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Prevalence of Work-Related Musculoskeletal Disorders and Their Associated Ergonomic Risk Factors among Glove Manufacturing Industry Workers in Malaysia

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Abstract: Introduction: Work-related musculoskeletal disorders (WRMSD) are a significant occupational health concern in the glove manufacturing sector. Despite its prominence, WRMSD prevalence in this sector remains unexplored. This study aims to determine the prevalence and associated risk factors of WRMSD among glove manufacturing workers in Malaysia. Method: A cross-sectional study used secondary data from three glove manufacturing facilities between 30 January and 30 June 2024. 750 production workers (aged 16–55) in similar job roles were included. Workers who had administrative roles or relevant medical histories were excluded. Secondary data included Cornell Musculoskeletal Discomfort Questionnaire (CMDQ), Depression, Anxiety, and Stress Scale–21 Items (DASS-21), medical records, and Rapid Entire Body Assessment (REBA) to assess musculoskeletal discomfort, mental health, WRMSD diagnosis, and ergonomic risk with posture, respectively. The primary outcome was WRMSD with independent variables including ergonomic postures, risk levels, overtime, absenteeism, age, gender, duration of employment, task repetition, and mental health status. Data was analysed using SPSS v.28, employing descriptive statistics, chi-square tests, and logistic regression. Result: The prevalence of WRMSD was 79.2%, with the wrist (35.9%), neck (22.7%), and shoulder (12.1%) being the most affected regions. Significant associated factors included smoking (aOR = 1.34,95% CI [1.21–1.64]), Awkward posture (aOR = 23.66,95% CI [14.28–38.94]), Repetitive Posture (aOR = 13.06,95% CI [12.03–14.11]), task duration (aOR=1.08,95% CI [1.01–1.15]), stress (aOR = 1.61, 95% CI [1.10–2.35]) and anxiety (aOR 1.51, 95% CI [1.42–1.88]). Conclusion: The study highlights a high prevalence of WRMSD in Malaysia's glove manufacturing industry. Findings emphasize the need for integrated preventive measures including manual handling training, workstation redesign, task rotation, and mental health support to protect worker's well-being and sustain industry productivity. The results provide a foundation for policy and workplace interventions, with future research recommended to explore causal relationships and evaluate the effectiveness of ergonomic interventions.

Keywords: WRMSD; ergonomics; glove manufacturing; Malaysia

1. Introduction

Despite advances in automation, Malaysia's manufacturing industry relies on human labour. The Department of Statistics Malaysia reported that approximately 2.4 million people were employed in this sector in 2024 [1]. The International Labour Office had identified 66,739 workers in the glove manufacturing industry, which accounts for 0.28% of the national manufacturing workforce [2]. While some heavy industries have adopted technology to improve productivity and safety, many important tasks require manual handling, which is associated with a risk of developing work-related musculoskeletal disorders (WRMSD) [3]. WRMSD are among Malaysia's common occupational health issues [4]. The World Health Organization defines musculoskeletal disorders as conditions impairing the locomotor system, with severity ranging from mild discomfort, such as finger numbness due to repetitive work, to more disabling conditions [5]. Direct disorder costs due to the compensation on musculoskeletal disorders by the Social Security Organisation of Malaysia (SOCSO) were reported to be approximately USD 2.8 billion from 2009 to 2014 [6]. This cost significantly affects the social economy due to substantial losses in compensation.

The Department of Occupational Safety and Health received 11,747 notifications, with 6259 confirmed occupational disease cases in 2023. Of the total workforce, 5659 were male and 600 were female employees. In terms of nationality, 4360 were Malaysians, while 1899 were foreign workers. The trend analysis from 2005 to 2023 demonstrates that the cases are increasing, with 454 cases in 2005 and 8155 cases in 2023, and manufacturing is a significant sector. An increasing trend of WRMSD, with 675 cases documented in 2014 and an increasing trajectory projected through 2025 [7]. About 281 cases of WRMSD have been recorded in the manufacturing industry in 2023, with no specific data available on the type of manufacturing industry [8]. The highest incidence of WRMSD occurred among employees aged 30 to 35 years. WRMSD remains a critical global occupational health concern, imposing significant economic and operational burdens through compensation costs and reduced productivity. Effective mitigation necessitates coordinated policy and organisational interventions targeting workplace risk factors [9–12].

The glove industry, with its high demands and limited job rotation, may inadvertently impact mental health. Empirical evidence had demonstrated a significant association between emotional distress and WRMSD [13]. The study also revealed that workers suffering from musculoskeletal symptoms frequently reported high levels of emotional distress, primarily attributed to occupational demands such as heavy workload, time pressure, and emotional exhaustion [14].

Publicly available research on the prevalence of WRMSD among employees in Malaysia's glove manufacturing sector is lacking. While other working processes have been automated, removing the gloves from the former is a crucial work process that still requires a major manual workforce [15].

There are several important steps in the glove manufacturing process. To improve the adhesive qualities, coagulant dipping is done after former cleaning, which involves reusing formers from the prior batch. A latex film is subsequently created by dipping and gelling nitrile butadiene rubber (NBR), which is subsequently exposed to leaching and beading. After cooling, chlorination, post-leaching, and drying, the process proceeds with vulcanization and drying as in Figure 1 to enhance the mechanical qualities of NBR gloves. Stripping and inspection are carried out to guarantee production quality and subsequently the gloves are packaged for distribution to final customers [16]. The manual labor that poses ergonomic hazards includes packing, stripping, and inspection [15].

Gender has been strongly associated with WRMSD, with female workers consistently demonstrating higher susceptibility due to physiological and occupational factors. Women typically have lower muscle mass and shorter stature, making them more vulnerable to biomechanical strain. The dual burden of employment and domestic responsibilities further exacerbates physical stress [17]. Task allocation and structured work rotation have a significant influence on WRMSD. Operational workers are often assigned to tasks involving ergonomic risk postures without sufficient variation. In glove manufacturing, roles such as stripping and packing are frequently performed without rotation, contributing to fatigue and inadequate muscular recovery [15,17–19]. Ageing can cause WRMSD through biomechanical and degenerative changes [17,20–23]. Moreover, lower levels of educational attainment are often associated with assignment to more physically demanding tasks, increasing the risk of WRMSD [24,25].

Occupational and psychosocial factors impacting WRMSD and their broad effects on employment, health, and the economy are given by the Panteia/VHP/IKei Work-Related MSD theoretical framework developed by Panteia [26]. It highlights the relationship between workplace structure, discrimination, and employee segregation, and illustrates how these elements exacerbate inequities in occupational health. The theory also discusses how WRMSD affects mental and physical health, taking into account both the costs to the public's health and the well-being of the individual [26]. The conceptual framework in Figure 2 was adapted [20] and outlines the relationship

between factors contributing towards the development of WRMSD. The problem statement has identified risks to WRMSD from manual handling within the sector. Despite rising cases and substantial compensation costs in Malaysia, industry-specific data and research on WRMSD in the glove manufacturing industry are lacking. This gap hinders the identification of key risk factors and the development of evidence-based ergonomic interventions and prevention programs.

This study seeks to investigate the prevalence of WRMSD and associated factors (sociodemographic factors, occupational characteristics, body postures, and mental health status) among employees in the glove manufacturing industry in Malaysia.

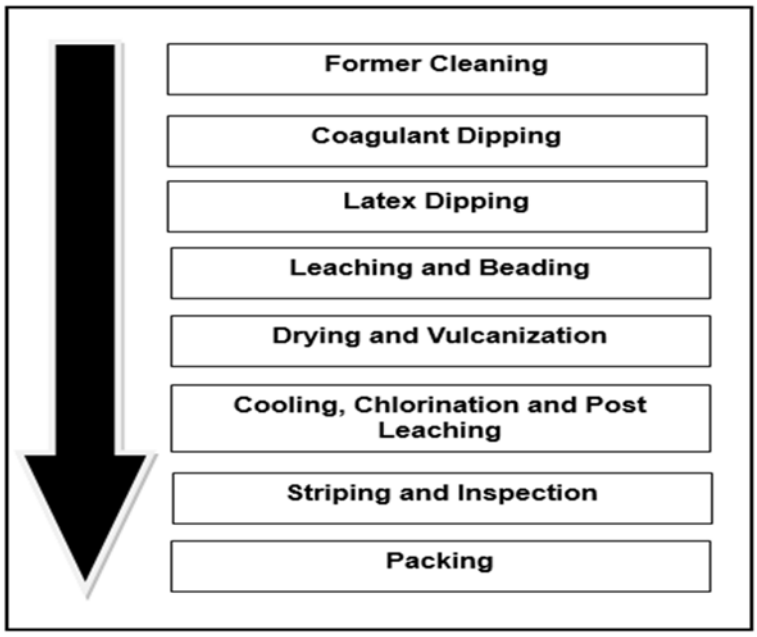

Figure 1. Glove manufacturing process. Adapted from Ref. [16]. Copyright 2019, Wiley-VCH Verlag GmbH & Co. KGaA.

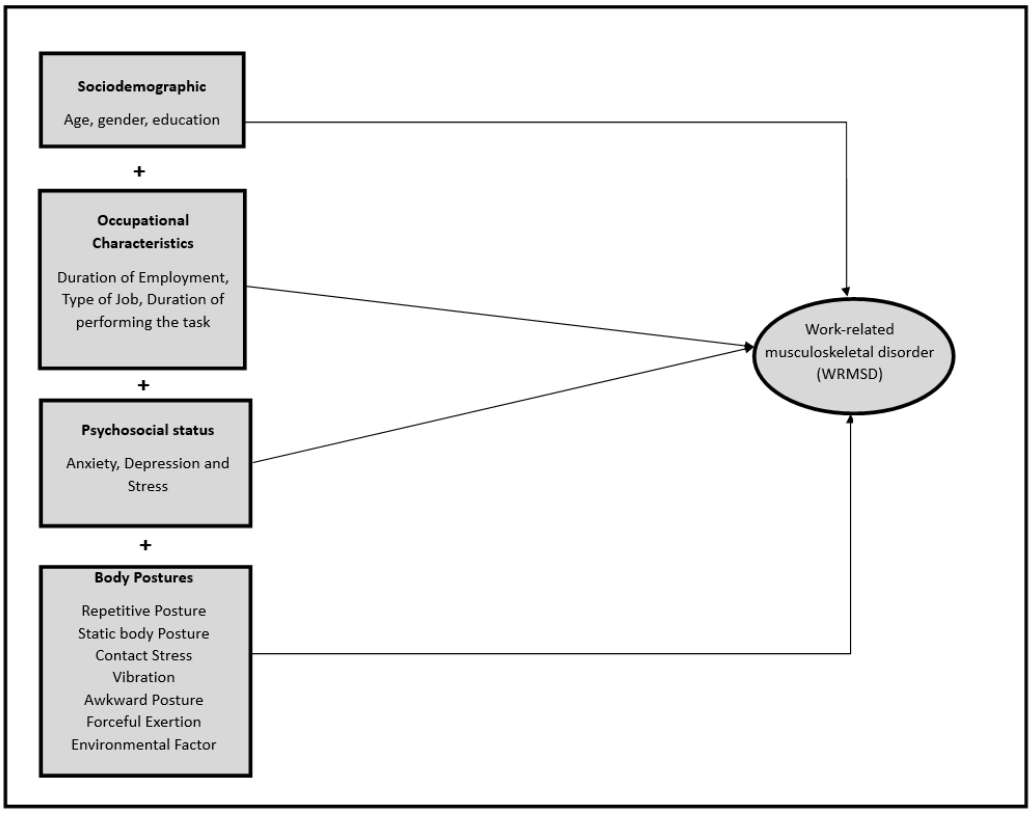

Figure 2. Conceptual framework.

2. Materials and Methods

A cross-sectional study design was employed, based on the analysis of secondary data provided by the industry, to examine the prevalence of WRMSD and associated factors (sociodemographic factors, occupational characteristics, body postures, and mental health status). This study was conducted at three separate glove manufacturing factories located at the industrial areas of 2 states (Perak and Selangor) from the central region of Malaysia. The sample size was determined based on a statistical significance of 0.05, a power of 0.80, a margin of error of 0.05, and an estimated prevalence of 60% in the population of 66,739 workers in the glove manufacturing industry in Malaysia [2,27]. Assuming potential issues related to secondary data attrition, missing values, and possible statistical power fluctuation due to data reliability and availability, a 25% sample size was incorporated into the initial estimation. This adjustment was made to ensure sufficient statistical power and the robustness of the study findings. The sample size was estimated using a sample size calculation for a study on association and Fleiss with continuity correction [28–30]. Therefore, a minimum sample size of 556 subjects was required. Information and selection bias was minimized by using official industry-provided secondary data, strict inclusion criteria, medical reports and confounder adjustment. However, residual confounding may persist due to unmeasured factors like workload intensity, psychosocial support, and job rotation. Out of 3650 workers, only 750 records were included in the study due to data completeness and alignment with the study criteria. The remaining records were excluded because 2133 had incomplete data, and 767 did not meet the inclusion criteria. They were included in the study due to lower risk and to maximise the findings' comprehensiveness and reliability [31]. The inclusion criteria were workers aged between 20 and 60 years as stipulated by the Minimum Retirement Age Act 2012 [9], who work in production or operational departments, the worker has one task that has been routinely performed, such as glove stripping from the former [4] and those who have worked for at least 1 year in the production line [9] Workers who performed non-routine tasks, administrative workers, workers with a history of trauma or suffering traumatic injuries due to non-occupational accidents affecting the musculoskeletal system, a history of mental illness with follow-up under a psychiatrist, and pathological musculoskeletal or metabolic disorders were excluded from this study through the manufacturer human resources and industrial clinic records in view the study uses secondary data [9,32–35].

The dependent variable, WRMSD, was clinically diagnosed by a registered medical practitioner based on clinical presentations, relevant investigations, and documented exposure to ergonomic risk postures during task performance [36], The independent variables included ergonomic risk postures, risk level, history of overtime, employee absenteeism, age, gender, employment duration, duration of performing the specific task on a routine basis, and the employees' mental health status. Age and gender were identified as potential confounders [37]. Quantitative variables such as age and employment duration were categorised into defined intervals based on their relevance to occupational exposure and ease of comparison between groups, which aligned with previous occupational health studies. Figure 3 shows the flow diagram of participant selection and inclusion process in the study.

The secondary data for this study were collected from multiple sources to ensure a comprehensive assessment of factors associated with work-related musculoskeletal disorders (WRMSD). Demographic information, including age, nationality, and employment status, was obtained from the organisation's Human Resources Department. Ergonomic risk assessments were conducted using the Rapid Entire Body Assessment (REBA) tool by Certified Ergonomics Trained Persons appointed by the companies between 9th September and 30th December 2023, in compliance with legal risk management requirements, especially Occupational Safety and Health Act 1994 which mandates employers to conduct risk management along with risk dissolution measures at workplace. These assessments identified ergonomic risk levels and associated working postures, with the REBA tool demonstrating high reliability and validity (0.93) [38]. In addition, the Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) was administered by respective manufacturer's Safety and Health Officers between 15th September and 30th December 2023 to capture self-reported musculoskeletal discomfort across various body regions, with a reported validity and reliability score of 0.84 [39]. Mental health status was assessed using the Depression, Anxiety, and Stress Scale–21 Items (DASS-21), which was administered as part of employee wellbeing programs between 10th August and 30th December 2023. This instrument evaluated levels of depression, anxiety, and stress, demonstrating excellent internal consistency with a Cronbach's alpha of 0.94 [40]. Finally, data on diagnosed WRMSD cases were obtained from the in-house industrial clinics to complement self-reported and clinical findings. CMDQ responses were dichotomised to indicate the presence or absence of musculoskeletal discomfort. DASS-21 scores were categorised using standard cut-offs, with at least mild levels classified as "present" (yes) and normal as "absent" (no). REBA scores were utilized in two forms: posture-specific exposures (awkward and repetitive postures) were dichotomised into yes/no variables, while overall REBA risk levels (negligible, low, moderate, high) were retained as categorical variables for analysis.

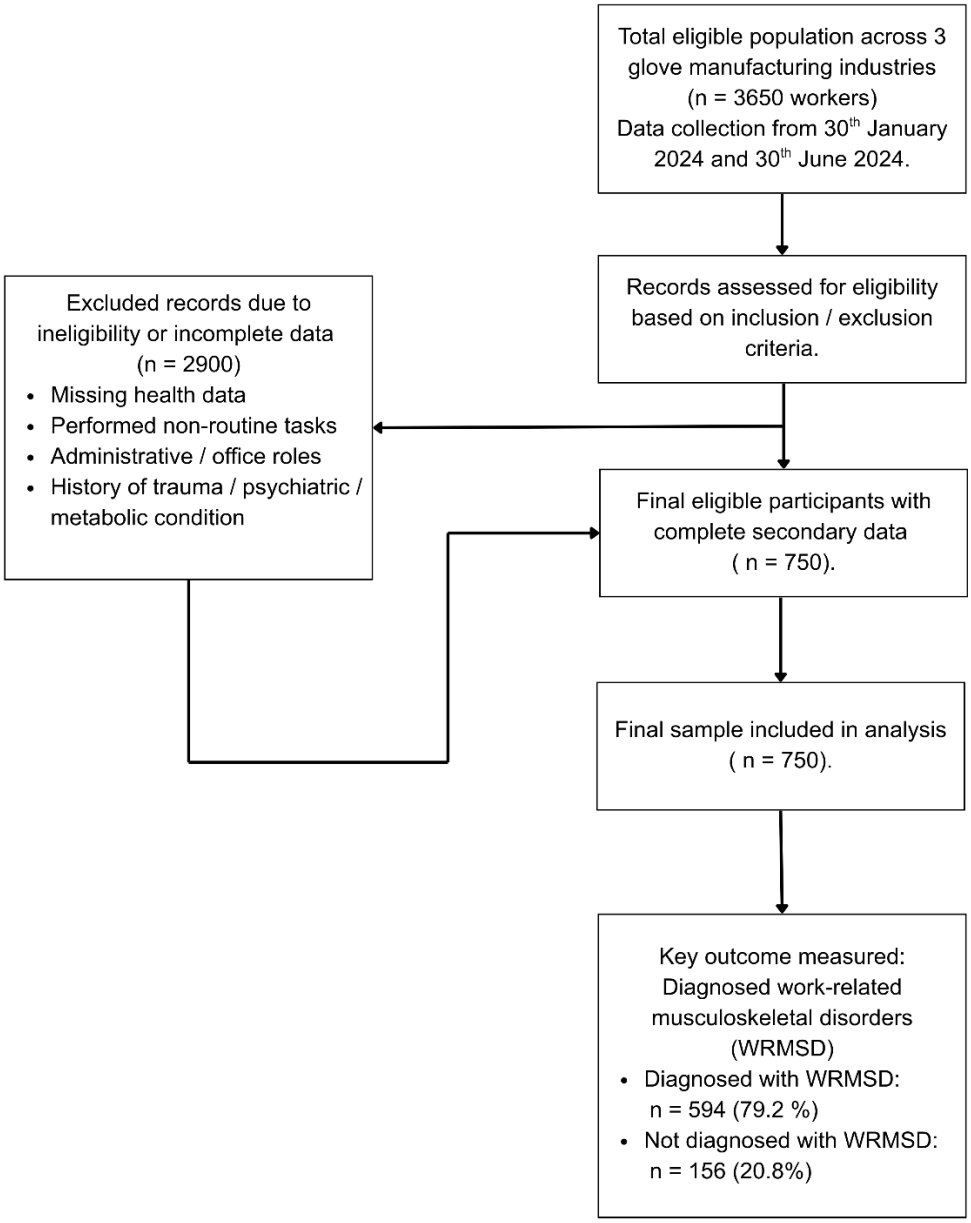

Figure 3. Flow diagram of participant selection and inclusion process in the study.

A multivariable logistic regression model was constructed to estimate adjusted odds ratios (aOR) with 95% confidence intervals for factors associated with work-related musculoskeletal disorders (WRMSD). Covariate selection was guided by epidemiological relevance, literature review, and statistical significance in bivariate analyses [41,42]. Variables included in the model were age, employment duration, smoking status, ergonomic training, task duration, overtime, absenteeism, ergonomic exposures (awkward and repetitive postures), and mental health indicators (stress, anxiety, and depression). Age was retained as a priori confounders irrespective of statistical significance, given their established associations with musculoskeletal outcomes to account for potential biological and occupational differences in WRMSD susceptibility. Stratified analyses by sex were not performed, as the primary objective of this study was to estimate overall associations within the study population while controlling for confounding. Model adequacy and assumptions were assessed using appropriate diagnostic measures, including goodness-of-fit tests and collinearity diagnostics, to ensure the robustness of the findings.

REBA risk level was entered into the regression model as a categorical variable, with the reference category explicitly specified in results section. The wide confidence intervals observed for some REBA strata likely reflect sparse observations and reduced precision after multivariable adjustment.

3. Results

Sociodemographic characteristics, occupational characteristics, and mental health status presented in Table 1. A total of 594 workers were diagnosed with WRMSD, yielding a prevalence of 79.2%. The mean age was 39.0

years (SD = 6.85), with a median of 39.24 years. The majority of WRMSD cases occurred among workers aged 36 to 45 years.

Table 1. Sociodemographic of glove manufacturing sector employees.

Variable	Frequency (*n*)	Percentage (%)
Age Group (years)		
20–25	0	0
26–35	248	33.1
36–45	319	42.5
46–55	183	24.4
55–60	0	0
Duration of experience (years)		
1–10	246	32.8
11–20	260	34.7
21–30	242	32.3
31 and above	2	0.3
Gender		
Male	456	60.8
Female	294	39.2
Ethnicity/non-citizen		
Malay	114	15.2
Chinese	111	14.8
Indian	195	26
Indonesian (non-citizen)	94	12.5
Nepalese (non-citizen)	236	31.5
Ergonomic Training		
Yes	453	60.4
No	297	39.6
Education		
Formal Education	472	62.9
No Formal education	278	37.1
Smoking		
Yes	470	62.7
No	280	37.3
Mental health status		
Stress		
Yes	515	68.7
No	235	31.3
Anxiety		
Yes	312	41.6
No	438	58.4
Depression		
Yes	339	45.2
No	411	54.8

Table 2 indicates that WRMSD prevalence was highest among workers aged 36–45 years (82.1%) and those with 11–20 years of experience (89.6%). Among gender and ethnic groups, female workers (81.0%) and Indian workers (83.1%) reported the highest prevalence, respectively. The prevalence of WRMSD among glove manufacturing employees was determined using clinical records and ergonomic exposure data, with an overall prevalence of 79.2%.

Table 3 presents the distribution of affected anatomical regions among workers with WRMSD. The wrist (35.9%) was the most affected site, followed by the neck (22.7%) and shoulder (12.1%), indicating a predominance of upper limb disorders. Other frequently reported areas included the upper back (7.7%), elbow (7.7%), hips and thighs (6.0%), lower back (5.6%), and knee (5.5%).

To address the third objective, the association between sociodemographic characteristics, occupational characteristics, body postures and mental health status with WRMSD was analysed using multivariable logistic regression, with adjustment for age as a priori confounders. The results are presented in Table 4.

Smoking was significantly associated with WRMSD (aOR = 1.34, 95% CI [1.21–1.64], $p < 0.05$). Ergonomic training demonstrated a protective trend, although it was not statistically significant (aOR = 0.70, 95% CI [0.48–1.02], $p > 0.05$).

Table 2. Subgroup analysis of WRMSD prevalence by age, experience, gender, and ethnicity (n = 750).

Variables	Frequency (*n*)	WRMSD	Percentage (%)
Age Group (years)			
26–35	248	191	77.0
36–45	319	262	82.1
46–55	183	141	77.0
Duration of employment (years)			
1–10	246	202	82.1
11–20	260	233	89.6
21–30	242	159	65.7
31 and above	2	0	0
Gender			
Male	456	356	78.1
Female	294	238	81.0
Ethnicity			
Malay	114	87	76.3
Chinese	111	83	74.8
Indian	195	162	83.1
Indonesian	94	73	77.6
Nepalese	236	189	80.1
Overall WRMSD Prevalence	750	594	79.2

Table 3. Distribution of affected body parts among workers with WRMSD (n = 750).

Body Part	Percentage (%)
Wrist	35.9
Neck	22.7
Shoulder	12.1
Upper back	7.7
Hips and thighs	6.0
Lower back	5.6
Knee	5.5
Elbow	7.7

Table 4. Multivariable logistic regression predicting work-related musculoskeletal disorders among glove manufacturing workers.

Variables			Logistic Regression	
	χ^2	df	aOR (95% CI)	*p*-value
Smoking history	18.14	1	1.34 (1.21–1.64)	<0.05
Formal education	2.93	1	1.40 (0.95–2.07)	0.09
Age Group (years)				
36–45	2.11	1	0.67 (0.39–1.15)	0.15
46–55	3.21	1	0.94 (0.89–1.01)	0.07
Ergonomic training	3.45	1	0.70 (0.48–1.02)	0.06
Task duration	5.55	1	1.08 (1.01–1.15)	<0.05
History of overtime	0.20	1	1.57 (1.45–1.88)	<0.05
History of unpaid leaves	2.58	1	1.36 (0.93–1.98)	0.11
Ergonomic risk postures				
Awkward posture	260.13	1	23.66 (14.28–38.94)	<0.05
Repetitive posture	114.98	1	13.06 (12.03–14.11)	<0.05
Mental health status				
Stress	5.97	1	1.61 (1.10–2.35)	<0.05
Anxiety	7.04	1	1.51 (1.42–1.88)	<0.05
Depression	0.17	1	0.93 (0.64–1.34)	0.69
Ergonomic risk level				
Low	3.10	1	7.96 (0.79–80.14)	0.08
Moderate	2.10	1	6.32 (0.89–90.15)	0.06
High	1.51	1	0.78 (0.53–1.16)	0.22

Reference categories: 26–35 years (age group); no exposure (ergonomic risk postures); no stress, anxiety, or depression (mental health status); negligible REBA risk level. Odds ratios are estimated relative to these reference categories.

Awkward and repetitive postures emerged as the most prominent ergonomic risk postures within the sector. Workers exposed to awkward postures were approximately 24 times more likely to develop WRMSD (95% CI: 14.28–38.94), while repetitive postures increased the likelihood by 13 times (95% CI: 12.03–14.11).

In addition, prolonged task duration (aOR = 1.08; 95% CI [1.01–1.15]; $p < 0.05$), stress (aOR = 1.61; 95% CI [1.10–2.35]; $p < 0.05$), and anxiety (aOR = 1.51; 95% CI [1.42–1.88]; $p < 0.05$) were significantly associated with WRMSD. In contrast, depression and overall ergonomic risk level categories were not statistically significant. These findings support the study hypothesis, demonstrating that WRMSD is significantly associated with sociodemographic, occupational, ergonomic, and psychosocial factors among glove manufacturing workers.

4. Discussion

These findings support the study hypothesis, demonstrating that WRMSD is significantly associated with sociodemographic, occupational, ergonomic, and psychosocial factors among glove manufacturing workers. The workforce was predominantly middle-aged, as younger generations, particularly those born between 1981 and 1996 showed limited interest in technical work due to low wages, limited career prospects, inadequate benefits, and job insecurity [43]. Younger Malaysians perceive manual labour as degrading to their social status [44]. Approximately 34.7% of workers had 11–20 years of experience in the sector, possibly reflecting employee loyalty [45]. The gender composition showed a male-dominated workforce, though lower than Malaysia's overall male labour force participation rate of 82.9%. The increase in female workforce participation from 55.5% in 2020 to 56.2% in 2023 reflects ongoing government efforts to empower women economically [46–48]. On the other hand, the workforce was ethnically diverse, with Nepalese comprising the majority, reflecting employers' preference for foreign labour due to low local participation. Language barriers, cultural beliefs, and limited health literacy may hinder symptom reporting and access to care among ethnically diverse workers. Ethnicity can also affect reporting and intervention through differences in language, training uptake, health perceptions, and access to resources [49,50]. As ethnicity was not analysed in the regression model, any observed differences at the descriptive level should be interpreted with caution and may reflect underlying occupational or structural factors rather than ethnicity per se.

Still, our results suggest that WRMSD are significantly associated with sociodemographic, occupational, ergonomic, and psychosocial factors among glove manufacturing workers. The high WRMSD prevalence mirrors global findings, emphasising the demanding nature of glove manufacturing, particularly in roles such as stripping and packing, which involve repetitive and awkward upper limb postures. The wrist was the most affected site, likely due to sustained ulnar deviation and gripping, which strain the flexor tendons. This finding aligns with reports from assembly-line industries, where such ergonomic postures are linked to tendon inflammation and carpal tunnel syndrome [51]. Higher levels of wrist and shoulder pain in medical device manufacturing were reported, reinforcing the notion that task specific exposures in manual works lead to upper limb disorders [52]. Muscles can exert substantial force in association with manual tasks and body postures, which can lead to fatigue and eventual injury, which leads to WRMSD. In contrast, lower back complaints were less frequent, aligning with the dynamic nature of standing work in this sector, which provides posture variability compared with other industries [11,23,35,53]. This variability allows intermittent activation and recovery of key postural muscles, particularly the erector spinae group, which is primarily responsible for maintaining upright posture and stabilising the lumbar spine. Reduced static loading on the erector spinae and associated trunk muscles help mitigate cumulative muscle fatigue and lower back strain. Despite the availability of ergonomic guidelines, their enforcement and practical uptake remain limited. This emphasizes the need to re-evaluate workstation design and apply evidence-based interventions such as microbreaks and targeted training to mitigate upper quadrant strain [21,54].

A large proportion of workers in this study reported smoking, exceeding the national adult smoking prevalence of 19.5% [55]. The significant association observed for smoking suggests the role of modifiable behavioural risk factors in WRMSD, potentially mediated through physiological mechanisms such as inflammation or as a proxy for psychosocial stress. A combination of psychosocial, occupational, and cultural factors often drives these findings. Smoking contributes to systemic inflammation and musculoskeletal vulnerability, supported by prior studies as a contributor to musculoskeletal degeneration. Smoking may serve as a coping mechanism to manage work-related stress, fatigue, and monotony. Nicotine provides short-term stimulation and relaxation, offering temporary relief. Peer influence contributes to smoking behavior in the workplace, as smoke breaks often foster camaraderie and social bonding among workers. Moreover, nicotine dependence and limited awareness of cessation support further sustain this behavior. These reflect not only personal habits but also systemic gaps in workplace wellness promotions, and tobacco cessation policies [56–58].

Lack of statistical significance for education may reflect the homogeneity of job roles within the production setting, where exposure to ergonomic risk factors remains similar regardless of educational attainment. Although

higher education is generally associated with reduced WRMSD due to less physically demanding job roles, this trend may not apply to this study. In operational work settings, educational attainment does not translate into job role differentiation due to hiring policies. The exposure to manual work is consistent across education levels, which justifies the lack of a protective effect attributed to higher education [24,25]. Although musculoskeletal complaints generally increase with age due to cumulative biomechanical stress and degenerative changes, other factors may influence the slightly lower WRMSD prevalence among workers aged 46–55. Age alone may not act as a direct risk factor in this study, but it could interact with task type, physical demand, or job reassignment practices [17,20,21,23]. A plausible explanation is the healthy worker effect, where older workers with musculoskeletal conditions may have left the workforce or been reassigned to less physically demanding roles. The study's exclusion criteria and sample may have further contributed to selection bias. This could underestimate the actual burden of WRMSD in older age groups and mask the cumulative effects of long-term occupational exposure [59].

The study findings indicate that biomechanical exposures, particularly awkward and repetitive postures, are the dominant factors associated with WRMSD in this population. The magnitude of these associations suggests a strong relationship between physical ergonomic stressors and musculoskeletal outcomes, reinforcing the critical role of task design and posture in occupational health. However, given the cross-sectional design, the observed associations cannot be assumed to represent causal relationships. Tasks like stripping and packing often involve sustained shoulder abduction, wrist flexion, and trunk leaning positions that increase static loading, reduce perfusion, and promote microtrauma. The high odds ratios observed suggest substantial cumulative strain resulting from limited rest or job variation, indicating gaps in ergonomic risk controls and rotation practices [60-64]. These effect sizes exceed those reported in other sectors, such as electronic waste handling [62], suggesting that glove manufacturing may entail greater biomechanical load due to minimal task variation and intense production demands with no job control.

Locally, awkward postures in Malaysian kitchens [63] and medical product manufacturing [52] were associated with WRMSD. The consistency in findings across sectors reinforces posture as a risk factor, suggesting potential shortcomings in task design, workstation layout, or enforcement of ergonomic standards within glove manufacturing settings. Poor posture can lead to musculoskeletal stiffness and compression, causing widespread pain and discomfort. Body posture influences force generation, and movements such as bending, twisting, or awkward positioning of the shoulders and wrists increase stress on joints, muscles, and nerves, leading to fatigue and potential injury. Malaysian ergonomic guidelines [4], classify tasks involving over 1 h of continuous repetition or more than 3 h per shift as high-risk. Similarly, awkward postures held for over 2 h continuously or cumulatively per shift also increased risk. Although this study lacked precise task frequency data, the high prevalence of WRMSD strongly suggests that repetitive and awkward strain over long shifts is a primary contributing factor. Untrained individuals may lack the necessary knowledge and skills to implement preventive measures against occupational musculoskeletal disorders, resulting in poor adherence to established protocols and unsafe work practices.

The study utilized secondary data sources, and variables related to work organisation such as break schedules and job rotation practices were not captured in the dataset. Therefore, no direct analysis of breaks or job rotation could be carried out. Yet, evidence-based strategies, including participatory ergonomics training and scheduled micro-breaks, have been shown to reduce WRMSD risk and support musculoskeletal recovery. Regular implementation represents a cost-effective preventive approach in high-risk industrial settings [18,19,57,65]. Prolonged task duration and mental health were associated with WRMSD reflecting the combined impact of physical and psychological strain on musculoskeletal outcomes. Workplace stress & anxiety arises from a mismatch between job demands and a worker's ability to cope, often exacerbated by factors such as high workload, monotonous tasks, lack of control, poor communication, and inadequate support from supervisors, which may cause job dissatisfaction, mental fatigue and vulnerability to WRMSD [32,66]. Job strain is associated with the WRMSD by increasing muscle tension, fatigue, and lowering pain thresholds with systemic health adverse condition, thereby amplifying the physical impact of poor ergonomic conditions without adequate rest in the sector [3,60,67–70]. WRMSD is also associated with muscle tension resulting from stress, reinforcing the interventions that address both physical and mental health dimensions in occupational settings [61,64,67]. Constant firing of low-threshold motor units triggered by both physical and mental aspects can lead to muscle fatigue even under low physical demands. Stress-induced alterations in the nervous and endocrine systems continuously affect the body's internal environment and adaptive mechanisms. Additionally, central nervous system responses may heighten pain perception, increasing WRMSD prevalence [68]. Psychosocial factors, such as co-worker support, may buffer these effects and reduce symptom severity.

Although ergonomic risk levels were not statistically significant, extended task exposure likely indicates cumulative biomechanical loading and inadequate recovery time, which aligns with established musculoskeletal disorder model and supported by findings from other sectors [21,35,64]. Promoting work-life balance has been recommended as a preventive approach to reduce musculoskeletal discomfort in glove industrial settings.

Psychological and organisational factors interact with physical exposures, emphasising the need for integrated ergonomic and mental health strategies in prevention efforts [13,67,70,71].

Despite high REBA scores indicating elevated ergonomic risk, no statistically significant association was found with WRMSD. This may reflect limitations in REBA's snapshot-based assessment, which lacks consideration of cumulative exposure, task duration, and repetition. The multifactorial nature of WRMSD shaped by recovery time, task variety, and individual resilience, may make REBA alone insufficient. Complementary tools like the Ovako Working Posture Analysis System (OWAS) are recommended for a more comprehensive risk evaluation [72,73]. Even though the overall sample size was large, the wide confidence intervals observed likely resulted from sparse data within specific subgroups, such as years of experience, age and ethnicity. Additionally, inherent variability in ergonomic exposures, biological characteristics, and mental health status may contribute to reduced statistical precision in the multivariable-adjusted models [74,75].

Our findings are consistent with previous studies in identifying ergonomic and psychosocial factors as key contributors to WRMSD, while aligning with Panteia/VHP/IKei Work-Related MSD Theoretical Framework as in Appendix A1, demonstrating how structural, ergonomic, and psychosocial factors contribute to health inequities and economic strain in the glove manufacturing. However, the magnitude of association observed for ergonomic postures in this study was notably higher compared to most previous studies. Overall, while the findings support the broader evidence base on WRMSD, they also highlight industry-specific risk intensification, reinforcing the need for context-specific ergonomic interventions in glove manufacturing.

Given the significant associations identified between ergonomic risk factors and WRMSD, targeted, evidence-informed interventions are warranted at both organisational and regulatory levels. At the workplace level, manufacturing industries should prioritize ergonomic risk reduction through task redesign, including minimising awkward and repetitive postures, implementing mechanical aids, and introducing job rotation strategies to reduce prolonged exposure. Work process automation with technological advancement are another strategic and impactful innovations that can be carried out by the industries. Regular ergonomic training and awareness programs should be institutionalized to enhance workers' risk perception and safe work practices. The intervention shall be evaluated as part of the industrial safety and health officer's key performance indexes with periodical review. In addition, psychosocial risk management, including stress reduction initiatives and mental health support, should be integrated into occupational safety and health (OSH) programs, given the observed associations with stress and anxiety. From a regulatory perspective, enforcement agencies, such as the Department of Occupational Safety and Health Malaysia, should strengthen surveillance and compliance monitoring of ergonomic risk assessments, particularly in high-risk manufacturing sectors. Industry stakeholders and manufacturing groups should collaborate to develop sector-specific ergonomic guidelines aligned with national regulations, such as the Occupational Safety and Health Act 1994 and Employee Social Security Act 1969, to ensure consistent implementation of preventive measures. While these recommendations are grounded in the present findings, further longitudinal and intervention-based studies are needed to evaluate their effectiveness in reducing WRMSD burden.

The study's strengths included its large sample size and REBA, as a robust ergonomic risk assessment tool, which enhanced the accuracy and reliability of ergonomic risk evaluation. The triangulation of sociodemographic, occupational, mental health and ergonomics data offers a broader understanding of WRMSD risks. The use of secondary, cross-sectional data limited control over data collection and causal inference [76]. The exclusion of over 80% of available records for data incompleteness may have underestimated the true WRMSD prevalence and attenuated the effect size due to selection bias. A formal sensitivity analysis was not conducted, as the study primarily focused on estimating associations using a predefined multivariable logistic regression model based on available secondary data. However, model robustness was addressed through variable selection, adjustment for key confounders such as age, and assessment of model adequacy, including goodness-of-fit and collinearity diagnostics. While these steps support the stability of the findings, the absence of formal sensitivity analysis represents a methodological limitation.

Gender was considered as a potential confounder; however, it was not included in the final regression model to preserve model parsimony and to prioritize modifiable occupational and ergonomic risk factors. Additionally, the relatively homogeneous distribution of job roles across sexes in the production setting may have limited its confounding effect. On the other hand, nationality was not analysed as an independent predictor in the regression model, as the study prioritized modifiable occupational and ergonomic risk factors. Including nationality without adequately accounting for its underlying structural and occupational correlates may lead to residual confounding or misinterpretation. Therefore, the analysis focused on variables with direct relevance to workplace exposures. However, nationality may act as a proxy for differences in job roles, training access, and socio-cultural factors, and this warrants further investigation in future research. Another limitation was while the study able to identify repetitive exposure qualitatively through ergonomic assessment, it did not include detailed quantitative measures

of task repetition intensity or frequency. This limits the ability to assess dose–response relationships between repetition and WRMSD. In addition to that, regression analysis shall be considered to include gender. Future studies should incorporate direct observational methods or time-motion analysis to quantify repetition more precisely along with the objective anthropometric data and workstation measurements to better quantify mismatch and its contribution to WRMSD risk.

The disproportionately wide confidence intervals observed for the low and moderate REBA risk categories indicate limited statistical precision, likely due to sparse data within specific strata and potential overlap with posture-specific ergonomic variables included in the regression model. In addition, given the cross-sectional design and use of secondary data, it was not possible to ascertain whether workers in lower-risk categories had been reassigned from higher-risk tasks after developing WRMSD symptoms. Such reassignment may reflect a healthy worker survivor effect, whereby workers with reduced physical capacity are relocated to less physically demanding roles. This may have influenced the observed associations and should be considered when interpreting the findings.

The findings of this study can be effectively interpreted through the theoretical framework of work-related musculoskeletal disorders proposed by Panteia/VHP/IKei Work-Related MSD Theoretical Framework which conceptualizes WRMSD as a multifactorial outcome arising from the interaction between physical, organisational, and psychosocial factors within broader socio-economic and regulatory contexts.[26] In alignment with this framework, the present study demonstrates that biomechanical exposures, particularly awkward and repetitive postures, represent dominant physical risk factors contributing to WRMSD. Concurrently, the significant associations observed with stress and anxiety reinforce the role of psychosocial determinants, suggesting that mental strain may amplify physiological responses such as muscle tension and fatigue. Furthermore, organisational factors, including prolonged task duration and limited task variation, reflect systemic work design issues that contribute to cumulative exposure and inadequate recovery. These findings collectively support the theoretical premise that WRMSD cannot be attributed to isolated factors but rather emerge from the dynamic interaction of multiple risk domains. The framework therefore provides a robust explanatory lens for understanding the high prevalence of WRMSD observed in this study and underscores the necessity for integrated intervention strategies addressing physical ergonomics, work organisation, and psychosocial wellbeing.

5. Conclusions

The prevalence of WRMSD among the workers in glove manufacturing industry in Malaysia was 79.2%. Smoking, awkward posture, repetitive posture, task duration, stress and anxiety were significantly associated with WRMSD. WRMSD impair quality of life through chronic pain and psychological distress, while reducing work productivity and increasing absenteeism. The economic burden is significant, with Social Security Organisation of Malaysia (SOCSO) ranking WRMSD among the top occupational claims, leading to high compensation, long-term disability, and workforce attrition. This can threaten the sustainability of the glove manufacturing sector, which is a significant contributor to Malaysia's economy. Integrated coordination is crucial among Ministry of Health, Ministry of Human Resources, SOCSO and industry stakeholders in ensuring employee well-being with global industrial competitiveness by complying with ergonomics standards and supporting the Sustainable Development Goals (SDG 3 & 8). The results obtained from this pioneering study on prevalence of WRMSD in the glove manufacturing sector provided crucial information for implementation and prevention control where the employers are recommended to conduct manual handling training, redesign workstations, implement task rotation, micro-break schedules, workplace mental health programs, smoking cessation programs, rest breaks, and revise task durations on each shift. Although mental health status was significantly associated with WRMSD, caution is warranted in interpretation, as the study involved screening rather than diagnostic assessment of mental health conditions. These findings emphasise the need for integrated intervention strategies that combine ergonomic improvements with psychosocial risk management. From a policy and practice perspective, strengthening workplace ergonomics, enhancing worker training, and reinforcing regulatory compliance are essential to mitigate the burden of WRMSD. For future research, it is recommended that longitudinal studies be conducted for causal inferences and interventional studies on ergonomic management in the workplace.

Author Contributions

A.K.R.: conceptualization, methodology, formal analysis, investigation, data curation, writing the original draft preparation and visualization; R.K.S.: supervision, validation, methodology, writing, reviewing and editing; M.D.S.: data curation, investigation, resources, project administration, writing, reviewing and editing. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was conducted in accordance with established ethical standards and received ethical approval from the Universiti Malaya Research Ethics Committee (UMREC Non-Medical). The research protocol titled "Prevalence of Work-Related Musculoskeletal Disorders and Its Associated Ergonomic Risk Factors among Glove Manufacturing Industry Workers in Malaysia" was approved under reference number UM.TNC2/UMREC_3142. Ethical approval was granted on 21 December 2023 and is valid from December 2023 until December 2026. All procedures performed in this study were in accordance with the ethical standards of the institutional research committee.

Informed Consent Statement

Patient consent was waived due to the use of secondary, anonymized data obtained from glove manufacturing industries. The study did not involve direct interaction with participants, and all data were de-identified prior to analysis. Ethical approval was obtained from the Universiti Malaya Research Ethics Committee (UMREC), which approved the waiver of informed consent in accordance with applicable ethical guidelines and regulations.

Data Availability Statement

The data used in this study were obtained from glove manufacturing industries and included confidential and proprietary information, as well as de-identified human data. Due to privacy, ethical, and institutional restrictions, the datasets are not publicly available. However, anonymized data may be made available from the corresponding author upon reasonable request and with permission from the respective organizations, in accordance with applicable data protection regulations.

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Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

During the preparation of this work, the authors used ChatGPT solely for language refinement, including grammar correction and clarity improvement. The authors critically reviewed and revised all content and take full responsibility for the accuracy and integrity of the manuscript.

Appendix A

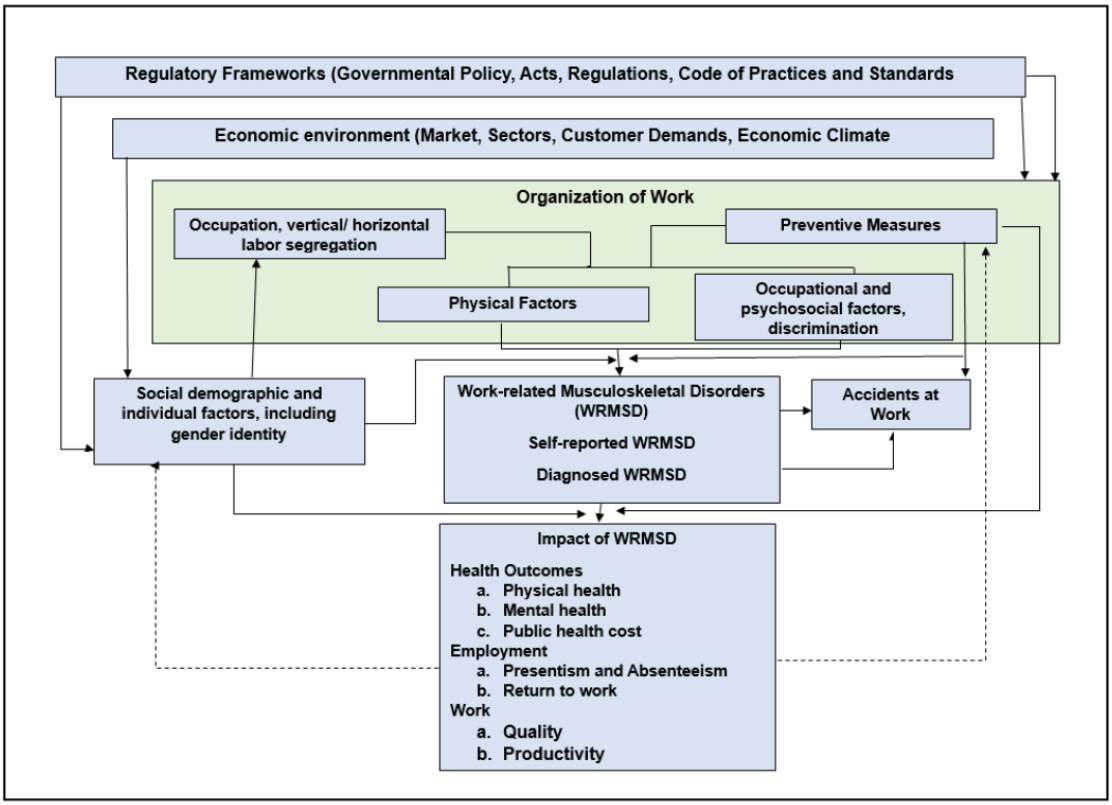

Figure A1. Panteia/VHP/IKei work-related MSD theoretical framework.

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