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# Prevalence and multivariate analysis of risk factors associated with musculoskeletal disorders among automotive assembly workers: a cross-sectional study

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## Abstract

**Background** Musculoskeletal disorders (MSDs) are a leading cause of occupational morbidity. This study investigates the prevalence and associated factors of MSDs across nine body regions among automotive parts assembly workers, considering demographic characteristics, mental workload, and Structured Multidisciplinary work Evaluation Tool (SMET) questionnaire components.

**Methods** The cross-sectional study included 211 workers (41.2% female; mean age  $33.9 \pm 6.9$  years). Demographic data, mental workload National Aeronautics and Space Administration-Task Load Index (NASA-TLX), and SMET questionnaire components (physical, environmental, and psychosocial demands) were collected. The Extended Nordic Musculoskeletal Questionnaire was used to assess MSD prevalence. Univariate and multivariate logistic regression analyses identified significant predictors.

**Results** The lifetime prevalence of MSDs was highest in the neck (44.5%) and lower back (44.1%), with the lowest rates in the elbow (6.8%) and hip/thigh (14.2%). Multivariate analyses revealed significant predictors of MSD prevalence. For neck disorders, male sex (OR = 0.361), smoking status (OR = 3.437), surgical history (OR = 2.800), total mental workload (OR = 1.032), and physical demand (OR = 1.396) were key contributors. Shoulder disorders were associated with smoking (OR = 2.542) and illness history (OR = 2.380), whereas upper back disorders were linked to illness history (OR = 3.287) and physical demand (OR = 1.663). Gender-specific vulnerabilities were evident in the hip/thigh and knee regions, with male gender being a significant predictor (hip/thigh: OR = 4.833; knee: OR = 2.711). Surgical history and psychosocial demands are critical factors for ankle/foot disorders.

**Conclusions** MSDs in assembly line workers result from the interaction of demographic, physical, and psychological factors.

**Keywords** Musculoskeletal disorders, Occupational health, Risk factors, Automotive workers, Ergonomics, Mental workload, SMET questionnaire, Logistic regression

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## Introduction

Work-related musculoskeletal disorders (WMSDs) represent one of the most pressing occupational health challenges worldwide. These disorders represent a considerable economic and social burden, prompting many countries to prioritize their prevention as a national imperative [1]. Industrialization and technological advancements in various sectors, including the assembly industry, have amplified occupational risk factors. These risks encompass physical, environmental, and psychosocial dimensions, each of which poses significant threats to workforce health [2].

Physical factors, such as awkward postures, manual material handling, repetitive motions, and high-speed work tasks [3, 4]; environmental factors, including inadequate lighting, noise, temperature, and vibration; and psychosocial factors, such as job stress, mental workload [5], low social support [6], job satisfaction, job security, and work demands [7], can individually or collectively contribute to the development of WMSDs [2]. While many interventions focus on mitigating a single category of these factors, addressing their interactive effects provides a more comprehensive and effective approach to risk management.

Several international studies have highlighted the prevalence and risk factors of WMSDs in automotive manufacturing settings. The automotive industry, particularly the assembly line sector, poses a significant risk for work-related musculoskeletal disorders (WMSDs) [8, 9], largely due to repetitive movements, awkward postures, and forceful exertions [10]. Recent longitudinal and cohort studies reinforce these findings across various contexts. For instance, Guerreiro et al. (2021) observed an increase in upper limb musculoskeletal symptoms among assembly line workers even after a 4-week job interruption [11]. Monaco et al. (2019) reported that higher biomechanical loads, assessed using the European Assembly Worksheet (EAWS), were associated with greater cumulative risk of work related upper limb disorders (WRULDs) [12]. Likewise, Assunção et al. (2021) found that short-term biomechanical exposures such as trunk flexion and shoulder elevation predicted increased pain in the neck, wrists, and shoulders over the course of a workweek [13]. Complementing these international findings, previous studies have highlighted specific risk factors in the automotive parts assembly sector that exacerbate WMSD risk. These include the high speed of production lines, limited time per task, heavy lifting, awkward postures, and exposure to chemical agents [14]. Such demanding occupational conditions further underscore why this sector is consistently classified as high-risk for WMSDs. Furthermore, a recent meta-analysis of 26 studies in the Chinese automotive manufacturing industry reported a 12-month WMSD prevalence of 53.1%, with the lower back being

the most affected region (36.5%), followed by the neck and shoulders (He et al., 2023). Similarly, Mishra et al. (2024) conducted a meta-analysis across various occupational groups in India and identified consistently high prevalence rates, particularly in the lower back, neck, and upper limbs. These findings provide further evidence of the global burden of MSDs in industrial sectors and reinforce the importance of examining these risks in assembly line workers [15, 16].

Accurate and holistic evaluation of occupational hazards requires advanced, multifactorial tools capable of simultaneously assessing diverse risk dimensions. The Structured Multidisciplinary Evaluation Tool (SMET) questionnaire provides a comprehensive framework by integrating physical, environmental, and psychosocial risk factors in occupational health assessment. The tool was originally developed by Haraldsson et al. in Sweden to support multidisciplinary ergonomic risk evaluations across diverse work environments [17].

Although numerous studies have investigated WMSDs in automotive manufacturing, most have examined physical, psychosocial, or environmental risk factors in isolation. There is a lack of integrated assessments that simultaneously capture the complex interplay between these dimensions in real-world industrial contexts. This is particularly true for assembly-line environments in low- and middle-income countries, where ergonomic interventions are often limited. By applying a structured, multidimensional approach through the validated SMET and NASA-TLX tools, the study aims to address this methodological gap and provide a more comprehensive understanding of MSD risk factors among automotive assembly workers.

Building on this framework, the present study analyzes the prevalence of musculoskeletal disorders (MSDs) among workers in the automotive parts assembly sector and examines their associations with demographic factors, mental workload dimensions, and SMET components. We hypothesize that (1) the neck and lower back will exhibit the highest prevalence of MSDs due to the physical demands of assembly work, (2) individual factors such as gender, smoking, and surgical history will significantly influence MSD prevalence, and (3) the combined effects of mental workload and SMET dimensions will provide a more nuanced understanding of MSD etiology. The findings aim to inform evidence-based recommendations for preventive and corrective measures to enhance worker safety and health.

## Materials and methods

### Study design

This descriptive-analytical cross-sectional study was conducted among workers in the automotive parts manufacturing and assembly industry located in the industrial

zone of Qom, Iran. Participants were employed in sections such as die-casting, pressing, machining, and assembling components such as mirrors, glass, lights, lighters, flashers, speakers, actuators, and wires. Eligible participants were between 15 and 55 years old, had a minimum of one year of work experience in their current role, and were actively involved in production-related tasks. Workers were excluded if they failed to provide sufficient data, refused to participate in interviews, were unable to complete physical evaluations due to specific conditions (e.g., amputations), or were employed in nonproduction roles (e.g., administrative or supervisory positions). A total of 211 workers from Barazesh Sanat Company were enrolled in the study out of 450 who met the inclusion criteria. The adequacy of this sample size was based on established guidelines for multivariate regression. According to Stevens (1996), a minimum of 15 participants is recommended per independent variable [18]. Since our final model included 14 independent variables, at least 210 participants were required. Therefore, the current sample size of 211 was deemed sufficient to ensure statistical power.

The recruitment process involved two phases. First, a field visit was conducted to observe production operations and identify relevant assembly sections. Supervisors provided workforce data, allowing the research team to determine the target population. Next, workers were screened through face-to-face interviews to ensure eligibility on the basis of the inclusion and exclusion criteria. This method ensured a comprehensive and accurate representation of workers in the selected industry. The study took place in a semi-industrial automotive assembly facility with limited ergonomic design. Workstations were non-personalized, and workers frequently rotated among different stations. Many tasks were performed while standing on hard stone floors, with limited seating and no adjustable worktable heights. In some stations (e.g., mirror or fog lamp assembly), no chairs were available at all. Workers reported long daily schedules—often up to 13 h away from home, including commute time. At the time of data collection, no formal ergonomic improvement program was in place.

The study protocol was approved by the Research Ethics Committee of the University of Social Welfare and Rehabilitation Sciences under the ethics code IR.USWR.REC.1400.178, with financial support provided by the same university.

### Assessment of exposures and outcomes

Demographic data, including age, sex, and work experience, were collected through a structured self-report questionnaire to provide a comprehensive profile of the participants. Since these variables were directly reported by participants, no additional standardized questionnaire

was required for their assessment. Additionally, physical activity was assessed through a single self-report item based on the World Health Organization (WHO) guidelines, asking participants whether they engage in regular physical activity (e.g., at least 150 min of moderate-intensity or 75 min of vigorous-intensity activity per week) [19]. This approach allowed for broad classification into physically active or inactive groups without the use of a standardized tool.

### Musculoskeletal disorders

The prevalence of MSDs was assessed using the Extended Nordic Musculoskeletal Questionnaire (NMQ-E), a widely recognized tool for evaluating musculoskeletal discomfort across nine body regions: the neck, shoulders, upper back, elbows, wrists, lower back, hips/thighs, knees, and ankles [20, 21]. While the full version of the NMQ-E collects information on symptom intensity, duration, and chronicity (acute vs. chronic), in this study we only analyzed binary (yes/no) responses related to symptom presence over four timeframes: lifetime, 12-month, 1-month, and point prevalence. The validated Persian version of the NMQ-E (NMQ-EP), translated and culturally adapted by Mokhtarinia et al. [21], was used in this study.

### Physical, environmental, and psychosocial risk factors

To comprehensively assess psychosocial risk factors, two validated tools were employed. The SMET was used to evaluate a broad range of physical, environmental, and psychosocial risks in the workplace. In addition, the NASA-TLX was specifically utilized to measure mental workload as a distinct component of psychosocial risk.

SMET was developed by Haraldsson et al., in Sweden [17] to identify workplace risk factors across three domains: physical, environmental, and psychosocial. This questionnaire provides a comprehensive assessment of workplace risk factors, facilitating targeted interventions to reduce occupational hazards and improve workplace safety. The full instrument consists of 30 items: physical workload (7 items), environmental workload (6 items), and psychosocial workload (10 items). In addition, each domain includes one item assessing the “highest perceived demand” within that domain, and three open-ended questions ask participants to describe the most strenuous aspects of their work. Overall job satisfaction is also assessed using a single-item Likert-scale question. Each item is rated on a 10-point numeric scale ranging from 0 (“desirable” workplace status) to 10 (“worst”). For each domain, a mean score was calculated and used in the analysis [22]. The Persian version of SMET was validated by Hosseini et al., demonstrating strong psychometric properties, including internal consistency and construct validity [23].

As part of the psychosocial risk assessment, mental workload was specifically evaluated using the NASA-TLX. This widely used multidimensional instrument assesses perceived cognitive workload across six subscales: mental demand, physical demand, and temporal demand (task-related), and performance, effort, and frustration [24, 25]. Each subscale is initially rated on a 21-point Likert-type scale (typically presented from 0 to 100 in 5-point increments). Participants first performed 15 pairwise comparisons among the six subscales to determine the relative importance of each dimension. The number of times a dimension was selected was used as its weight. Each subscale rating was then multiplied by its corresponding weight, and the sum of these products was divided by 15 to obtain the final workload score (range: 0–100) [26]. This tool provides a more detailed and focused evaluation of workload-related stressors than does the broader scope of the SMET. The Persian version of the NASA-TLX, validated by Mazloumi et al., demonstrated strong reliability with a Cronbach's alpha of 0.86 [27]. Incorporating the NASA-TLX into the psychosocial assessment allowed for a detailed evaluation of workload-related stressors among workers.

### Statistical analyses

All the statistical analyses were conducted via SPSS software version 16. Descriptive statistics, including frequencies (percentages) and means  $\pm$  standard deviations (SDs), were used to summarize the demographic and baseline data. The Kolmogorov–Smirnov test was applied to assess the normality of continuous variables. Binary logistic regression analysis was used to examine the associations between independent risk factors and the presence of MSDs in different body regions. Separate models were developed for each body region, with the dependent variable coded as 0 (absence of disorder) or 1 (presence of disorder). A backward elimination approach was used to identify significant predictors in the final models. A

p-value of less than 0.05 was considered statistically significant for all analyses.

## Results

### Descriptive results

The study included 211 participants, 87 of whom were women (41.2%). The average age of the participants was  $33.9 \pm 6.9$  years, and their mean work experience was  $3.92 \pm 4.1$  years. Anthropometric data revealed an average height of  $1.69 \pm 0.09$  m and a weight of  $72.9 \pm 15.67$  kg, resulting in a mean BMI of  $25.4 \pm 4.8$ , which was classified as overweight. Descriptive statistics for mental workload (NASA-TLX) revealed high effort levels ( $80.75 \pm 21.23$ ) and temporal demand ( $75.07 \pm 24.35$ ), whereas frustration was moderate ( $37.14 \pm 27.38$ ). The overall mental workload averaged  $68.24 \pm 12.57$ . For physical, environmental, and psychosocial demands, the mean scores from the SMET questionnaire were  $7.01 \pm 1.38$ ,  $3.85 \pm 1.53$ , and  $6.61 \pm 1.41$ , respectively.

### Prevalence of musculoskeletal disorders in nine body regions

The prevalence of MSDs was analyzed across nine body regions via the NMQ-E. The lifetime prevalence was highest in the neck (44.5%), lower back (44.1%), and shoulders (34.6%). The lowest lifetime prevalence was recorded in the elbows (6.2%) and hips/thighs (14.2%). The annual prevalence data revealed similar trends, with the lower back (41.2%) and neck (39.8%) regions being the most affected. The lowest rates were observed in the elbows (6.6%) and hips/thighs (13.8%). The point prevalence also revealed that the lower back had the highest percentage (39.3%), whereas the elbows (4.7%) and hips/thighs (12.3%) had the lowest percentage (Table 1).

To explore potential gender-based differences, Table 2 displays the prevalence of MSDs among male and female workers across all body regions and time frames. As illustrated in Table 2, female workers reported higher rates of MSDs in several regions, particularly the neck, hands/wrists, and knees, whereas male workers showed slightly higher prevalence in the lower back and elbows. This highlights the importance of considering gender-related ergonomic risks in preventive strategies.

### Factors associated with the prevalence of musculoskeletal disorders

#### Associations between demographic factors and MSD prevalence

Logistic regression analysis revealed significant relationships between demographic factors and MSD prevalence across body regions. The key predictors included sex, smoking status, surgical history, and physical activity. The detailed results, including odds ratios (ORs) and 95% confidence intervals (CIs), are presented in Table 3.

**Table 1** Prevalence of musculoskeletal disorders (MSDs) across nine body regions in the study sample ( $n = 211$ )

| Body region  | Lifetime prevalence (%) | Annual prevalence (%) | Monthly prevalence (%) | Point prevalence (%) |
|--------------|-------------------------|-----------------------|------------------------|----------------------|
| Neck         | 44.5                    | 39.8                  | 39.8                   | 38.4                 |
| Shoulders    | 34.6                    | 32.7                  | 32.7                   | 30.3                 |
| Upper Back   | 25.6                    | 23.7                  | 23.7                   | 23.2                 |
| Elbows       | 6.8                     | 6.6                   | 6.6                    | 4.7                  |
| Wrists/Hands | 30.8                    | 28.4                  | 28.4                   | 27.0                 |
| Lower Back   | 44.1                    | 41.2                  | 40.8                   | 39.3                 |
| Hips/Thighs  | 14.2                    | 13.8                  | 13.3                   | 12.3                 |
| Knees        | 31.8                    | 31.3                  | 30.8                   | 28.9                 |
| Ankles/Feet  | 30.8                    | 29.4                  | 28.9                   | 28.0                 |

**Table 2** Gender-specific prevalence of musculoskeletal disorders (MSDs) across nine body regions and four time frames ( $n = 211$ )

| Body region  | Gender | Lifetime prevalence (%) | Annual prevalence (%) | Monthly prevalence (%) | Point prevalence (%) |
|--------------|--------|-------------------------|-----------------------|------------------------|----------------------|
| Neck         | Female | 52.9                    | 43.7                  | 42.5                   | 42.5                 |
|              | Male   | 38.7                    | 37.1                  | 37.1                   | 35.5                 |
| Shoulders    | Female | 40.2                    | 35.6                  | 35.6                   | 34.5                 |
|              | Male   | 30.6                    | 30.6                  | 30.6                   | 27.4                 |
| Upper Back   | Female | 28.7                    | 25.3                  | 24.1                   | 24.1                 |
|              | Male   | 23.6                    | 22.6                  | 22.4                   | 22.2                 |
| Elbows       | Female | 5.7                     | 5.7                   | 5.7                    | 4.6                  |
|              | Male   | 7.5                     | 7.3                   | 7.3                    | 4.8                  |
| Wrists/Hands | Female | 47.1                    | 41.4                  | 41.4                   | 37.9                 |
|              | Male   | 19.4                    | 19.4                  | 19.4                   | 19.4                 |
| Lower Back   | Female | 43.7                    | 39.1                  | 39.1                   | 35.6                 |
|              | Male   | 44.4                    | 42.7                  | 41.9                   | 41.9                 |
| Hips/Thighs  | Female | 4.6                     | 3.4                   | 3.4                    | 3.4                  |
|              | Male   | 21.0                    | 20.5                  | 20.2                   | 18.5                 |
| Knees        | Female | 23.0                    | 21.7                  | 20.7                   | 20.7                 |
|              | Male   | 37.9                    | 37.1                  | 36.9                   | 34.7                 |
| Ankles/Feet  | Female | 32.2                    | 27.6                  | 26.4                   | 26.4                 |
|              | Male   | 31.2                    | 30.6                  | 30.6                   | 29.0                 |

**Table 3** Associations between demographic variables and MSD prevalence, including significant predictors for each body region

| Body region | Significant variables | P-value | OR    | 95% CI       |
|-------------|-----------------------|---------|-------|--------------|
| Neck        | Gender                | 0.042   | 0.563 | 0.323–0.980  |
|             | Smoking               | 0.012   | 3.401 | 1.307–8.845  |
|             | Surgical History      | 0.006   | 2.398 | 1.279–4.498  |
| Upper Back  | Smoking               | 0.066   | 2.510 | 0.942–6.692  |
|             | Illness History       | 0.016   | 3.036 | 1.230–7.493  |
| Elbow       | Marital Status        | 0.023   | 0.176 | 0.039–0.791  |
|             | Number of Children    | 0.036   | 0.389 | 0.161–0.940  |
| Hand/Wrist  | Gender                | 0.001   | 0.269 | 0.146–0.497  |
|             | Surgical History      | 0.001   | 4.106 | 2.137–7.834  |
| Hip/Thigh   | Gender                | 0.002   | 6.802 | 1.988–23.271 |
|             | Surgical History      | 0.029   | 2.726 | 1.110–6.692  |
| Knee        | Gender                | 0.008   | 2.772 | 1.309–5.871  |
|             | Age                   | 0.031   | 1.069 | 1.006–1.135  |
|             | Physical Activity     | 0.020   | 2.634 | 1.163–5.963  |
| Ankle/Foot  | Surgical History      | 0.005   | 2.539 | 1.317–4.898  |

**Table 4** Significant associations between NASA-TLX workload dimensions and MSD prevalence across body regions

| Body region | Significant variables | p-value | OR    | 95% CI      |
|-------------|-----------------------|---------|-------|-------------|
| Upper Back  | Mental Demand         | 0.025   | 0.977 | 0.957–0.997 |
| Hip/Thigh   | Physical Demand       | 0.002   | 1.056 | 1.020–1.093 |
| Knee        | Time Demand           | 0.022   | 1.028 | 1.004–1.053 |
| Ankle/Foot  | Performance           | 0.043   | 1.018 | 1.001–1.036 |
|             | Frustration           | 0.039   | 1.014 | 1.001–1.028 |
| Lower Back  | Frustration           | 0.012   | 1.016 | 1.004–1.029 |

**Associations between mental workload dimensions and MSD prevalence**

Significant associations were observed between mental workload dimensions (NASA-TLX) and MSD prevalence in several body regions. Notably, mental demand was

negatively associated with upper back disorders, physical and time demands significantly predicted disorders in hips/thighs and knees, and frustration was linked to lower back and ankle/foot disorders.

Detailed results of these associations are presented in Table 4.

**Associations between SMET dimensions and MSD prevalence**

SMET questionnaire analysis revealed significant associations between physical, psychosocial, and environmental demands and the prevalence of musculoskeletal disorders (MSDs) across body regions. Physical demand was the strongest predictor of MSDs in the neck, upper back, and knees. Psychosocial demand significantly influences MSDs in the hips/thighs and ankles/feet. The environmental demand showed an inverse relationship with the MSDs in the hands/wrists.

Detailed statistical results, including odds ratios (ORs) and 95% confidence intervals (CIs), are provided in Table 5.

**Final analysis of factors associated with Musculoskeletal Disorders (MSDs)**

The final multivariate logistic regression analysis identified independent predictors of MSDs across various body regions. Significant variables from prior univariate analyses were incorporated into a backward elimination model to isolate factors that independently influenced MSD prevalence ( $p < 0.05$ ). Independent variables with a  $p$ -value less than 0.20 in the univariate analyses were initially entered into the model. The backward elimination method based on the likelihood ratio test was used, and variables with  $p$ -values  $\geq 0.05$  were sequentially removed.

**Table 5** Associations between SMET dimensions and MSD prevalence, highlighting significant factors for different body regions

| SMET dimension       | Body region | p-value | OR    | 95% CI      |
|----------------------|-------------|---------|-------|-------------|
| Physical Demand      | Neck        | 0.015   | 1.301 | 1.053–1.607 |
|                      | Upper Back  | 0.001   | 1.553 | 1.192–2.023 |
|                      | Hip/Thigh   | 0.006   | 1.584 | 1.137–2.205 |
|                      | Knee        | 0.007   | 1.379 | 1.091–1.743 |
| Psychosocial Demand  | Hip/Thigh   | 0.005   | 1.580 | 1.151–2.168 |
|                      | Knee        | 0.032   | 1.266 | 1.020–1.571 |
|                      | Ankle/Foot  | 0.001   | 1.465 | 1.163–1.845 |
| Environmental Demand | Hand/Wrist  | 0.014   | 0.781 | 0.642–0.951 |
| Total Score SMET     | Upper Back  | 0.013   | 1.424 | 1.078–1.881 |
|                      | Hand/Wrist  | 0.030   | 0.760 | 0.596–0.974 |
|                      | Hip/Thigh   | 0.002   | 1.788 | 1.232–2.596 |
|                      | Knee        | 0.008   | 1.425 | 1.098–1.850 |
|                      | Ankle/Foot  | 0.009   | 1.422 | 1.093–1.850 |

Only predictors with  $p < 0.05$  remained in the final model. This integrative approach considers demographic variables, NASA-TLX workload dimensions, and SMET components, offering a comprehensive understanding of MSD determinants. The key results, including significant predictors for each body region, ORs, and 95% CIs, are summarized in Table 6. These findings provide critical insights for developing targeted prevention and intervention strategies to reduce MSD risk.

## Discussion

This study aimed to assess the prevalence and associated factors of MSDs across nine body regions among workers in the automotive parts assembly sector. By incorporating demographic characteristics, mental workload dimensions (NASA-TLX), and SMET questionnaire components, this research provides comprehensive insights into the multifactorial nature of MSDs and their occupational and individual determinants.

Our findings regarding the high prevalence of MSDs in the neck and lower back are consistent with previous research [15, 16, 28–30]. He et al. (2023) reported the lower back as the most commonly affected region among Chinese automotive workers, while Mishra et al. (2024) found a similarly high burden in the neck, shoulders, and upper limbs among various occupational groups in India [15, 16]. These patterns support the broader applicability of our results and emphasize the universal biomechanical challenges in industrial settings. In the etiological network of cervical and lower back musculoskeletal disorders (MSDs), the postural load plays a pivotal role [31, 32]. Sustained or awkward postures, which are common in workers in the automotive parts assembly sector, directly contribute to mechanical stress on the cervical and lumbar spine [33, 34]. This mechanical stress can result in microtrauma, muscle fatigue, and eventual degenerative changes, all of which increase the likelihood of MSDs. Moreover, the high prevalence of neck pain can also be attributed to repetitive tasks, fine motor control

**Table 6** Final multivariate logistic regression results for independent predictors of musculoskeletal disorders (MSDs) across nine body regions

| Body region | Significant variables         | p value | OR    | 95% CI       |
|-------------|-------------------------------|---------|-------|--------------|
| Neck        | Gender (Male*)                | 0.003   | 0.361 | 0.184–0.708  |
|             | Smoking                       | 0.016   | 3.437 | 1.261–9.369  |
|             | Surgical History              | 0.002   | 2.800 | 1.469–5.338  |
|             | Total Workload (NASA-TLX)     | 0.022   | 1.032 | 1.004–1.059  |
|             | Physical Demand (SMET)        | 0.013   | 1.396 | 1.074–1.815  |
| Shoulder    | Smoking                       | 0.047   | 2.542 | 1.013–6.378  |
|             | Illness History               | 0.035   | 2.380 | 1.062–5.334  |
| Upper Back  | Illness History               | 0.009   | 3.287 | 1.352–7.989  |
|             | Physical Demand (SMET)        | 0.001   | 1.663 | 1.235–2.239  |
| Elbow       | Marital Status (Single)       | 0.035   | 0.215 | 0.051–0.897  |
|             | Illness History               | 0.033   | 3.318 | 1.126–12.562 |
| Hand/Wrist  | Gender (Male)                 | 0.001   | 0.288 | 0.151–0.548  |
|             | Surgical History              | 0.001   | 4.091 | 2.137–7.834  |
| Hip/Thigh   | Gender (Male)                 | 0.008   | 4.833 | 1.522–13.493 |
|             | Surgical History              | 0.024   | 2.632 | 1.136–6.100  |
| Knee        | Gender (Male)                 | 0.004   | 2.711 | 1.376–5.342  |
|             | Age                           | 0.002   | 1.080 | 1.030–1.132  |
|             | Exercise History (Protective) | 0.018   | 0.634 | 0.185–0.856  |
| Ankle/Foot  | Surgical History              | 0.003   | 2.614 | 1.375–4.969  |
|             | Psychosocial Demand (SMET)    | 0.001   | 1.532 | 1.208–1.942  |

\*Gender was coded as 0 = Female (reference), 1 = Male."

demands, and static loading of the cervical region [35, 36], which are characteristic of assembly line work. These factors not only exacerbate biomechanical stress but also interfere with the recovery of cervical tissues, leading to chronic discomfort.

For the lower back, prolonged sitting or standing in fixed positions, combined with manual material handling tasks, heightens compressive forces on the lumbar spine [37, 38]. Poor ergonomics, such as inadequate workstation design, can further compound this issue by forcing workers into suboptimal postures [33]. These conditions are consistent with findings in the occupational health literature, which highlight postural strain and ergonomic inadequacies as major contributors to lumbar disorders [39, 40].

While the prevalence of MSDs in the knees and ankles/feet observed in our study may appear higher than in some prior research, several studies in automotive manufacturing have also reported notable involvement of lower extremities. For example, Nurhayati et al. (2014) found knee complaints in 15.8% and hip/thigh complaints in 14.5% of plastic part assemblers in Malaysian automotive plants [41]. These results indicate that lower limb symptoms, while sometimes underreported, are a relevant concern in repetitive industrial tasks. In our context, many workers experienced long working hours and were required to stand for extended periods—often on hard flooring due to workstation design and task requirements. These conditions are recognized risk factors for lower limb MSDs, particularly in the knees and feet. Similarly, the relatively high prevalence of wrist and hand symptoms aligns with existing literature. Repetitive manual tasks involving tool use, small hand movements, and forceful gripping are known to increase the risk of distal upper limb disorders. Previous findings in comparable environments confirm the relevance of these risk exposures in assembly-line settings [12, 13]. These data reinforce the need for targeted ergonomic assessments and localized interventions addressing both upper and lower body strain.

The initial univariate analyses highlighted the independent roles of demographic variables, mental workload dimensions, and SMET components in MSD prevalence. The sex differences were notable, with male workers showing a significantly lower risk for neck and hand/wrist disorders (e.g., 64% lower odds of neck MSDs compared to females) but a greater susceptibility to hip/thigh and knee disorders. These findings are consistent with prior research suggesting that biomechanical differences, hormonal factors, and task-specific exposures may influence susceptibility to MSDs [42, 43]. Smoking is a significant risk factor for neck and shoulder disorders, potentially because of its adverse effects on musculoskeletal tissues, including reduced oxygenation and delayed

healing [44–46]. Surgical history is strongly associated with MSDs in multiple regions [47], underscoring the long-term impact of surgical interventions on musculoskeletal health [43].

The analysis revealed statistically significant but relatively weak associations between mental workload dimensions and MSD prevalence across various body regions. For example, frustration was linked to lower back disorders (OR=1.016) and ankle/foot disorders (OR=1.014), and mental demand had a protective effect on upper back disorders (OR=0.977). These findings suggest that while mental workload dimensions contribute to MSDs, their individual effects are modest. These findings are consistent with previous research reporting modest associations between mental workload dimensions and MSDs [48–50]. For example, Habibi et al. (2015) reported that mental demand alone had limited predictive power for MSDs among nurses [48]. Similarly, Hoboubi (2018) reported that the effort and physical demand of NASA-TLX dimensions were significantly associated with MSD prevalence among workers of a steel company [49]. These examples highlight the multifaceted nature of MSDs, where mental workload dimensions act as contributing factors rather than primary determinants.

The SMET dimensions showed significant but varying associations with MSD prevalence across body regions. Physical demand was the strongest predictor, particularly in the neck, upper back, and knee regions, highlighting the influence of repetitive and high-strain tasks on musculoskeletal health. Similarly, psychosocial demand was linked to MSDs in the hip/thigh and ankle/foot, emphasizing the role of occupational stress in exacerbating physical strain. Interestingly, environmental demand exhibited a protective association with hand/wrist disorders, suggesting that optimized ergonomic conditions may mitigate risks in this area. The total SMET score was independently associated with multiple regions, reflecting the cumulative burden of these demands.

While univariate analyses identify individual risk factors, they may oversimplify the multifaceted nature of MSD development. The multivariate analysis revealed significant associations among demographic variables, mental workload dimensions, and SMET components in predicting MSD prevalence across various body regions. These findings emphasize the interdependent nature of MSD etiology and the necessity of integrated approaches to reduce occupational health risks effectively.

For neck MSDs, sex, smoking status, surgical history, total workload, and physical demand emerged as significant predictors. Male workers presented a lower risk (OR=0.361), potentially due to reduced exposure to heavy physical tasks, whereas smoking (OR=3.437) and surgical history (OR=2.800) increased vulnerability, reflecting their negative impact on musculoskeletal

health. Smoking contributes to reduced oxygenation and impaired healing, exacerbating susceptibility to strain-related injuries, whereas prior surgeries may alter cervical biomechanics, increasing the load on adjacent tissues. Additionally, nicotine has been shown to affect fibroblast function and collagen synthesis, potentially weakening connective tissue integrity [51]. In addition to its physiological effects, smoking may also reflect underlying psychosocial stress within the work environment [52]. Automotive assembly workers are frequently exposed to high time pressure, monotonous tasks, and limited autonomy, factors that are often associated with higher smoking rates as a coping strategy. This occupational context may help explain the relatively high prevalence of smoking observed in our sample and supports the need for integrated health promotion interventions targeting both physical and behavioral risk factors.

The total mental workload (OR=1.032) and physical demand (OR=1.396) highlighted the combined burden of cognitive and physical stressors in assembly tasks, necessitating ergonomic and behavioral interventions.

Shoulder MSDs were influenced by smoking (OR=2.542) and illness history (OR=2.380), indicating the combined effects of systemic health issues and repetitive strains. Similarly, illness history (OR=3.287) and physical demand (OR=1.663) were significant for upper back disorders, underscoring the impact of preexisting health conditions and high-intensity tasks.

In the elbow region, single marital status (OR=0.215) appeared protective, possibly reflecting variations in physical activity levels or task allocation among married and single individuals. Conversely, illness history (OR=3.318) increased susceptibility, suggesting that both social and health factors contribute to risk. For hand/wrist MSDs, male sex (OR=0.288) was associated with reduced risk, potentially due to differences in task distribution or physical strength demands, whereas surgical history (OR=4.091) significantly increased vulnerability. These findings highlight the need for ergonomic adjustments and tailored rehabilitation to address post-surgical risks.

Knee disorders were also associated with age (OR=1.080), reflecting age-related degenerative changes, whereas regular physical activity had a protective effect (OR=0.634), supporting its role in enhancing joint stability and muscular support. For hip/thigh and knee disorders, male sex emerged as a key predictor (hip/thigh: OR=4.833; knee: OR=2.711), reflecting sex-specific biomechanical vulnerabilities, particularly in weight-bearing joints. Surgical history (hip/thigh: OR=2.632; ankle/foot: OR=2.614) was another critical factor, highlighting the long-term impacts of medical interventions on joint health. Knee disorders were also associated with age (OR=1.080), reflecting age-related degenerative changes,

whereas regular physical activity had a protective effect (OR=0.634), supporting its role in enhancing joint stability and muscular support.

In the ankle/foot region, psychosocial demand (OR=1.532) demonstrated the interaction of physical and psychological stressors in physically demanding roles. Elevated psychosocial stress has been shown to exacerbate musculoskeletal strain by increasing muscle tension and reducing recovery capacity, emphasizing the need for holistic approaches addressing both mental and physical health in occupational settings.

The practical implications of our findings are noteworthy. In particular, several studies have explored predictive and intervention-based approaches to reduce WMSD risk. Falahati et al. (2019) used a fuzzy logic model incorporating fatigue, posture, and strain, demonstrating that modeling can improve risk prediction by integrating physical and psychosocial parameters [53]. Similarly, Kim et al. (2021) observed that long-term use of arm-support exoskeletons in automotive assembly settings may reduce neck and shoulder discomfort, especially during overhead tasks [54]. Additionally, Lowe et al. (2017) showed that implementing structured workplace exercise programs can mitigate shoulder disorders among assembly workers [55]. These examples support the potential for multi-pronged interventions—including risk modeling, ergonomic support devices, and worker training—to enhance musculoskeletal health in high-demand manufacturing environments.

### Limitations and recommendations for future research

This study has several limitations that should be acknowledged. First, its cross-sectional design restricts the ability to draw causal inferences, as exposures and outcomes were measured at a single point in time. Longitudinal studies incorporating repeated assessments are needed to establish temporal relationships and to capture fluctuations in symptoms and working conditions.

Second, although we used validated self-administered questionnaires (e.g., Nordic, NASA-TLX, SMET), the reliance on subjective reporting introduces potential recall and response biases. These biases may affect the accuracy of data related to musculoskeletal symptoms and workload. Future studies could benefit from the inclusion of objective measures such as wearable sensors, biomechanical analyses, and direct observational methods. Third, variability in environmental and ergonomic factors—such as temperature, noise levels, workstation design, and daily production demands—was not continuously monitored and may have influenced the participants' experiences and responses. Finally, our study population was drawn from a single occupational group within the automotive assembly industry. This limits the

generalizability of our findings to other job types and industrial settings. Expanding the research to include a more diverse workforce would enhance the applicability and external validity of the results.

## Conclusion

This study underscores the multifactorial and interdependent nature of MSDs in the workplace, highlighting the roles of demographic factors, mental workload dimensions, and physical, psychosocial, and environmental demands. Key findings reveal the significant impacts of smoking, surgical history, sex differences, and workload stressors on MSD incidence across different body regions. The interaction between physical and mental demands, as well as preexisting health conditions, emphasizes the necessity of integrated interventions that address both ergonomic and behavioral factors. These insights can inform occupational health policies by emphasizing the need for regular ergonomic assessments, targeted health promotion initiatives (e.g., smoking cessation and physical activity programs), and modifications to workstation design and task distribution. Employers and policymakers in manufacturing sectors should prioritize holistic strategies that incorporate both physical and psychosocial risk assessments to reduce MSD burden and improve worker well-being. Future research should focus on longitudinal analyses and include diverse occupational groups to enhance generalizability and support the development of sector-specific guidelines.

## Abbreviations

|          |                                           |
|----------|-------------------------------------------|
| MSDs     | Musculoskeletal disorders                 |
| WMDSs    | Work-related musculoskeletal disorders    |
| SMET     | Structured Multifactorial Evaluation Tool |
| NMQ-E    | Extended Nordic Questionnaire             |
| SMET     | Structured Multifactorial Evaluation Tool |
| NASA-TLX | NASA Task Load Index                      |
| SD       | Standard deviation                        |
| OR       | Odds ratio                                |
| CI       | Confidence interval                       |

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## Clinical trial number

Not applicable.

## Authors' contributions

All the authors contributed to the study conception, methodology and design. Material preparation and data collection were performed by HR. M and S.Z.JH. Data analysis was performed by HR.M., M.M. and M.V. The first draft of the manuscript was written by HR.M., S.Z.JH. and M.M. Review and editing were completed by all authors who contributed to subsequent manuscript versions and to the final draft. All the authors read and approved the final manuscript.

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## Data availability

The data that support the findings of this study are not openly available owing to information that could compromise the privacy of research participants and are available from the corresponding author upon reasonable request through his email: hrmokhtarinia@yahoo.com.

## Declarations

### Ethical approval and consent to participate

The study involving human participants was reviewed and approved by the Ethics Committee of the University of Social Welfare and Rehabilitation Sciences (code: IR.USWR.REC. 1400.178). Written informed consent was obtained from all the subjects and their legal guardians. All methods of assessment were performed in accordance with the relevant guidelines and published papers.

### Consent for publication

Not applicable.

### Competing interests

The authors declare no competing interests.

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