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Ergonomic interventions to improve musculoskeletal disorders among vehicle assembly workers: a one-year longitudinal study

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Abstract

Background Musculoskeletal disorders (MSDs) constitute a significant challenge in the realm of occupational health, especially in the manufacturing sector, necessitating the development of efficacious intervention strategies to enhance musculoskeletal health and reduce the incidence of MSDs. The present study is designed to assess the efficacy of a comprehensive ergonomic intervention, specifically tailored to diminish ergonomic risk factors and the prevalence of MSDs among workers engaged in vehicle assembly line operations.

Method This interventional study, conducted over a one-year period, was implemented among assembly line workers within a rail bound vehicle manufacturing shop. The study engaged 181 participants who were subjected to a comprehensive ergonomic intervention plan. This intervention encompassed an ergonomic training program, enhancements in auxiliary tool, and the distribution of an ergonomic educational brochure. Workstation ergonomics, including postures and movements, vibrations, and work stress, were evaluated using the Quick Exposure Check (QEC). Participants scored their postural exposure and the intensity, duration, and frequency of musculoskeletal symptoms at nine anatomical sites in the modified Nordic Musculoskeletal Questionnaire. All evaluations were conducted at baseline and after a one-year follow-up.

Results After the one-year intervention, the QEC scores for the neck, back, shoulders/arms, and wrists/hands decreased significantly ($p < 0.01$). The self-rated exposure scores for 22 awkward postures and repetitive movements were much lower than at baseline ($p < 0.05$). Moreover, the self-reported intensity, duration, and frequency of musculoskeletal symptoms in nine body areas all decreased significantly ($p < 0.05$).

Conclusions The findings from this prospective study indicated enhancements in ergonomic conditions and a reduction in musculoskeletal disorders (MSDs) among vehicle assembly workers following a comprehensive ergonomic intervention.

Keywords Occupational health, Ergonomics, Musculoskeletal disorders, Intervention, Work posture

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Introduction

Musculoskeletal disorders (MSDs) represent a major challenge in workplaces globally. Affecting approximately one-third of the worldwide population, MSDs are among the most significant contributors to occupational health issues, including sick leave, chronic disability, and diminished quality of life and work productivity [1, 2]. According to the Global Burden of Disease (GBD) Study, MSDs account for 17.53% of all years lived with disability (YLDs), making them one of the leading causes of disability globally [3]. Epidemiological studies in China further highlight this burden, showing a prevalence of MSDs ranging from 20.7% to 66.4% across various industries [4].

The vehicle manufacturing industry, characterized by high exposure to ergonomic risks such as repetitive movements, awkward postures, forceful exertion, and vibrations, is particularly vulnerable to MSDs. For instance, over half of the workers in this industry in Europe report work-related MSDs, resulting in significantly higher rates of absenteeism and decreased productivity compared to workers without MSDs [2]. Another two studies from the United States also showed the prevalence of upper extremity MSDs in vehicle manufacturing workers ranged from 41% to 58.9% [5, 6]. MSDs can also lead to significant declines in mental health, increased risk of developing other chronic health diseases, and increased all-cause mortality [7–10]. Furthermore, these disorders lead to high costs to enterprises and society [11]. The estimated total yearly cost of lost productivity attributable to MSDs is approximately 240 billion euros in the European Union, corresponding to up to 2% of the GDP [12].

Under the background of high disease burden of MSDs in occupational population, in addition to strengthening high-quality epidemiologic study and carrying out etiological mechanism research, targeted intervention and prevention methods are important means to reduce the occurrence of such diseases and promote the health of occupational population, and also one of the urgent problems to be solved at present. It is generally agreed that MSDs are of multifactorial origin, influenced by a complex interplay of individual characteristics, as well as physical and psychosocial risk factors [13, 14]. These factors may include age, gender, physical workload, repetitive movements, and workplace stress. For instance, repetitive tasks and prolonged static postures can lead to physical strain, while high job demands or low job control may exacerbate psychosocial stressors that contribute to musculoskeletal disorders [15, 16].

Therefore, an ideal ergonomic intervention program should address these multiple and interacting factors rather than focusing on a single factor. Previous research has demonstrated the potential effectiveness of ergonomic interventions in reducing the prevalence and severity of MSDs. Common strategies include workstation improvement, job rotation, and participatory ergonomics [17–19]. A study, for instance, revealed that a participatory ergonomic intervention reduced the likelihood of neck musculoskeletal complaints by 26% (hazard ratio = 0.74) and wrist complaints by 80% (hazard ratio = 0.20) among office workers [20].

Although these interventions are promising, many of the reported ergonomic interventions have been evaluated only over brief durations, typically ranging from a few weeks to several months, and are often limited to addressing a single ergonomic risk factor. The lack of a comprehensive, long-term approach is particularly problematic in industries with complex ergonomic challenges, such as automotive manufacturing. In China, the modern vehicle manufacturing industry, though relatively young, has experienced rapid growth since the turn of the twenty-first century. According to the latest estimates from China's National Bureau of Statistics, about 46.36 million people are employed in the manufacturing sector, of which 6.3 million are employed in automobile manufacturing, making up a large proportion of the country's manufacturing workforce [21]. Previous epidemiological investigations have shown that the prevalence of MSDs among workers in the vehicle manufacturing industry is high, and workers are exposed to risk factors, such as repetitions, forceful exertion, awkward posture, and vibration [22–24]. In view of this, there is clearly an urgent need for targeted ergonomic interventions in vehicle manufacturing industry. However, intervention studies in this field are still limited. For the automobile manufacturing industry with more obvious risk factors, there is a significant lack of comprehensive multi-component ergonomic interventions [25]. Moreover, for businesses in developing countries, cultural and economic considerations such as limited awareness of workplace ergonomics and constraints on financial resources to implement improvements add to the complexity of the problem.

In this study, a comprehensive ergonomic intervention strategy was carried out, encompassing the identification of ergonomic risk factors within a vehicle manufacturing facility and the subsequent formulation of an ergonomic intervention protocol. The primary objective of this research endeavor was to delineate and quantitatively assess the efficacy of this ergonomic intervention, with a particular focus on the reduction of ergonomic exposure and the mitigation of musculoskeletal symptoms.

Methods

Study design, setting and participants

This prospective study was conducted following an intervention plan, with the participants serving as their own controls. It was conducted among assembly workers in a vehicle manufacturing plant between June 2017 and October 2019. All procedures of this study were approved by the ethics committee of Peking University (IRB0000105218077). A cluster sampling method was used to select participants from an assembly workshop of a railway vehicle manufacturing plant in Changchun, China. This workshop involves tasks such as structural installations, wiring, and the mounting of components like seats, doors, and panels. This single workplace was chosen to ensure consistent working conditions, simplify follow-up challenges, and enhance collaboration with management when implementing the intervention. This plant represents a high-risk environment for MSDs, making it a suitable setting for ergonomic intervention.

All workers in the selected workshops who were eligible to participate gave their informed consent to take part in the survey. Workers who were aged over 18 years, and had worked in the present position for at least 1-year were recruited. Those who had been diagnosed with musculoskeletal system injuries, rheumatoid arthritis, tumors, tuberculosis, infections, autoimmune diseases, or other diseases affecting the musculoskeletal were excluded. Finally, 324 workers participated in this study at the baseline.

Data collection

Information on demographic characteristics (gender, age, job tenure, body mass index (BMI), educational level, physical exercise, smoking and drinking behavior), ergonomic factors (vibration, repetitive motions, postural and psychosocial factors), and musculoskeletal symptoms (symptom intensity, symptom duration, and symptom frequency) was obtained at baseline assessment between June 2017 and April 2018.

For ergonomic factors and musculoskeletal symptoms, we used validated tools such as the Rapid Upper Limb Assessment (RULA), Quick Exposure Check (QEC) and the revised Nordic Musculoskeletal Questionnaire (NMQ) [26, 27]. The NMQ was adapted to the Chinese context based on previous validation studies conducted by Dong et al. to ensure cultural and linguistic applicability [28].

After the baseline assessment, all participants received the ergonomic intervention (see details below) between September 2018 and October 2019. The follow-up assessment was performed at the end of the study, in average that was about a year after the start of the intervention.

Intervention

The procedure of creating and implementing the intervention included the following three phases.

Phase 1: ergonomic analysis and baseline assessment (June 2017-April 2018)

The purpose of the ergonomic analysis was to identify work-related risk factors. Firstly, ergonomists and the researchers visited the workplace to interview with managers and workers, and to conduct worksite observations. Information on materials and equipment used, auxiliary tools, workstations, protective equipment, job organization, work environment, and improvement needs were collected through one-on-one interviews with managers and workers. Information on work postures, movements of each body region (amplitude and frequency) and work cycles were observed using Quick Exposure Check (QEC) [27].

Secondly, the Ergonomic Checkpoint was applied by researchers to check and assess risks in the workplace and provide best practice recommendations for implementing effective improvements in the workplace [29]. The Ergonomic Checkpoint was jointly developed by the International Labour Office and the International Ergonomic Association to examine and assess workplace risks and provide best practice recommendations for implementing effective improvements in the workplace. It included 24 items covering material storage and handling, hand tools, workstation design, lighting, machine safety, hazardous substances and agents, and welfare facilities. Ergonomists and researchers performed the risk assessments, asked managers and workers whether each item needs improvement, and recorded their answers and comments. All items have three answers yes/no/priority, and each respondent can choose up to five priority items.

Finally, self-rated postural exposure was assessed using the revised Nordic Musculoskeletal Questionnaire, and workstation ergonomics, vibrations, and work stress were assessed by using the QEC with all participating workers [28].

Phase 2: formulation of the intervention program (May 2018-August 2018)

Based on the above ergonomic analysis and epidemiological investigation, the risk factors of MSDs among the vehicle assembly workers such as awkward postures, high mental stress, vibration, insufficient lighting, and inappropriate footstools, were identified and the comprehensive intervention program of "human-technology-organization" was formulated by the research team. Ergonomists were invited to evaluate the intervention program by scoring each intervention item, and the implementable intervention measures were selected through consultation with the managers.

The proposed interventions were consisted of four aspects, including i) workstation intervention; ii) environment changes; iii) management training; and iv) individual intervention. Considering the practicability of the interventions in the workshop site and the compliance of managers and workers, the interventions that were ultimately selected from proposed interventions included comprehensive ergonomic training, auxiliary tool improvements, and an ergonomic training brochure.

Phase 3: implementation of the intervention program (September 2018- October 2019)

The intervention program consisting of comprehensive ergonomic training, auxiliary tool improvements, and an ergonomic training brochure were implemented after consultation with the managers. The implementation plan for each intervention is as follows:

Comprehensive ergonomics training: Comprehensive training sessions were conducted quarterly over the one-year intervention period, with each session lasting approximately two hours. These sessions were led by professional ergonomists and researchers. The training covered basic principles of ergonomics, highlighted the impact of workplace design on musculoskeletal health, and identified key risk factors such as repetitive movements, awkward postures, and excessive exertion. Practical demonstrations focused on correct handling techniques, postural correction, and strategies to minimize awkward movements, while interactive exercises allowed workers to adjust workstation heights and practice ergonomically correct movements for specific assembly tasks.

The ergonomics training brochure: The brochures were distributed at the start of the intervention. They served as supplementary resources and provided an overview of MSDs with definitions, types, and symptoms. The brochures include easy-to-understand illustrations to highlight the ergonomic risks associated with the task, such as overhead extension, bending, and twisting. Besides, the brochures provide practical advice on reducing these risks, including micro-breaks, proper tool usage, and maintaining a neutral posture, and is accompanied by photographic illustrations showing correct and incorrect working postures, as well as suggested ergonomic adjustments.

Auxiliary tool improvement: Adjustable double-decker foot stools were provided to all participants as part of the intervention. These footstools are specifically designed for workers of different heights, reducing overhead for long periods of time. In addition, they allow for better alignment of posture during the task, thereby minimizing stress on the shoulders, neck, and lower back. Feedback from staff was collected regularly to ensure proper use and necessary improvements were made to improve usability.

Outcome measures

The self-administered musculoskeletal questionnaire was used to evaluate postural factors in the workplace. Postural factors in this questionnaire were composed of several items on each body region, which were modified from RULA [26]. More information regarding postural items is described in Table 2. The QEC was also used for ergonomic exposure assessment. It covers 16 questions, which are divided into two domains [27]. The first domain, including postures and movements performed by the cervical spine (neck), lumbar spine, shoulders and arms, wrists, and hands, was assessed by the evaluator. The second domain, including the amount of weight handled, the time necessary to perform a task, the level of exerted hand force, visual demand of the tasks, driving time at work, vibration, work pacing, and stress, was assessed by the worker.

Musculoskeletal symptoms

Most of the musculoskeletal symptom items were designed based on NMQ and have been translated and evaluated in our previous work [28]. The participants were asked if they experienced musculoskeletal symptoms such as ache, pain or discomfort during the past 12 months in a body map with nine body regions: neck, shoulders, upper back, low back, elbows, wrists/hands, hips/thighs, knees and ankles/feet. Furthermore, symptoms in the past 12 months were assessed by self-reported symptom duration (less than 1 day, 1–7 days, 8–30 days, more than 30 days), symptom frequency (1–2 times/year, 1–2 times/quarter, 1–2 times/month, 1–2 times/week, almost every day) and symptom intensity (0 to 10 Visual Analogue Scale, VAS) in each body part. Participants who suffered musculoskeletal symptoms such as discomfort, numbness, pain, or limitations of movement, for more than 24 h within the past 12 months, and whose symptoms did not alleviate after rest, were defined as cases [30].

Statistical analysis

EpiData 3.1 software (The EpiData Association, Odense, Denmark) was used for data entry, and the double-entry method was used to minimize data entry error. Descriptive statistics were performed with SPSS 21.0 (IBM, New York, NY, USA) to reveal the characteristics of participants by using count, percentage, mean with standard deviation (SD), and median with interquartile range

(IQR). The normality of distribution was determined by the Shapiro–Wilk test. The paired t test (for normally distributed data) and Wilcoxon signed rank test (for nonnormally distributed data) were used to evaluate the differences in the QEC scores before and after the intervention. The Wilcoxon signed rank test was used to evaluate the differences in the self-rated exposure scores of awkward postures before and after the intervention. The Chi-square ($\chi 2$) test and the Wilcoxon signed rank test was used to evaluate the differences in prevalence, intensity, duration and frequency of musculoskeletal symptoms before and after the intervention, respectively. A p-value < 0.05 was assessed as statistically significant.

Results

Participant flow and loss to follow-up

Figure 1 shows the participant flow through enrollment, intervention process, and data analysis of participants in this study. A cohort of 400 individuals was initially enrolled, and the sample size was reduced to 357 under the inclusion criteria. At the commencement of the study, 33 participants withdrew from the study at baseline. Over the course of the one-year intervention, 113 participants withdrew from the study due to job-related relocation and turnover, 11 participants withdrew due to musculoskeletal injury, 19 participants opted not to complete the questionnaire. Ultimately, a total of 181 participants adhered to the study protocol, completed and returned the follow-up questionnaire as stipulated.

Demographic characteristics of participants

Table 1 represents the demographic characteristics of participants, including the absolute number and percentage of participants in each demographic category who reported musculoskeletal symptoms at baseline. Among them, males constituted 93.4% of the population. The median age of participants was 30 years with an interquartile range of 26 to 33 years. The median tenure of participants was 8 years with an interquartile range of 4.6 to 11 years. The average level of BMI was 22.8 ± 3.6 kg/m^2. The majority of participants had an educational attainment below college level (91.2%). Approximately 62.0% of the participants reported infrequent or no engagement in physical exercise. About 26.0% and 45.0% of the participants had smoking and drinking behaviors, respectively.

Evaluation of intervention

Effect of intervention on ergonomic exposure

The exposure scores of awkward postures and repetitive movements before and after the intervention are described in Table 2. The results of the Wilcoxon signed rank test showed that the exposure scores of B1, B2, B8, B9, B10, B11, B12, B13, B14, B15, B16, B17, B18, B19, B20, B21, B22, B23, B24, B25, B26, and B28 were significantly lower after than before the intervention (p < 0.05).

Table 3 shows the means and SD, median and IQR relating to the QEC scores for participants before and after the intervention. The paired t-test revealed that the QEC scores of neck and shoulders/arms were all

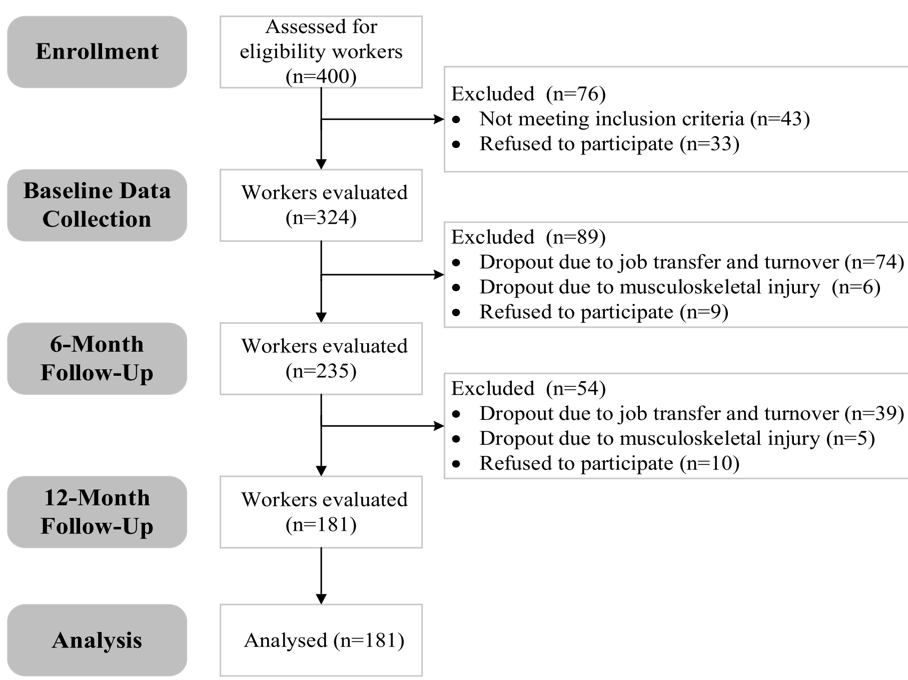

Fig. 1 The participant flow through enrollment, the intervention process, and the data analysis in this study

Table 1 Demographic characteristic of participants at baseline ($n = 181$)

Variables	n (%)	Number of MSDs case (%)
Gender		
Male	169 (93.4)	89 (52.7)
Female	12 (6.6)	7 (58.3)
Age (years)		
20–29	78 (43.1)	42 (53.8)
30–39	76 (42.0)	44 (57.9)
≥ 40	27 (14.9)	10 (37.0)
Job tenure (years)		
1–9	115 (63.5)	59 (51.3)
10–19	39 (21.5)	27 (69.2)
≥ 20	27 (14.9)	10 (37.0)
BMI (kg/m^2)		
18.5–23.9	98 (54.1)	48 (49.0)
< 18.5	18 (9.9)	10 (55.6)
24.0–27.9	52 (28.8)	29 (55.8)
≥ 28.0	13 (7.2)	9 (69.2)
Education		
Junior middle school or below	11 (6.1)	2 (18.2)
Senior high school	61 (33.7)	23 (37.7)
Junior college	93 (51.4)	61 (65.6)
Bachelor degree or above	16 (8.8)	10 (62.5)
Exercise		
Never	87 (48.0)	47 (54.0)
1–3 times/quarter	26 (14.4)	12 (46.2)
2–3 times/month	30 (16.6)	19 (63.3)
1–2 times/week	29 (16.0)	15 (51.7)
More than 3 times/week	9 (5.0)	3 (33.3)
Smoking		
No	134 (74.0)	69 (51.5)
Yes	47 (26.0)	27 (57.4)
Drinking		
No	100 (55.2)	48 (48.0)
Yes	81 (44.8)	48 (59.3)

significantly lower after than before the intervention ($p < 0.05$). The Wilcoxon signed rank test showed the QEC scores of back and wrists/hands were all significantly lower after than before the intervention ($p < 0.05$).

Effects of the intervention on musculoskeletal symptoms

The prevalence of musculoskeletal symptoms among the participants before and after the intervention is shown in Table 4. The χ^2 test showed that the decrease in the overall prevalence of musculoskeletal symptoms, which decreased from 53% at baseline to 37% after 12 months of the multifaceted ergonomic intervention, was significant ($p < 0.05$). Also, the prevalence of musculoskeletal symptoms in the neck, shoulders, low back, wrists/hands, knees, and ankles/feet was significantly lower after the intervention than before ($p < 0.05$).

The intensity, duration, and frequency of musculoskeletal symptoms of participants before and after the intervention are shown in Table 5. The results of the Wilcoxon signed rank test revealed that the VAS scores of nine body sites were significantly lower after the intervention than before ($p < 0.05$). The duration and frequency of musculoskeletal symptoms in nine body sites were significantly lower after the intervention than before ($p < 0.05$).

Discussion

This study is to evaluate the effectiveness of a multifaceted ergonomic intervention regarding the occurrence of musculoskeletal symptoms and the ergonomic load among vehicle assembly workers. The prevalence of MSDs among vehicle assembly workers in the present study was 53.0%, which was comparable to rates found in the same industry in other studies ranging from 41% to 58.9% [5, 6]. The previous result of related study showed that there were a series of problems to be solved in the vehicle manufacturing plants, such as insufficient or inappropriate footstools, workers exposed to awkward postures and high mental stress, and low ergonomic risk awareness, which were associated with MSDs [31]. Previous studies in other types of work have shown that ergonomic interventions such as improving workstations and workplaces, changing organization and management, or carrying out health education and training for workers may have a positive impact on preventing MSDs [32, 33]. Therefore, the implementation of a multifaceted intervention program is very necessary. The program was widely accepted and the workers were willing to participate. Dropouts, either prior to the start or while the program was being implemented, usually resulted from personal or random factors such as illness, accidental musculoskeletal injury, job transfer and turnover rather than lack of interest or disapproval.

The results of this study indicated that the multifaceted ergonomic intervention may have a beneficial effect on working postures and physical workload. Specifically, the QEC scores for key body regions, such as the neck, low back, and shoulders, showed statistically significant reductions, reflecting improved postural ergonomics. This may be related to participatory ergonomic training, targeted ergonomic intervention design, and application of auxiliary tools. These findings are in agreement with previous studies [34–36]. To cite but one example, Esmaeilzadeh et al. found a significant

Table 2 Comparison of self-reported exposure scores of awkward postures and movements before and after the intervention ($n = 181$)

Body Part [a]	Items	Pre-intervention		Post-intervention		Wilcoxon test
		Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	*p*
Neck	B1: Keeping head in a backward posture for a long time (> 1 min)	3.45 (1.30)	4.00 (2–5)	3.02 (1.22)	3.00 (2–4)	< 0.001***
	B2: Bending one's head backwards frequently (> 4 times/min)	3.27 (1.23)	3.00 (2–4)	3.05 (1.13)	3.00 (2–4)	0.020*
	B3: Keeping head twisted for a long time (> 1 min)	3.05 (1.21)	3.00 (2–4)	2.92 (1.11)	3.00 (2–4)	0.188
	B4: Twisting one's head frequently (> 4 times/min)	3.10 (1.18)	3.00 (2–4)	2.96 (1.08)	3.00 (2–4)	0.135
	B5: Keeping head in a forward posture for a long time (> 1 min)	3.24 (1.21)	3.00 (2–4)	3.25 (1.07)	3.00 (2–4)	0.922
	B6: Bending one's head forwards frequently (> 4 times/min)	3.28 (1.09)	3.00 (2–4)	3.18 (1.09)	3.00 (2–4)	0.239
	B7: Keeping head twisted sideways for a long time (> 1 min)	2.96 (1.19)	3.00 (2–4)	2.82 (1.04)	3.00 (2–4)	0.105
	B8: Twisting one's head sideways frequently (> 4 times/min)	3.07 (1.14)	3.00 (2–4)	2.87 (1.00)	3.00 (2–4)	0.025*
Back	B9: Bending one's trunk backward frequently (> 4 times/min)	3.06 (1.26)	3.00 (2–4)	2.85 (1.12)	3.00 (2–4)	0.022*
	B10: Keeping trunk in a backward posture for a long time (> 1 min)	3.02 (1.24)	3.00 (2–4)	2.83 (1.09)	3.00 (2–4)	0.038*
	B11: Bending one's trunk sideways frequently (> 4 times/min)	2.97 (1.25)	3.00 (2–4)	2.73 (1.12)	3.00 (2–4)	0.009**
	B12: Keeping trunk in a side bent posture for a long time (> 1 min)	3.01 (1.24)	3.00 (2–4)	2.80 (1.10)	3.00 (2–4)	0.024*
	B13: Bending one's trunk frequently (> 4 times/min)	3.26 (1.16)	3.00 (2–4)	2.99 (1.10)	3.00 (2–4)	0.005**
	B14: Keeping trunk in a bent posture for a long time (> 1 min)	3.28 (1.17)	3.00 (2–4)	3.09 (1.11)	3.00 (2–4)	0.045*
	B15: Twisting one's trunk frequently (> 4 times/min)	3.16 (1.16)	3.00 (2–4)	2.97 (1.04)	3.00 (2–4)	0.028*
	B16: Keeping trunk in a twisted posture for a long time (> 1 min)	3.19 (1.17)	3.00 (2–4)	2.91 (1.05)	3.00 (2–4)	0.002**
Arm	B17: Raising one's arms frequently (> 4 times/min)	3.61(1.27)	4.00 (2–5)	3.13 (1.17)	3.00 (2–4)	< 0.001***
	B18: Keeping arms up for a long time (> 1 min)	3.52 (1.30)	4.00 (2–5)	3.08 (1.12)	3.00 (2–4)	< 0.001***
	B19: Twisting one's arms frequently (> 4 times/min)	3.29 (1.16)	3.00 (2–4)	3.01 (1.10)	3.00 (2–4)	0.001**
	B20: Keeping arms in a twisted posture for a long time (> 1 min)	3.17(1.19)	3.00 (2–4)	2.93 (1.06)	3.00 (2–4)	0.004**
Elbow	B21: Bending one's elbows frequently (> 4 times/min)	3.39 (1.11)	3.00 (3–4)	3.15 (0.98)	3.00 (2–4)	0.005**
	B22: Keeping elbows in a bent posture for a long time (> 1 min)	3.44 (1.09)	4.00 (3–4)	3.20 (1.01)	3.00 (2–4)	0.003**
Wrist	B23: Bending one's wrists up/down frequently (> 4 times/min)	3.47 (1.10)	4.00 (3–4)	3.09 (1.00)	3.00 (2–4)	< 0.001***
	B24: Keeping wrists bent up/down for a long time (> 1 min)	3.44 (1.09)	4.00 (3–4)	3.14 (1.02)	3.00 (2–4)	< 0.001***
	B25: Twisting one's wrists frequently (> 4 times/min)	3.35 (1.09)	3.00 (3–4)	2.99 (1.01)	3.00 (2–4)	< 0.001***
	B26: Keeping wrists in a twisted posture for a long time (> 1 min)	3.29 (1.12)	3.00 (2–4)	2.99 (1.06)	3.00 (2–4)	< 0.001***
Foot	B27: Bending one's feet up/down frequently (> 4 times/min)	3.03 (1.14)	3.00 (2–4)	2.91 (1.09)	3.00 (2–4)	0.139
	B28: Keeping feet bent up/down for a long time (> 1 min)	3.12 (1.24)	3.00 (2–4)	2.91 (1.15)	3.00 (2–4)	0.017*

[a] The questions, modified from RULA, were used for the self-reported postural load of the Chinese Musculoskeletal Questionnaire (CMQ). The questions were rated on a 5-step scale: 1(never), 2 (seldom), 3 (sometimes), 4 (often), and 5 (always)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

improvement in the working postures among computer workers after a three-part intervention plan consisting of comprehensive ergonomic training, workstation evaluations, and an ergonomic training brochure [34]. In line with our findings but limited to single-component interventions, several studies showed an improvement in working postures and a significant decrease in the workload among workers after ergonomic training or auxiliary tool improvements [32, 33, 37]. Nevertheless, some research results showed that ergonomic training or auxiliary tool improvements alone was not enough to effectively reduce workload and prevent MSDs [20, 35]. Dropkin et al. reported no significant difference between the single workstation intervention and control group for RULA scores assessed specifically for the spine and lower extremities [20]. Robertson

Table 3 Comparison of Quick Exposure Check (QEC) scores before and after intervention ($n = 181$)

Items	Pre-intervention		Post-intervention		Paired-t/Wilcoxon
	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	*p*
Neck [a]	15.63 (2.17)	16.00 (14–18)	14.48 (2.10)	14.00 (14–16)	0.002**
Shoulders/Arms [a]	39.23 (8.42)	38.00 (32–46)	30.83 (4.66)	30.00 (26–34)	< 0.001***
Back [b]	28.83 (6.68)	30.00 (22–34)	25.63 (4.58)	22.00 (22–30)	0.001**
Wrists/Hands [b]	33.87 (7.74)	34.00 (28–34)	27.89 (5.39)	28.00 (22–30)	< 0.001***
Vibration [b]	1.52 (1.71)	1.00 (1–1)	1.40 (1.03)	1.00 (1–1)	0.577
Work pace [b]	2.85 (1.80)	4.00 (1–4)	2.56 (1.51)	4.00 (1–4)	0.256
Stress [b]	3.35 (2.64)	4.00 (1–4)	3.12 (1.38)	4.00 (1–4)	0.270

[a] The paired t-test

[b] The Wilcoxon signed-rank test

** $p < 0.01$, *** $p < 0.001$

Table 4 Comparison of prevalence of musculoskeletal symptoms before and after intervention ($n = 181$)

Items	Pre-intervention n (%)	Post-intervention n (%)	χ^2	*p*
Prevalence of musculoskeletal symptoms				
Total	96 (53.0)	67 (37.0)	9.386	0.002**
Neck	87 (48.1)	61 (33.7)	7.726	0.005**
Shoulders	80 (44.2)	59 (32.6)	5.150	0.023*
Upper back	72 (39.8)	56 (30.9)	3.094	0.079
Low back	79 (43.6)	55 (30.4)	6.825	0.009**
Elbows	46 (25.4)	38 (21.0)	0.992	0.319
Wrists/Hands	63 (34.8)	44 (24.3)	4.790	0.029*
Hips/Thighs	51 (28.2)	37 (20.4)	2.943	0.086
Knees	60 (33.1)	39 (21.5)	6.131	0.013*
Ankles/Feet	60 (33.1)	37 (20.4)	7.450	0.006**

* $p < 0.05$, ** $p < 0.01$

et al. found that awkward postures and RULA scores of office workers decreased significantly after implementing an office ergonomics intervention consisting of office ergonomics training and a highly adjustable chair, while the RULA scores of the training-only group or the control group did not decrease significantly [35].

The result of the active multifaceted ergonomic intervention was encouraging. After 12 months of the multifaceted ergonomic intervention, there were significant improvements in the prevalence, intensity, duration, and frequency of musculoskeletal symptoms among vehicle assembly workers in certain body sites. Similarly, Esmaeilzadeh et al. reported a decrease in the intensity, duration, and frequency of musculoskeletal symptoms after a comprehensive ergonomic intervention [34]. Consistent with our findings but limited to single-component interventions, some studies showed that the prevalence and intensity of musculoskeletal symptoms in certain body sites among workers were significantly decreased after ergonomic training or workstation design intervention [38, 39]. In contrast, Graves et al. found that single-component interventions such as auxiliary tool improvements have no significant effects on improving the musculoskeletal symptoms among office workers [40]. Alternatively, Amick et al. found that the combination of training with appropriate, adjustable office chairs is better in working postures and improving musculoskeletal symptoms than either training or adjustable equipment alone [41]. Roberston et al. reported a significant reduction in the prevalence and intensity of musculoskeletal symptoms among office workers in the workstation and training intervention group, while there was no significant reduction in the workstation intervention group [35]. Ergonomic interventions may be designed in different ways, and there may be difficulties in obtaining statistical power because of dropouts and other practical issues (such as worker cooperation and intervention quality control) in prospective studies at real workplaces. Also, the tailored approach in this study underscores the importance of industry-specific solutions, such as interactive training and practical tools, to address these challenges effectively.

To sum up, the multifaceted ergonomic intervention in this study may have a positive impact on improving working posture and musculoskeletal symptoms among vehicle assembly workers, which may be related to the following facts. The multifaceted intervention program including comprehensive ergonomic training, auxiliary tool improvements, and an ergonomic training brochure may improve workers' ergonomic awareness and adherence to correct working postures, and reduce awkward postures in the neck, back, arms, elbows, and wrists. Awkward or unnatural postures are thought to be risk factors for MSDs, which may place excessive force on

Table 5 Comparison of intensity, duration and frequency of musculoskeletal symptoms before and after intervention ($n = 181$)

Sites	Intensity of symptoms (0–10 points) [c]				Duration of symptoms (0–4 points) [d]				Frequency of symptoms (0–5 points) [e]			
	Pre-intervention	Post-intervention	Change [a]	p [b]	Pre-intervention	Post-intervention	Change [a]	p [b]	Pre-intervention	Post-intervention	Change [a]	p [b]
Neck	3 (2–4)	1 (0–3)	–1 (–3–0)	< 0.001***	2 (1–2.75)	1 (0–2)	–1 (–2–0)	< 0.001***	2 (1–4)	1 (0–3)	–1 (–2–0)	< 0.001***
Shoulders	3 (2–4)	2 (0–3)	–1 (–2–0)	< 0.001***	2 (1–3)	1 (0–2)	–1 (–2–0)	< 0.001***	2 (1–4)	1 (0–2.25)	–1 (–2–0)	< 0.001***
Upper back	3 (1–4)	2 (0–3)	–1 (–2–0)	0.001**	2 (1–2)	1 (0–2)	–1 (–1–0)	0.003**	2 (1–3)	1 (0–2)	–1 (–2–0)	0.001**
Low back	3 (2–5)	1 (0–4)	–1 (–3–0)	< 0.001***	2 (1–3)	1 (0–2)	–1 (–2–0)	< 0.001***	2 (1–3.25)	1 (0–2)	–1 (–2–0)	< 0.001***
Elbows	2 (1–4)	1 (0–3)	–1 (–2–0.25)	0.034*	2 (0–3)	1 (0–2)	–1 (–2–1)	0.002**	2 (0–3)	1 (0–2.25)	–1 (–2–1)	0.049*
Wrists/Hands	3 (1.75–4)	2 (0–3)	–1 (–3–0)	< 0.001***	2 (1–3)	1 (0–2)	–1 (–2–0)	0.001**	2 (1–3)	1 (0–2)	–1 (–2–0)	< 0.001***
Hips/Thighs	2 (1–4)	1 (0–3)	–1 (–2.5–0.5)	0.010*	2 (1–2.75)	1 (0–2)	–1 (–2–0.75)	0.008**	2 (1–3)	1 (0–2)	–1 (–2–0)	0.005**
Knees	2 (1–3)	1 (0–3)	–1 (–2–0)	0.004**	1 (1–2)	1 (0–2)	–1 (–1–0)	0.002**	2 (1–3)	1 (0–2)	–1 (–2–0)	< 0.001***
Ankles/Feet	2 (1–4)	1 (0–3)	–1 (–3- –1)	< 0.001***	2 (1–2)	1 (0–2)	–1 (–2–0)	< 0.001***	2 (1–3)	1 (0–2)	–1 (–2–0)	< 0.001***

[a] Change = Post-intervention – Pre-intervention

[b] The Wilcoxon signed-rank test

[c] Self-reported symptom intensity was rated on a 10-point scale (VAS scores, ranging from 0 to 10 points)

[d] Self-reported symptom duration was rated on a 4-step scale: 1 (less than 1 day), 2 (1–7 days), 3 (8–30 days), and 4 (more than 30 days)

[e] Self-reported symptom frequency was rated on a 5-step scale: 1 (1–2 times/year), 2 (1–2 times/quarter), 3 (1–2 times/month), 4 (1–2 times/week), and 5 (almost every day)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

joints and overload the muscles and tendons around the affected joint, and then lead to musculoskeletal discomfort [42–44].

Occasionally, the efficacy of the interventions gradually decreases and disappears after a long time. This may be unavoidable, particularly in implementations that are not reinforced [45]. In order to avoid the effect of ergonomic intervention fading over time, strict quality control was carried out for the intervention in this study. For example, the ergonomics training recurred every three months, the brochures were intensively studied once a month, and the use of adjustable footstools provided for workers was checked weekly under the supervision of the managers and researchers.

Limitations of this study must be kept in mind when considering the current results. Firstly, a key limitation of our study is the lack of a control group, a group of assembly workers who did not receive the multifaceted ergonomics intervention program. It is not possible to make strong causal inferences in the one-group pretest–posttest design without the control group, because in addition to the ergonomics intervention program, some changes between the pretest and posttest may lead to the improvements observed [46]. Therefore, this study may provide weak evidence in demonstrating that the positive effects observed in working posture, ergonomic load, and musculoskeletal symptoms were directly attributed to the ergonomics intervention program. The results of this study are consistent with similar studies that demonstrated the effectiveness of ergonomic intervention programs in reducing musculoskeletal symptoms and improving workplace ergonomics. However, due to the absence of a control group, the observed improvements cannot be definitively attributed to the ergonomics intervention program alone. Other factors, such as increased worker awareness or workplace environmental changes, may have contributed to the outcomes. There are also examples of longitudinal studies without interventions where the pain level stays relatively constant during a follow-up year [47]. A second limitation is that there may be a recall bias in using self-report questionnaires to evaluate musculoskeletal symptoms. More objective methods such as clinical examination and bioinstrumentation should be used in future research [48]. Finally, the participants were chosen from only one plant, and it is quite advisable to include more vehicle manufacturing plants to verify the results in future studies.

Despite these limitations, our study had a number of strengths. A major strength of this study was the design of a multifaceted intervention program based on ergonomic analysis instead of a single-component intervention. Another strength of the study was the involvement of a relatively large worker group. Additionally, the presence of different outcome measures such as the one-year follow-up of ergonomic exposure, workload, and MSDs after intervention better assessed the effect of the intervention.

Conclusions

The results indicated that a multifaceted intervention program consisting of comprehensive ergonomic training, auxiliary tool improvements, and an ergonomic training brochure, as the one implemented in this study may have a positive impact on ergonomic exposures as well as on MSDs. Although further randomized controlled intervention studies should be carried out in different vehicle manufacturing plants to confirm these prospective findings, this study can likely contribute to the prevention of MSDs and improve workers' health and overall productivity in the assembly industry.

The findings of this study underscore the critical role of task-specific, multifaceted ergonomic interventions in addressing the unique challenges faced by high-risk industrial workers. By reducing ergonomic risks and musculoskeletal symptoms, the intervention demonstrated significant health and productivity benefits, providing a replicable model for similar industrial settings. Furthermore, the improvements in worker health are likely to have broader organizational impacts, such as reduced absenteeism and enhanced operational efficiency, thereby highlighting the strategic importance of investing in ergonomic solutions. To build on the findings of this study, future interventions should integrate advanced workplace design principles. Dynamic workstations, allowing for height and angle adjustments tailored to specific tasks, could further minimize ergonomic risks. Task rotation mechanisms should be systematically implemented to distribute physical loads across different body parts, reducing the strain of repetitive tasks. Additionally, real-time feedback systems, such as wearable sensors, can provide workers with immediate corrections for poor posture, reinforcing training benefits. Lastly, incorporating psychosocial support programs and fostering organizational commitment to ergonomic interventions will ensure sustained worker health and productivity improvements.

Abbreviations

MSDs	Musculoskeletal disorders
QEC	Quick Exposure Check
YLDs	Years lived with disability
BMI	Body mass index
RULA	Rapid Upper Limb Assessment
NMQ	Nordic Musculoskeletal Questionnaire

Supplementary Information

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Supplementary Material 1.

Authors' contributions

X.J. Conceptualization, Methodology, Data collection, Formal anlysis, Writing an original draft. Y.D. Data curation, Methodology. L.Y. Data curation, Methodology. W.H. Data curation, Writing an original draft. L.C. Data curation, Writing an original draft. Z.Z. Methodology, Data collection. L.H. Validation, Conceptualization, Methodology, Supervision. All authors read and approved the final manuscript.

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Data availability

The data presented in this study are available on request from the corresponding author.

Declarations

Ethics approval and consent to participate

The study protocol adhered to the ethical standards of the Declaration of Helsinki and was approved by the ethics committee of Peking University, Beijing, China (ethical code: IRB0000105218077). Privacy was maintained for all collected data, and informed consent was obtained from all participants.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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