-192949

Chaiklieng, S., Suggaravetsiri, P. & Pruktharathikul, V. 2024. Risk factors for developing occupational back pain in electronics industry workers: A cross-sectional study. *Safety* 10(4): 90. https://doi.org/10.3390/safety10040090

Chiasson, M. È., Imbeau, D., Major, J., Aubry, K. & Delisle, A. 2015. Influence of musculoskeletal pain on workers' ergonomic risk-factor assessments. *Applied Ergonomics* 49: 1–7. https://doi.org/10.1016/j.apergo.2014.12.011

Chuppawa, W., Thongkum, W., Yoosuk, W. & Tudpor, K. 2025. Risk factors for work-related musculoskeletal disorders among informal garment workers in Thailand. *International Journal of Public Health Science (IJPHS)* 14(2): 773. https://doi.org/10.11591/ijphs.v14i2.24285

Colim, A., Sousa, N., Carneiro, I., Costa, N., Arezes, P. & Cardoso, A. 2020. Ergonomic intervention on a packing workstation with robotic aid – case study at a furniture manufacturing industry. *Work* 66(1): 229–237. https://doi.org/10.3233/wor-203144

Cook, T. M., Rosecrance, J. C. & Zimmermann, C. L. 2001. The Quick Exposure Check (QEC) for assessing exposure to risk factors for work-related musculoskeletal disorders. *Applied Ergonomics* 32(6): 517–522.

Cunha, J., Faria, C., Colim, A., Oliveira, J., Rocha, L., Silva, M. et al. 2021. From handcrafting to a certified and ergonomic collaborative workstation: The digital transformation process. *IEEE International Conference on Intelligence and Safety for Robotics (ISR)*, Tokoname, Japan, 363–366. https://doi.org/10.1109/ISR50024.2021.9419376

Darvishi, E., Osmani, H., Aghaei, A. & Moloud, E. 2024. Hidden risk factors and the mediating role of sleep in work-related musculoskeletal discomforts. *BMC Musculoskeletal Disorders* 25(1). https://doi.org/10.1186/s12891-024-07387-0

Daud, A., Basri, I., Ahmad, E., Hairon, S., Nordin, R., Azmir, N. et al. 2025. Assessing ergonomic risks: REBA analysis of food delivery riders in eastern Peninsular Malaysia. *International Journal of Occupational Medicine and Environmental Health* 38(2): 170–178. https://doi.org/10.13075/ijomeh.1896.02558

David, G., Woods, V., Li, G. & Buckle, P. 2008. The development of the Quick Exposure Check (QEC) for assessing exposure to risk factors for work-related musculoskeletal disorders. *Applied Ergonomics* 39(1): 57–69. https://doi.org/10.1016/j.apergo.2007.03.002

Dewantari, N. & Herlina, L. 2022. Literature review: Human factors and ergonomics (HFE) in the food industry. *Jurnal Teknik Industri* 17(3): 174–190. https://doi.org/10.14710/jati.17.3.174-190

da Costa, B. R. & Vieira, E. R. 2010. Risk factors for work-related musculoskeletal disorders: A systematic review of recent longitudinal studies. *American Journal of Industrial Medicine* 53(3): 285–323. https://doi.org/10.1002/ajim.20750

Domínguez-Alfaro, D., Mendoza-Muñoz, I., Montoya-Reyes, M., Vargas-Bernal, O. & Jacobo-Galicia, G. 2023. Design and implementation of integral ergo-value stream mapping in a metal-mechanical company to improve ergonomic and productive conditions: A case study. *Logistics* 7(4): 100. https://doi.org/10.3390/logistics7040100

Domínguez-Alfaro, D., Mendoza-Muñoz, I., González, C., Montoya-Reyes, M., Cruz-Sotelo, S. & Vargas-Bernal, O. 2021. Ergovsm: A new tool that integrates ergonomics and productivity. *Journal of Industrial Engineering and Management* 14(3): 552. https://doi.org/10.3926/jiem.3507

Egozi, L., Reiss-Hevlin, N., Dallasheh, R. & Pardo, A. 2021. Couriers' safety and health risks before and during the COVID-19 pandemic. *International Archives of Occupational and Environmental Health* 95(3): 589–598. https://doi.org/10.1007/s00420-021-01795-8

Ercan, S., İnce Parpucu, T., Başkurt, Z. & Başkurt, F. 2023. Gender differences, ergonomics risks and upper quadrant musculoskeletal pain in hairdressers. *International Journal of Occupational Safety and Ergonomics* 29(2): 685–689. https://doi.org/10.1080/10803548.2022.2066315

Fasanya, B. K. & Shofoluwe, M. 2019. Occupational ergonomics: Emerging approaches toward improved worker productivity and injury reduction. Dlm. *Advances in Physical Ergonomics & Human Factors*, disunting oleh R. Goonetilleke & W. Karwowski. Cham: Springer. https://doi.org/10.1007/978-3-319-94484-5_40

Guerreiro, M. M., Serranheira, F., Cruz, E. B. & Sousa-Uva, A. 2021. Working time and upper limb musculoskeletal symptoms: A longitudinal study among assembly line workers. *Industrial Health* 59(1): 43–53. https://doi.org/10.2486/indhealth.2020-0155

Harun, W., Ghani, S. & Noh, M. 2025. Evaluation of work-related musculoskeletal disorders (WRMSDs) among manual assembly workers in the medical device manufacturing industry. *Journal of Physics: Conference Series* 2933(1): 012023. https://doi.org/10.1088/1742-6596/2933/1/012023

Hasanain, B. 2024. The role of ergonomic and human factors in sustainable manufacturing: A review. *Machines* 12(3): 159. https://doi.org/10.3390/machines12030159

Hawari, N., Sulaiman, R. & Rosalam, C. 2023. Conceptual design, fabrication and validation on prototype of industrial ergonomic trolley-lifter for wood furniture industry. *Alam Cipta International Journal of Sustainable Tropical Design & Practice* 16(2): 71–78. https://doi.org/10.47836/ac.16.2.paper08

Hultén, A., Holmgren, K. & Bjerkeli, P. 2023. Work-related stress, reason for consultation and diagnosis-specific sick leave: How do they add up? *PLoS One* 18(7): e0288751. https://doi.org/10.1371/journal.pone.0288751

Hossain, M. D., Aftab, A., Al Imam, M. H., Mahmud, I., Chowdhury, I. A., Kabir, R. I. & Sarker, M. 2018. Prevalence of work-related musculoskeletal disorders (WMSDs) and ergonomic risk assessment among readymade garment workers of Bangladesh: A cross-sectional study. *PLoS One* 13(7): e0200122. https://doi.org/10.1371/journal.pone.0200122

Ibrahim, B. & Gaafar, S. 2024. Work-related musculoskeletal complaints: Risk factors and impact on work productivity among university administrative employees. *Journal of Egyptian Public Health Association* 99(1). https://doi.org/10.1186/s42506-024-00156-w

Ismaila, S., Salami, I. Y., Kuye, S., Dairo, O. & Adekunle, N. 2020. Ergonomic evaluation of packaging workers' posture in a food manufacturing company. *Journal of Engineering Studies and Research* 26(1). https://doi.org/10.29081/jesr.v26i1.6

Jose, J. A., Sharan, D. & Rajkumar, J. 2018. Analysis of ergonomic risk factors in a pharmaceutical manufacturing company. Dlm. *Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018)*, 355–356.

Khoshakhlagh, A., Sulaie, S., Mirzahosseininejad, M., Yazdanirad, S., Orr, R., Laal, F. et al. 2024. Occupational stress and musculoskeletal disorders in firefighters: The mediating effect of depression and job burnout. *Scientific Reports* 14(1). https://doi.org/10.1038/s41598-024-55468-w

Khoshakhlagh, A., Sulaie, S., Yazdanirad, S., Orr, R. & Laal, F. 2024. Relationships between job stress, post-traumatic stress and musculoskeletal symptoms in firefighters and the role of job burnout and depression mediators: A Bayesian network model. *BMC Public Health* 24(1). https://doi.org/10.1186/s12889-024-17911-5

Kim, J. & Jeong, B. 2024. Food manufacturing workers and structural causality among work environment, work–family conflict, musculoskeletal pain, sleep-related problems, and burnout. *Applied Sciences* 14(17): 7489. https://doi.org/10.3390/app14177489

Laberge, M., Caroly, S., Riel, J. & Messing, K. 2019. Considering sex and gender in ergonomics: Exploring the hows and whys. *Applied Ergonomics* 78: 103039. https://doi.org/10.1016/j.apergo.2019.103039

Li, X., Xu, Y., Sun, X., Xue, Q., Ma, X. & Liu, J. 2021. Associations of musculoskeletal disorders with occupational stress and mental health among coal miners in Xinjiang, China: A cross-sectional study. *BMC Public Health* 21(1). https://doi.org/10.1186/s12889-021-11379-3

Mahboobi, M., Taghipour, M. & Ali Azadeh, M. 2020. Assessing ergonomic risk factors using combined data envelopment analysis and conventional methods for an auto parts manufacturer. *Work* 67(1): 113–128. https://doi.org/10.3233/WOR-203257

Marchisio, R. & Collao-Diaz, M. 2023. Analysis of the application of ergonomics to increase productivity in manufacturing companies: A systematic review of the literature. https://doi.org/10.46254/au02.20230240

Marklund, S., Mienna, C., Wahlström, J., Englund, E. & Wiesinger, B. 2019. Work ability and productivity among dentists: Associations with musculoskeletal pain, stress, and sleep. *International Archives of Occupational and Environmental Health* 93(2): 271–278. https://doi.org/10.1007/s00420-019-01478-5

Marzuki, M. M., Nik Abdul Majid, W. Z., Abu Bakar, H., Mohamad Rosman, M. R., Abdul Wahid, K. & Mohd Zawawi, M. Z. 2023. Occupational safety and health across small and medium-sized enterprises: Investigation of risk management practices in Malaysia. *Journal of Occupational Safety and Health* 20(1): 59–77.

Muthukumar, A., Mohanraj, K. & A, H. 2020. Association of work related risk factors on the development of the neck and upper extremity pain among adult and middle aged population – a survey based analysis. *International Journal of Research in Pharmaceutical Sciences* 11(SPL3): 588–595. https://doi.org/10.26452/ijrps.v11ispl3.2988

Mohd Suadi Nata, D. H., Azlan Hisham, N. & Mohamad Jamil, P. A. S. 2024. Initial assessment of musculoskeletal disorders and ergonomics risk factors among laboratory workers, Kuala Lumpur. *Work* 80(4): 1733–1742. https://doi.org/10.1177/10519815241297470

Ng, Y., Voo, P. & Maakip, I. 2019. Psychosocial factors, depression, and musculoskeletal disorders among teachers. *BMC Public Health* 19(1). https://doi.org/10.1186/s12889-019-6553-3

Nguyen, T. P. 2009. *A trial evaluation of the participatory action oriented training programme in small and medium scale enterprises in Vietnam*. Ph.D. Dissertation, University of Birmingham.

Nestorova, V. & Mircheva, I. 2018. Work-related musculoskeletal disorders (WMSDs): Risk factors, diagnosis and prevention. *Scripta Scientifica Salutis Publicae* 4: 15. https://doi.org/10.14748/sssp.v4i0.5076

Occupational Health Clinics for Ontario Workers (OHCOW). 2024. Quick Exposure Check (QEC) tool & calculator. https://www.ohcow.on.ca/quick-exposure-check-qec-tool/

Onofrejova, D., Andrejiova, M., Porubcanova, D., Pacaiova, H. & Sobotova, L. 2024. A case study of ergonomic risk assessment in Slovakia with respect to EU standard. *International Journal of Environmental Research and Public Health* 21(6): 666. https://doi.org/10.3390/ijerph21060666

Pawar, P. G. & Anandh, S. 2020. Prevalence of musculoskeletal disorders in small scale food industry in Karad. *Indian Journal of Physiotherapy and Occupational Therapy* 14(2): 2137.

Patil, A. & Patil, P. 2023. Comparative study of ergonomics among manufacturing industry workers in rural and urban industries. *International Journal of Biological and Health Sciences* 13(2): 95–102. https://doi.org/10.37622/ijbhs/13.2.2023.95-102

Peter, O. 2023. Industrial ergonomics of manufacturing industries in South West Nigeria. *Journal of Engineering Research and Reports* 25(4): 79–90. https://doi.org/10.9734/jerr/2023/v25i4904

Pramitasari, R., Pitaksanurat, S., Phajan, T. & Laohasiriwong, W. 2015. Association between ergonomic risk factors and work-related musculoskeletal disorders in beverage factory workers, Indonesia. Dlm. *International Seminar Workshop Public Health Action Building Healthy Community*, 196–200.

Robertson, M. M., Huang, Y. H., O'Neill, M. J. & Schleifer, L. M. 2008. Flexible workspace design and ergonomics training: Impacts on the psychosocial work environment, musculoskeletal health, and work effectiveness among knowledge workers. *Applied Ergonomics* 39(4): 482–494. https://doi.org/10.1016/j.apergo.2008.02.022

Sardar, S. K. & Lee, S. C. 2024. An ergonomic evaluation using a deep learning approach for assessing postural risks in a virtual reality-based smart manufacturing context. *Ergonomics* 67(11): 1715–1728. https://doi.org/10.1080/00140139.2024.2349757

Selamat, M., Omar, N., Mohd, R., Aziz, S. & Hamid, F. 2021. Analysis on ergonomic factor of duties and organizations towards stress and occupational disease in manufacturing industry in Malaysia. *International Journal of Academic Research in Accounting, Finance and Management Sciences* 11(3). https://doi.org/10.6007/ijarafms/v11-i3/10813

Sun, W., Yin, L., Zhang, T., Zhang, H., Zhang, R. & Cai, W. 2023. Prevalence of work-related musculoskeletal disorders among nurses: A meta-analysis. *Iranian Journal of Public Health* 52(3): 463–475. https://doi.org/10.18502/ijph.v52i3.12130

Suokko, T. & Reiman, A. 2021. Ergonomics is profitable – experiences from a holistic manufacturing plant level development process. Dlm. *Proceedings*, 89–95. https://doi.org/10.1007/978-3-030-74608-7_12

Sombatsawat, E., Saeng-Iam, K. & Kaewdok, T. 2025. Prevalence and risk factors of musculoskeletal symptoms among women handloom weavers in Lampang Province, Thailand. *Clinical Epidemiology and Global Health* 34: 102093. https://doi.org/10.1016/j.cegh.2025.102093

Soteriades, E., Psalta, L., Leka, S. & Spanoudis, G. 2019. Occupational stress and musculoskeletal symptoms in firefighters. *International Journal of Occupational Medicine and Environmental Health*. https://doi.org/10.13075/ijomeh.1896.01268

Teixeira, R., Guimarães, W., Ribeiro, J., Fernandes, R., Nascimento, L., Torné, I. et al. 2022. Analysis of the reduction of ergonomic risks through the implementation of an automatic tape packaging machine. *International Journal of Environmental Research and Public Health* 19(22): 15193. https://doi.org/10.3390/ijerph192215193

Teles, F., Espinosa, M., Santos, E., Souza, R., Muraro, A. & Freitas, R. 2024. Work-related musculoskeletal symptoms among public municipal elementary school teachers in Cuiabá, Brazil. *Revista Brasileira de Medicina do Trabalho* 22(3): 1–10. https://doi.org/10.47626/1679-4435-2023-1131