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Assessing Cumulative Musculoskeletal Strain in Automotive Mechanics: Insights from Real-World Occupational Analysis

Hadi Daneshmandi[1,*], Reyhane Sadeghian[2,1], Niloofar Rahgoshay[2], Nahideh Sartavi[2], Fardin Negahdari[2], Laleh Golkari[3]

[1]Research Center for Health Sciences, Institute of Health, Shiraz University of Medical Sciences, Shiraz, Iran
[2]Student Research Committee, Shiraz University of Medical Sciences, Shiraz, Iran
[3]Food Industries Educational Group, District 3, The Education Department, Shiraz, Iran

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Abstract

Background: *This cross-sectional study aims to assess cumulative loads affecting the lower back, shoulders, and distal upper extremities among automotive mechanics.* **Methods:** *The survey was conducted in automotive repair workshops in Shiraz, involving 157 independent mechanics selected through convenience sampling. Data were collected using a multiple-questionnaire including the Persian Cornell Musculoskeletal Discomfort Questionnaire (P-CMDQ), the Lifting Fatigue Failure Tool (LiFFT), the Shoulder Work Assessment Tool (SWAT), and the Distal Upper Extremity Tool (DUET). Descriptive statistics were used to assess musculoskeletal discomfort, and Partial correlation analyses, adjusted for age and Body Mass Index (BMI), examined the relationships between risk levels from LiFFT, SWAT, and DUET and discomfort reported in the P-CMDQ.* **Results:** *The results showed a high level of musculoskeletal discomfort, especially in the lower back, shoulders, and hands. Risk assessments indicated that the cumulative loads are in the high range for the lower back in 42.7% of cases, the shoulders in 40.8%, and the distal upper extremities in 36.3%. A strong correlation was observed between cumulative load on the lower back and perceived discomfort in this region (r = 0.730), whereas the correlations for the shoulders (r = 0.611) and distal upper extremities (r = 0.537) were moderate.* **Conclusions:** *The findings highlight the significant influence of workplace factors on the musculoskeletal health of automotive mechanics, emphasizing the importance of preventive measures and ergonomic solutions to enhance their health and productivity.*

1. Introduction

Modern industrialization has transformed how human needs are met through the widespread use of advanced machinery, equipment, and complex processes. Although this progress has led to significant economic and technological improvements, it has also posed considerable risks to workers. Industrial environments expose workers to a range of hazards, including physical, chemical, biological, mechanical, psychological, and ergonomic factors, all of which can significantly impact their health, safety, and overall well-being [1, 2]. Among these risks, work-related musculoskeletal disorders (WMSDs) have become a widespread problem across multiple industries, especially in the automotive sector [3, 4].

Musculoskeletal disorders (MSDs) encompass a broad range of conditions that affect the muscles,

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*Corresponding Author: Reyhane Sadeghian; E-mail: sadeghianreyhane1@gmail.com

joints, tendons, nerves, and bones, and may occasionally involve the circulatory system [5]. MSDs are marked by symptoms such as discomfort, numbness, pain, and limited mobility in the affected areas [6]. The severity of these conditions can vary significantly, ranging from mild, localized discomfort to severe injuries that require medical treatment and extended sick leave [7]. Common examples include lower back pain, neck strain, and carpal tunnel syndrome, all of which can significantly hinder a person's ability to perform daily activities and stay productive [8].

Research on WMSDs has been conducted across various industries, including studies involving hospital staff [9], dentists [10], and office workers [11]. However, studies specifically focusing on WMSDs in the automotive repair and maintenance sector have been limited [12]. In the automotive field, physical work often involves repetitive movements, lifting heavy objects, maintaining poor postures for extended periods, and performing tasks such as repetitive turns, prolonged bending, or excessive leaning [13, 14]. These activities lead to a high rate of MSDs, especially in the lower back, shoulders, wrists, and neck among vehicle mechanics [4]. Consequently, vehicle repair work is consistently ranked as one of the highest-risk jobs for WMSDs, with prevalence rates highlighting the urgent need for ergonomic improvements and better workplace practices [13, 15, 16].

Recent research underscores the high prevalence of WMSDs among workers in the automotive industry [12, 17, 18]. Zhang et al. (2023) found that 32% of automobile maintenance workers in their epidemiological study. 8% of workers experienced WMSDs. The most affected areas were the lower back (17.1%), neck (16.3%), and shoulders (14.5%) [12]. Likewise, Patel et al. (2023) reported that nearly 80% of car garage workers experienced work-related musculoskeletal pain, with the lower back being the most commonly affected site. The shoulder and neck were the second and third-most-affected regions, respectively. Additionally, many workers reported pain in multiple body parts, highlighting how widespread the problem is [19]. Further evidence comes from He et al. (2023), who conducted a systematic review and meta-analysis on the prevalence of WMSDs among workers in China's automobile manufacturing industry. Their findings revealed an overall prevalence of WMSDs of 53.1% (95% Confidence Interval [CI] = 46.3% to 59.9%), with the lower back and waist being the most affected areas (36.5%, 95% CI = 28.5% to 44.5%) [17].

Cumulative loads on the body are crucial in the development of MSDs. These loads result from repeated exposure to physical stressors, such as lifting, carrying, repetitive motions, and holding awkward postures, over time. Extended exposure to these stressors can cause tissue fatigue, microtrauma, and eventually chronic pain or injury in vulnerable areas such as the lower back, shoulders, and distal upper extremities. Assessing cumulative loads is crucial for understanding the long-term effects of work activities on the body and for developing effective interventions [6, 20, 21]. Tools like the Lifting Fatigue Failure Tool (LiFFT), Shoulder Work Assessment Tool (SWAT), and Distal Upper Extremity Tool (DUET) help evaluate these loads and identify high-risk tasks. By measuring cumulative exposure, employers can apply targeted ergonomic solutions to lower the risk of MSDs and support long-term musculoskeletal health [22-24]. These measures not only offset initial costs but also help reduce workers' compensation claims and healthcare expenses, benefiting both employees and the organization. Therefore, this study aimed to evaluate cumulative injuries impacting the lower back, shoulders, and distal upper extremities among automotive mechanics.

2. Methods

2.1. Study Design, Setting, and Population

This cross-sectional study was carried out in automotive repair workshops in Shiraz, focusing on automotive mechanics as the research population. The inclusion criteria for this study included male gender, willingness to participate, at least one year of work experience, no involvement in secondary employment, no history of musculoskeletal disorders (either chronic or acute) in any body region, no prior musculoskeletal surgeries, no use of medications related to musculoskeletal conditions, and no use of protective equipment aimed at reducing musculoskeletal disorders. The exclusion criterion was unwillingness to continue participation during the study. A total of 157 automotive mechanics were included in the study through convenience sampling. All participants were self-employed mechanics working in independent repair settings. The study received approval from the Ethics Committee of Shiraz University of Medical Sciences (Approval ID: IR.SUMS.SCHEANUT.REC.1403.044).

2.2. Data Gathering Tools

2.2.1. Demographic/Occupational Questionnaire

A questionnaire was used to gather demographic and occupational data, including details such as age (in years), height (in centimeters), weight (in kilograms), years of work experience, daily working hours, and marital status (single or married).

2.2.2. Persian Version of the Cornell Musculoskeletal Discomfort Questionnaire (P-CMDQ)

The Cornell questionnaire was initially developed by Hedge et al. in 1999 [25]. This questionnaire is designed to measure the frequency, severity, and interference with work ability related to the last working week. It evaluates 12 body regions. Additionally, this questionnaire has demonstrated validity and reliability in ergonomic assessments, with the psychometric properties of the Persian version evaluated by Afifeh-zadeh Kashani et al. [26]. We used a weighting system to better identify the most serious issues. The scoring method for the Frequency Score is as follows:

- Never = 0
- 1-2 Times/Week = 1.5
- 3-4 Times/Week = 3.5
- Every Day = 5
- Several Times Every Day = 10

These Frequency Scores are then multiplied by the Discomfort Score (ranging from 1 to 3) and the Interference Score (also ranging from 1 to 3). The final score ranges from 0 to 90.

2.2.3. The Lifting Fatigue Failure Tool (LiFFT)

This tool is used for risk assessment of manual material handling tasks. It is based on fatigue failure theory, which evaluates the cumulative damage to materials subjected to repeated stress. The LiFFT tool has been validated using two well-established epidemiological databases, demonstrating strong links with lower back disorders and back pain [24]. Its goal is to assess the accumulated load on the lower back during a workday. Using the LiFFT cumulative damage measure, it estimates the probability of a job being classified as high-risk, defined as having 12 or more injuries per 200,000 work hours [27]. To operate the LiFFT tool, three factors are needed for each lifting task: 1) the weight of the load, 2) the maximum horizontal distance from the hip joint to the load's center during lifting (measured with a tape measure), and 3) the number of repetitions of the task throughout the workday. For jobs involving multiple lifting tasks, the tool adds together the cumulative damage of each task to determine the overall risk.

2.2.4. The Shoulder Work Assessment Tool (SWAT)

The Shoulder Risk Assessment is designed to evaluate risks related to occupational tasks that involve stressful shoulder exertions. Based on fatigue failure theory, this tool estimates cumulative damage by analyzing shoulder moments and loading cycles. To use the tool, three pieces of information are required for each shoulder task: 1) the weight held or force exerted by the hands, 2) the maximum horizontal distance from the acromion (the flat bone at the top of the shoulder) to the center of the hand or load during the task (measured with a tape measure), and 3) the total number of repetitions performed throughout the workday. For tasks involving pushing forward or backward, the measuring tape should be held vertically. Load weight should be divided between the hands, either evenly or unevenly, as estimated by the analyst if one shoulder bears more load. When measuring lever arms for both shoulders, the maximum lever arm for each shoulder must be assessed, as it may occur at different times during the task. The tool can analyze single-task jobs, multi-task jobs by summing cumulative damage, or highly variable jobs using a binning procedure to group tasks by shoulder moments. The output indicates the probability of shoulder symptoms severe enough to require medical attention [22].

2.2.5. The Distal Upper Extremity Tool (DUET)

The DUET tool assesses risks associated with tasks involving the distal upper extremities, based on fatigue failure theory. Research provides substantial evidence that upper extremity disorders and other musculoskeletal disorders result from cumulative damage due to repetitive stress [28]. The DUET tool has been validated using a cross-sectional epidemiological database, showing strong associations with upper extremity outcomes. The tool's primary goal is to determine the cumulative upper extremity load experienced during a workday, calculating the probability of symptoms severe enough to prompt a first-time medical visit [23].

To use the DUET tool, two pieces of information are required for each task: 1) the intensity rating of the exertion, and 2) the number of task repetitions throughout the workday. Exertion intensity can be assessed subjectively by the worker using the 10-point RPE (OMNI-RES) scale, were workers rate effort, strain, discomfort, or fatigue [29], or by observers using descriptors from the Strain Index [30]. The tool can analyze mono-task jobs, multi-task jobs by summing cumulative damage, or highly variable jobs using a binning procedure to group tasks by exertion level, providing actionable insights for task redesign.

2.3. Implementation of the Study

Participants completed an informed consent form, a demographic and occupational questionnaire, and the P-CMDQ after being briefed on the study process. Following this, assessors collected and recorded data using the LiFFT, SWAT, and DUET tools. The collected information was then used to calculate the cumulative loads on the lower back, shoulders, and distal upper extremities of the mechanics, utilizing these tools.

2.4. Statistical Analysis

The data were analyzed using version 16 of the Statistical Package for the Social Sciences (SPSS) software. Descriptive statistics were calculated for the variables of interest. To evaluate the normality of the data, the Kolmogorov-Smirnov and Shapiro-Wilk tests were conducted, and the results indicated significant deviations from normality. Partial correlation analyses, adjusted for age and Body Mass Index (BMI), were employed to examine relationships between risk levels for the lower back, shoulders, and distal upper extremities, assessed with the LiFFT, SWAT, and DUET tools, and musculoskeletal discomfort reported through the P-CMDQ. A significance level of 5% ($\alpha = 0.05$) was used for all statistical analyses.

3. RESULTS

Table 1 provides an overview of the personal and occupational characteristics of the automotive mechanics participating in the study.

The frequency of WMSDs reported in the 12 months before the study is detailed below: 'every day' (14.6%), 'several times per week' (10.2%),

Table 1. Some personal and occupational details of the participants (n=157).

Quantitative variable	Mean ± SD†	Min–Max
Age (years)	34.03±8.64	20-60
Weight (kg)	79.05±10.63	59-120
Height (cm)	175.17±6.82	159-190
BMI* (kg.m^2)	25.75±2.99	18.21-34.89
Job experience (years)	11.58±9.12	1-30
Working hours per day	11.18±1.51	6-12
Qualitative variable	**No. (%)**	
Marital status		
Single	64 (40.8)	
Married	93 (59.2)	
Education level		
High school diploma or less	126 (80.3)	
Post-secondary education	31 (19.7)	

**Body Mass Index.*
†Standard Deviation.

'several times per month' (19.1%), 'several times per year' (18.5%), 'several times every few years' (12.7%), and 'only once' (24.8%) of participants. The duration of WMSDs during the 12 months leading up to the study is outlined as follows: '0 days' (26.1%), '7 days' (37%), '8-30 days' (16.6%), 'more than 30 days but not every day' (7%), and 'every day' (13%).

Table 2 shows the reported musculoskeletal discomfort in various body regions of automotive mechanics over the past week, as assessed by the P-CMDQ. The highest discomfort is found in the lower back, shoulders, and hands regions among the participants.

Table 3 presents the results obtained from the LiFFT, SWAT, and DUET tools, which analyzed the lower back, shoulders, and distal upper extremities. For a more detailed assessment, the results are categorized into three ranges: 0–33% (low), 34–66% (moderate), and 67–100% (high). As shown, the cumulative loads fall within the high range for the lower back in 42.7% of cases, the shoulders in 40.8% of cases, and the distal upper extremities in 36.3% of cases.

Table 2. Reported musculoskeletal discomfort according to the P-CMDQ (n=157).

Body region	**Mean ± SD**	**Min–Max**
Neck	34.3 ± 7.0	0-90
Shoulder	59.2 ± 8.7	0-90
Upper back	30.7 ± 8.1	0-90
Arm	27.7 ± 7.1	0-90
Lower back	66.0 ± 11.2	0-90
Forearm	23.1 ± 6.8	0-90
Hand	46.1 ± 7.0	0-90
Hip	25.3 ± 3.2	0-90
Thigh	23.7 ± 9.9	0-90
Knee	38.0 ± 9.7	0-90
Shank	20.3 ± 6.0	0-90
Foot	38.1 ± 7.0	0-90

Table 3. Risk levels for the lower back, shoulders, and distal upper extremities were assessed using the LiFFT, SWAT, and DUET tools (n=157).

	Low	**Moderate**	**High**
	No. (%)	**No. (%)**	**No. (%)**
Lower back	46 (29.3)	44 (28)	67 (42.7)
Shoulders	54 (34.4)	39 (24.8)	64 (40.8)
Distal upper extremities	56 (35.7)	44 (28)	57 (36.3)

Table 4. Partial correlations between risk levels for the lower back, shoulders, and distal upper extremities, assessed by the LiFFT, SWAT, and DUET tools, and musculoskeletal discomfort reported via the P-CMDQ (n=157).

	Discomfort in lower back	
	r	**p-value***
Cumulative load on the lower back	0.730	<0.001
	Discomfort in shoulders	
	r	**p-value***
Cumulative load on the shoulders	0.611	<0.001
	Discomfort in distal upper extremities	
	r	**p-value***
Cumulative load on the distal upper extremities	0.537	<0.001

**Partial correlation analyses, adjusted for age and Body Mass Index (BMI).*

Table 4 displays the Partial correlations between risk levels for the lower back, shoulders, and distal upper extremities, assessed using the LiFFT, SWAT, and DUET tools, and musculoskeletal discomfort reported through the P-CMDQ for 157 participants. A strong correlation was observed between cumulative load on the lower back and perceived discomfort in this region (r = 0.730), whereas the correlations for the shoulders (r = 0.611) and distal upper extremities (r = 0.537) were moderate. These findings suggest that elevated risk levels, as identified by the assessment tools, correspond to higher discomfort scores in the respective regions of the P-CMDQ [31].

4. Discussion

This study aimed to assess cumulative loads affecting the lower back, shoulders, and distal upper extremities among automotive mechanics. Musculoskeletal discomfort, reported through the

P-CMDQ, showed significant issues in these areas, with the lower back being the most affected, followed by the shoulders and hands. Risk assessments using the LiFFT, SWAT, and DUET tools indicated considerable occupational hazards. Specifically, 42.7% of participants had high-risk profiles for lower back disorders, suggesting their jobs are likely to cause 12 or more lower back injuries per 200,000 hours worked, as evaluated by the LiFFT tool [24,27], which has shown strong links to manual materials handling (MMH) and the Quick Exposure Check (QEC) technique [32]. Likewise, 40.8% of participants displayed elevated risk levels for shoulder disorders, implying a significant chance of developing shoulder symptoms severe enough to need medical attention, as calculated by the SWAT [22]. Additionally, 36.3% of participants exhibited high-risk profiles for distal upper extremity disorders, indicating a notable likelihood of symptoms in these areas requiring medical consultation, as assessed by the DUET tool [23]. Partial correlations, ranging from 0.537 to 0.730, were seen between the risk levels for all three regions and the corresponding P-CMDQ discomfort scores, confirming the effectiveness of LiFFT, SWAT, and DUET in identifying manual handling hazards [31]. These results underscore the importance of targeted ergonomic measures to reduce risks linked to these high-hazard tasks.

The high rate of WMSDs among automotive mechanics can be linked to interconnected factors. The physical requirements of the job, including repetitive tasks, awkward postures, and heavy lifting, accumulate loads that raise the risk of WMSDs in the lower back, shoulders, and distal upper extremities. During vehicle maintenance, mechanics often adopt non-neutral postures, such as bending or twisting while working underneath or beside a vehicle, which contribute to low back pain [13]. Personal traits, such as higher BMI and more years of job experience, also increase vulnerability to WMSDs [17]. The occurrence of WMSDs varies across different job roles, with risk rising when multiple factors occur simultaneously [12]. Importantly, vehicle repair workers without professional training are twice as likely to develop WMSDs compared to trained workers, highlighting the importance of proper training in injury prevention [33]. Figure 1 shows the main task categories, related physical demands, and their musculoskeletal impacts in automotive mechanics.

Recent studies have reported a high prevalence of WMSDs among vehicle repair workers, with an overall rate of 47.7% (95% CI, 42.7–53.2%). Lower

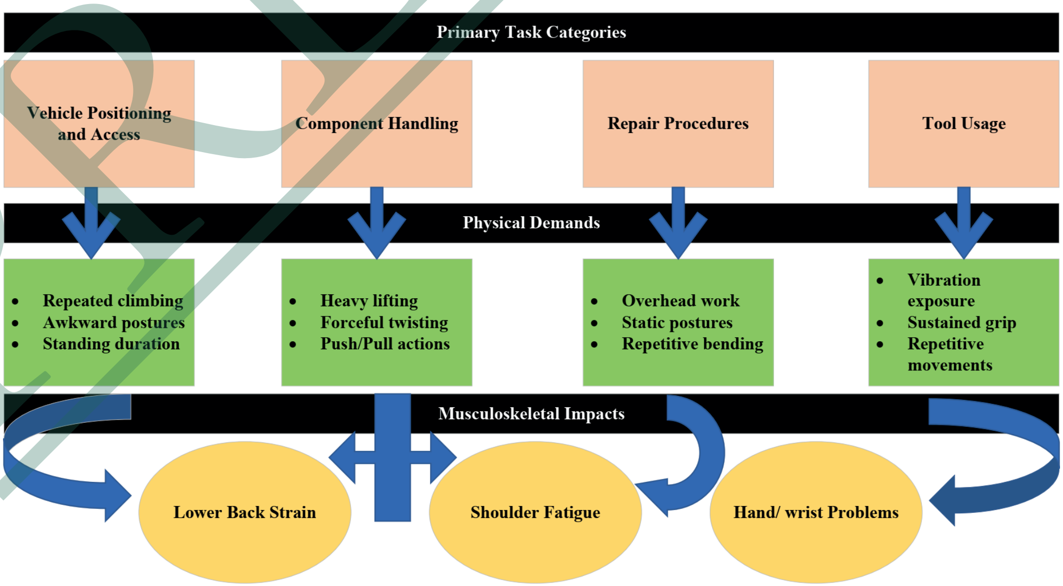

Figure 1: Primary task categories associated physical demands, and their musculoskeletal impacts in automotive mechanics.

back pain is the most common, affecting 62.8% of workers, followed by shoulder pain at 61% [18]. Abaraogu et al. reported a 76.02% prevalence of back pain, with 63.3% of individuals experiencing activity limitations [13]. He et al.'s meta-analysis confirmed that the lower back (36.5%), shoulders (31.4%), and wrist/hand (26.6%) are the most affected regions [17]. Zhang et al. reported similar patterns, with lower back (17.1%) and shoulder (14.5%) issues being prevalent [12]. WMSDs in these areas are linked to work absences [34]. Hernandez et al. found a mean Rapid Entire Body Assessment (REBA) technique score of 10.49 among truck mechanics, indicating very high risk [16]. Our study of 157 automotive mechanics confirms these findings, showing high-risk profiles for the lower back, shoulders, and distal upper extremities, emphasizing the need for ergonomic interventions.

4.1. Strengths and Limitations

The strengths of this study lie in its use of the LiFFT, SWAT, and DUET tools, which are specifically designed to quantify cumulative loads and risk levels of WMSDs in the lower back, shoulders, and distal upper extremities, respectively. These tools provide accurate risk assessments by incorporating specific inputs, such as load weight, distance, and task frequency for LiFFT and SWAT, and exertion intensity for DUET. Additionally, correlations between tool-assessed risk levels and P-CMDQ discomfort scores offer valuable insights into occupational hazards among automotive mechanics.

This study has several limitations. First, the sample only included male mechanics (n=157), which limits how well the results can be applied to female or mixed-gender groups and may overlook gender-specific risk factors. Second, the sample size might be too small to detect subtle trends in correlation analyses, and a larger sample could improve statistical power. Third, the subjective nature of the assessments—especially the reliance on self-reported data from tools like the P-CMDQ and DUET—may be prone to bias. Adding objective biomechanical measures in future research could improve validity. Finally, the study could not measure hand-arm vibration (HAV) exposure because of equipment limitations, which restricted the analysis of this potential WMSD risk factor.

4.2. Practical Strategies for Reducing WMSDs in Automotive Mechanics

The following recommendations aim to enhance workplace ergonomics and reduce musculoskeletal disorders among automotive mechanics. Ergonomic awareness and training: Mechanics should participate in training programs about ergonomics. Learning how to maintain proper body alignment, use tools effectively, and adopt safe lifting techniques can significantly decrease physical strain during daily tasks [33].

Use ergonomic tools: Mechanics should consider using specialized ergonomic tools and equipment designed to lessen physical effort. Tools that require less force, adjustable work surfaces, and lifting aids can help reduce strain on the back and shoulders.

Workstation adjustments: Employers should assess and improve workstations to make them ergonomically friendly. This includes adjusting the height and layout of work areas to reduce awkward postures and repetitive motions. Incorporate regular breaks: Mechanics should be encouraged to take short, frequent breaks during their shifts. These breaks allow for stretching and repositioning, helping to relieve muscle tension and prevent fatigue.

Strengthening and Flexibility Exercises: Establishing a routine that incorporates targeted strengthening and stretching exercises can greatly benefit mechanics by enhancing physical resilience, flexibility, and reducing musculoskeletal discomfort. Recent studies indicate that structured workplace stretching programs—especially when integrated into daily routines, such as during mid-shift or break times—can decrease fatigue and strain, improving worker well-being and performance [35, 36].

Monitoring Health: Regular health assessments focusing on musculoskeletal conditions can help identify issues early. Proactive monitoring enables prompt intervention, helping to prevent further problems and support overall well-being. Open Communication about Symptoms: Creating a culture where mechanics feel comfortable reporting discomfort or MSD symptoms without fear of repercussions is essential. Early reporting enables timely interventions and adjustments to work.

Prioritize Recovery and Rest: Mechanics should be encouraged to focus on proper rest and recovery, especially after demanding shifts involving heavy lifting or awkward postures. Adequate recovery time is vital for muscle repair and long-term health.

Job Rotation Opportunities: Implementing job rotation strategies within a comprehensive ergonomic program can help distribute physical demands and reduce localized musculoskeletal stress among mechanics. However, recent evidence suggests that job rotation alone might not be sufficient to lower musculoskeletal disorders, particularly when high-risk tasks are involved. In such cases, redesigning and improving high-risk tasks should be prioritized. Once overall risk levels decrease, job rotation can then more effectively help reduce physical overload and support worker health [37, 38]. Management Support: Management must recognize the risks associated with MSDs and actively support efforts to mitigate these risks. This includes investing in ergonomic solutions and emphasizing health and safety in workplace policies.

4.3. Recommendations for Future Studies

Future studies should involve larger and more diverse populations to improve the generalizability of the findings. It is recommended that upcoming research compare the sensitivity and validity of LiFTT, DUET, and SWAT across different workplace settings and task types. To reduce self-reporting bias and enhance measurement accuracy, using objective ergonomic assessment methods—such as motion capture systems and wearable sensors—is recommended. Additionally, future research could examine including hand-arm vibration (HAV) as a variable, analyzing its presence and potential role in musculoskeletal complaints. Ultimately, intervention-focused studies evaluating the effectiveness of ergonomic improvements and worker training programs could identify practical strategies to reduce the occurrence and severity of work-related musculoskeletal disorders in physically demanding jobs.

5. Conclusion

This study highlights a high prevalence of WMSDs among automotive mechanics, especially affecting the lower back, shoulders, and distal upper extremities. Using the P-CMDQ and standardized tools (LiFFT, SWAT, DUET), our results show that 42.7%, 40.8%, and 36.3% of participants face high risks for WMSDs in the lower back, shoulders, and distal upper extremities, respectively. These risks are mainly caused by workplace factors such as repetitive movements and awkward postures. The positive correlations between tool-assessed risks and P-CMDQ discomfort scores support the effectiveness of the tools in identifying manual handling hazards. These findings underscore the pressing need for ergonomic interventions and preventive measures to enhance the health and productivity of automotive mechanics.

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Declaration of Generative AI: During the preparation of this work the authors used ChatGPT 4 in order to improve readability, language, and grammar of some of the text in the submitted manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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