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Effects of Ergonomic Intervention on Musculoskeletal Complaints and Fatigue in the Abaca Banana Fibre Carpet Industry

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ABSTRACT

Traditional fibre-based craft industries contribute substantially to employment and community welfare, yet their highly manual production processes often expose workers to significant ergonomic hazards. In the Abaca banana fibre carpet industry, tasks such as fibre extraction, cleaning, drying, sorting, spinning, weaving, and finishing require repetitive movements, prolonged awkward postures, and sustained physical effort, thereby increasing the risk of musculoskeletal complaints and work-related fatigue. This study evaluated the effects of ergonomic intervention on musculoskeletal complaints and fatigue among workers in this industry. This intervention study included 152 workers selected through stratified random sampling and grouped according to the principal production stages. Ergonomic risk was evaluated using the Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA), musculoskeletal complaints were assessed using the Nordic Body Map (NBM), and fatigue was measured using the Borg Rating of Perceived Exertion scale. Assessments were performed one month before the intervention and repeated at follow-up after the intervention. At baseline, workers demonstrated moderate-to-high ergonomic risk, with mean RULA scores ranging from 4.6 to 4.9 and mean REBA scores ranging from 5.2 to 5.6. Musculoskeletal complaints and fatigue were also reported at moderate levels, with mean NBM scores ranging from 43.4 to 47.6 and mean Borg scores ranging from 10.9 to 11.2. Post-intervention analysis showed significant reductions in all outcome measures ($p < 0.05$), indicating improvements in ergonomic risk exposure, musculoskeletal complaints, and perceived fatigue across production stages. The findings suggest that ergonomic intervention is an effective approach for improving worker health in traditional craft-based industries. Integrating ergonomic measures into manual production systems may help reduce physical burden, enhance occupational well-being, and support sustainable productivity.

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1. Introduction

Traditional fibre-based craft industries continue to play a critical role in supporting employment, local economic development, and community welfare, particularly in developing regions. Despite ongoing technological advancement, many craft industries remain highly manual production processes because production processes rely heavily on manual skills, simple tools, and inherited work practices. One such industry is the Abaca banana fibre carpet craft industry, which utilizes natural abaca fibre (Musa textilis) to produce carpets and interior products with high economic and environmental value. While this industry persists due to product quality and sustainability, its production system places considerable physical demands on workers.

The production process of abaca fibre carpet involves multiple manual stages, including fibre extraction, cleaning and drying, sorting, manual spinning, weaving, and finishing. These activities require repetitive upper-limb movements, prolonged static or awkward postures, manual material handling, and sustained physical exertion over extended working hours. Similar to other traditional industries, work systems in abaca carpet production are often difficult to modify due to strong work culture, limited technological adoption, and priority allocation of output over worker comfort (Setiawan et al., 2025; Suarbawa et al., 2024; Jayawickrama et al., 2016). Consequently, workers are frequently exposed to high ergonomic risks, increasing their vulnerability to musculoskeletal complaints and work-related fatigue.

Musculoskeletal complaints remain among the most prevalent occupational health problems globally and are a leading cause of reduced work capacity and productivity loss. Recent studies consistently report that workers engaged in manual and repetitive tasks experience high prevalence of discomfort in the neck, shoulders, lower back, upper limbs, and lower extremities (Anwar et al., 2025; Setiawan, et al., 2025; Greggi et al., 2024; Velasco et al., 2020). Prolonged exposure to awkward postures, repetitive movements, and excessive physical workload has been strongly associated with the development of work-related musculoskeletal disorders (WMSDs), particularly in highly manual production processes and informal work sectors (Crandall et al., 2025; Setiawan et al., 2024).

Table 1 demonstrates that previous studies have primarily focused on musculoskeletal complaints or fatigue separately, with limited integration of both outcomes within an ergonomic intervention design. Studies using RULA and REBA have mainly examined postural risk and musculoskeletal complaints, whereas fatigue-related studies have generally not included standardized ergonomic risk assessment. Although some intervention studies reported improvements in musculoskeletal outcomes, evidence on the simultaneous effects of ergonomic intervention on ergonomic risk, musculoskeletal complaints, and fatigue remains scarce. This gap is particularly evident in traditional craft-based industries, including the Abaca fibre carpet sector.

In addition to musculoskeletal complaints, work-related fatigue represents a significant yet often underexplored occupational health outcome. Fatigue encompasses physical exhaustion, reduced motivation, impaired concentration, and decreased work performance. Evidence from recent occupational health studies indicates that sustained physical workload and repetitive manual tasks significantly increase both physical and mental fatigue, which may further exacerbate musculoskeletal symptoms and elevate injury risk (Alex et al., 2025; Nurdiyanti et al., 2025; Wu et al., 2024). The interaction between musculoskeletal complaints and fatigue creates a cumulative burden that threatens worker health and long-term work sustainability.

Ergonomic risk assessment provides a systematic approach to identifying and managing physical work hazards. Observational tools such as the Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) are widely used to evaluate postural and biomechanical risks associated with musculoskeletal complaints. These tools have demonstrated strong associations with reported musculoskeletal symptoms across various occupational settings (Kim & Cho, 2025; Scataglini et al., 2025). Complementary self-reported instruments, including the Nordic Body Map (NBM) and the Borg Rating of Perceived Exertion, are commonly used to assess musculoskeletal complaints and perceived work fatigue, respectively, providing valuable insight into workers' subjective health experiences. Over the past five years, many studies have investigated musculoskeletal complaints and fatigue in manufacturing, healthcare, and assembly-line work. However, evidence from traditional craft industries is still limited, and most studies are cross-sectional and focus on prevalence. Intervention research also rarely links objective ergonomic risk with subjective health outcomes, and few studies compare different production stages despite major differences in task demands (Valtonen et al., 2025; Haftu et al., 2023; Yang et al., 2022).

Table 1. Comparison of recent studies on Musculoskeletal complaints and work fatigue (2013-2025)

Author (Year)	Industry / Sector	Study Design	Ergonomic Tools	Outcome Variables	Intervention	Key Findings	Identified Gaps
Oestergaard et al.(2022); Gómez-Galán et al.(2020)	Manufacturing	Cross-sectional	RULA	MSDs	No	Awkward postures associated with MSDs	No fatigue analysis
Olorunsogo Tabiti et al. (2025); Greggi et al. (2024)	Mixed industries	Review	–	MSDs	No	Strong link between workload and MSDs	No intervention data
Hida et al. (2022); Kee (2022)	Assembly work	Observational	RULA, REBA	MSDs	No	High ergonomic risk predicts MSDs	No fatigue outcome
Stock et al. (2018); Sundstrup et al. (2013)	Manufacturing	Intervention	Mixed tools	MSDs	Yes	MSDs reduced after intervention	Fatigue not assessed
Ahmad et al. (2025); Rizkya et al.(2018)	Industrial work	Quasi-experimental	REBA	MSDs	Yes	Postural risk reduction achieved	No subjective fatigue
Setiawan et al. (2023); Rizkya et al. (2018)	Healthcare	Longitudinal	Questionnaire	Fatigue	No	Workload linked to fatigue	No ergonomic risk tools
This study (2025)	Abaca fibre carpet craft	Ergonomic intervention	RULA, REBA	MSDs, fatigue	Yes	Significant reduction in risk, MSDs, and fatigue	–

In the context of the Abaca banana fibre carpet craft industry, ergonomic research is particularly scarce. Existing literature has primarily focused on the socio-economic contributions of Abaca-based industries, with minimal attention given to workers' physical health and ergonomic risks. Given the manual and repetitive nature of production activities, workers are likely to face ergonomic challenges comparable to or exceeding those observed in other traditional industries. Without targeted ergonomic interventions, these risks may lead to persistent musculoskeletal complaints, chronic fatigue, reduced productivity, and diminished quality of life. Fig. 1 shows an unergonomic work posture on the production floor. Ergonomic intervention offers a practical and evidence-based strategy to address these challenges by integrating improvements in work methods, workstation design, tool modification, work–rest organization, and worker education. Recent intervention studies demonstrate that participatory and task-specific ergonomic interventions can significantly reduce ergonomic risk scores, musculoskeletal complaints, and fatigue when interventions are aligned with workers' actual needs and work culture (Krishnanmoorthy et al., 2025; Rosiani et al., 2025; Setiawan et al., 2024b). Nevertheless, empirical evidence supporting such interventions in traditional fibre-based craft industries remains insufficient.

Fig. 1. An unergonomic work posture on the production floor

Therefore, this study aimed to evaluate the effects of ergonomic intervention on musculoskeletal complaints and work-related fatigue among workers in the Abaca banana fibre carpet craft industry. Using a stratified random sampling approach, 152 workers were grouped according to major production stages to capture task-specific ergonomic exposure. By integrating RULA, REBA, NBM, and Borg scale assessments before and after ergonomic intervention, this study seeks to provide comprehensive evidence on the effectiveness of ergonomic intervention in reducing ergonomic risk, musculoskeletal complaints, and fatigue in a traditional craft industry setting. The novelty of this study lies in: (a) Its focus on a traditional fibre-based craft industry, a sector that remains underrepresented in ergonomic intervention research, (b) The integration of objective ergonomic risk assessment (RULA and REBA) with subjective health outcomes (NBM and Borg scale) within a single intervention framework, (c) The evaluation of intervention effects across distinct production stages, allowing identification of process-specific ergonomic challenges and (d) The simultaneous analysis of musculoskeletal complaints and work-related fatigue, addressing their interrelated impacts on worker health.

2. Method

2.1. Research Design

This study employed an ergonomic intervention design with a longitudinal pre-post evaluation in the Abaca banana fibre carpet craft industry. The research focused on manual production activities, including fibre extraction, cleaning and drying, sorting, manual spinning, weaving, and finishing, which were predominantly performed without mechanical assistance. These tasks involved repetitive movements, prolonged awkward postures, and sustained physical workload, making this setting appropriate for ergonomic intervention research. Workers generally performed production activities for approximately 7-8 hours per day, five to six days per week, without a structured job rotation system. Baseline assessment was conducted one month before the ergonomic intervention, followed by post-intervention evaluations at one month and eight months to examine both short-term and medium-term effects. This longitudinal approach is consistent with recent ergonomic intervention studies emphasizing the importance of repeated follow-up measurements to capture sustained changes in musculoskeletal complaints and fatigue (Leder et al., 2025; Setiawan, & Alfian, 2025). Screening questionnaires were used to identify musculoskeletal complaints and work fatigue, while video-based observations supported postural and task analyses (Rasoulivalajoozi et al., 2023).

2.2. Subjects and Sampling

The study population consisted of workers engaged in the Abaca banana fibre carpet craft industry. A stratified random sampling method was used to ensure proportional representation across the main production stages, recognising that each stage involved distinct task characteristics and physical demands. Based on these production stages, participants were divided into three groups: Group 1 (fibre extraction, cleaning, and drying), Group 2 (sorting and manual spinning), and Group 3 (weaving and finishing), as shown in Fig. 2. Fig. 2, study flowchart showing the study population, stratified random sampling, grouping by major production stages, baseline assessment, ergonomic intervention, and follow-up assessments at 1 and 8 months.

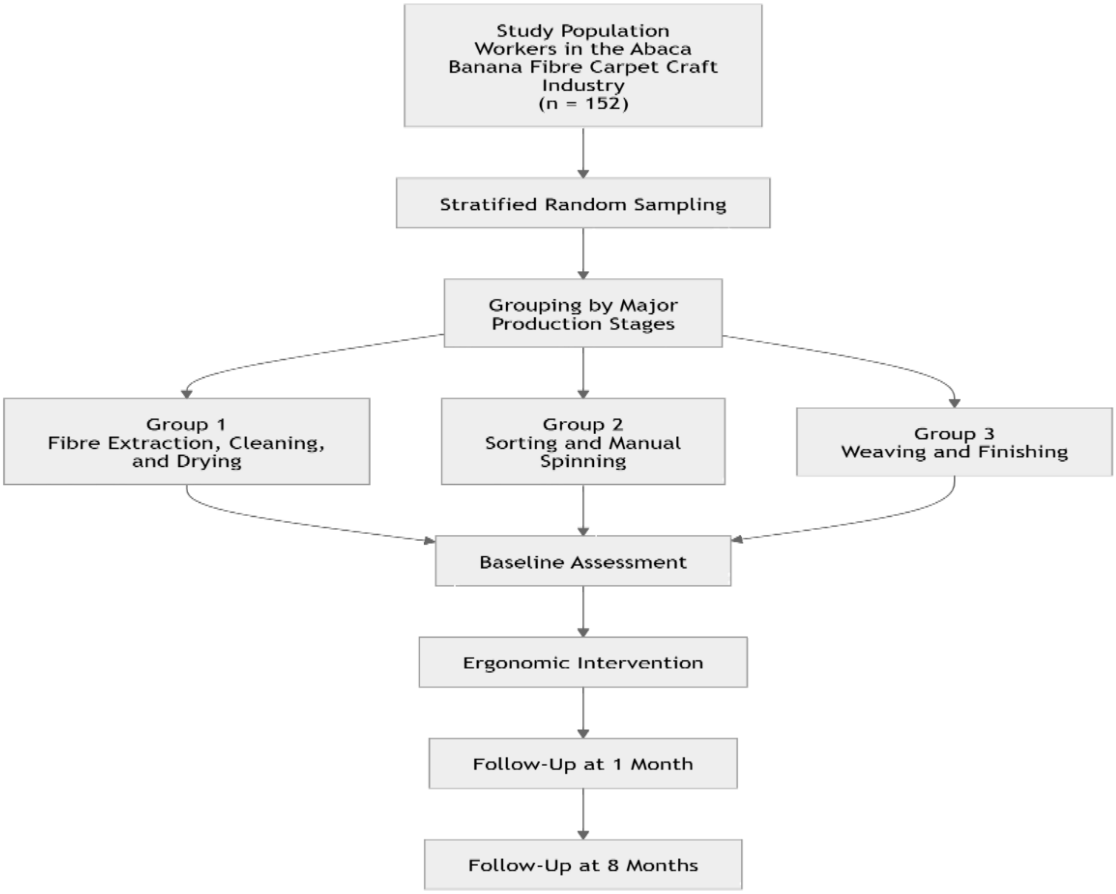

Fig. 2. Research design: group 1: fibre extraction, cleaning & drying, group 2: sorting & manual spinning, and group 3: weaving & finishing

Participants were recruited from the Abaca banana fibre carpet craft industry using stratified random sampling and were grouped according to the major production stages. Baseline assessment was conducted before the ergonomic intervention, followed by post-intervention follow-up at 1 month and 8 months. Based on inclusion criteria, 152 workers were selected and divided into three groups according to major production stages: (a) Group 1-fibre extraction, cleaning, and drying, (b) Group 2-sorting and manual spinning, and Group 3-weaving and finishing. The inclusion criteria were as follows: (1) presence of musculoskeletal complaints in at least 5-10 anatomical areas within the previous month, assessed using the NBM, (2) work experience of ≥5 years in the abaca carpet craft industry, (3) age range 20-45 years, (4) body mass index (BMI) within 18.5-25 kg/m^2, (5) physically and mentally healthy at the time of assessment, and (6) provision of written informed consent.

Workers with acute injuries, diagnosed musculoskeletal disorders unrelated to work, or chronic medical conditions affecting physical performance were excluded. Randomization success was examined by comparing baseline characteristics including age, body weight, height, work experience, blood pressure, and BMI across groups. The characteristics of participants at baseline are presented in Table 2, demonstrating comparability between groups.

Table 2. Baseline characteristics of workers by production-stage group in the Abaca banana fibre carpet craft industry

Variable	Group 1: Fibre extraction, cleaning & drying ($n = 51$)	Group 2: Sorting & manual spinning ($n = 50$)	Group 3: Weaving & finishing ($n = 51$)	p-value
Age (years), mean ± SD	32.7 ± 6.5	27.9 ± 6.0	33.1 ± 6.1	0.001
Body weight (kg), mean ± SD	58.2 ± 3.1	57.9 ± 3.4	58.8 ± 4.2	0.041
Height (cm), mean ± SD	162.1 ± 3.1	161.9 ± 7.8	158.5 ± 4.7	0.001
Work experience (years), mean ± SD	15.5 ± 5.2	14.1 ± 7.8	14.7 ± 4.6	0585
Body Mass Index (kg/m²), mean ± SD	21.7 ± 1.3	23.4 ± 1.6	22.2 ± 1.5	0.001
Systolic blood pressure (mmHg), mean ± SD	121.8 ± 2.1	119.2 ± 3.3	123.6 ± 3.1	0.001
Diastolic blood pressure (mmHg), mean ± SD	78.1 ± 3.9	80.2 ± 2.1	75.9 ± 4.2	0001
Baseline RULA score, mean ± SD	6.8 ± 0.9	6.5 ± 0.8	6.9 ± 1.0	0.394
Baseline REBA score, mean ± SD	8.2 ± 1.1	7.9 ± 1.0	8.4 ± 1.2	0.017
Baseline NBM score, mean ± SD	61.3 ± 9.2	58.6 ± 8.7	62.1 ± 9.6	0.054
Baseline Borg fatigue score, mean ± SD	13.8 ± 2.1	14.5 ± 2.3	14.1 ± 2.2	0.953

2.3. Ergonomic Intervention

The ergonomic intervention was implemented across all three production-stage groups and was designed using a participatory ergonomic approach, which has been shown to enhance intervention effectiveness and worker compliance (Setiawan, et al., 2025; Henry, 2025). The intervention focused on aligning work demands with workers' physical capabilities while respecting existing work culture.

Key components of the ergonomic intervention included: (a) Work method improvement-modification of task sequences to reduce repetitive movements and static postures during fibre processing, spinning, and weaving, (b) Posture adjustment and workstation improvement-optimization of sitting and standing postures through height adjustment of work surfaces and improved seating support during spinning and weaving tasks, (c) Tool and equipment modification-introduction of ergonomically designed hand tools and aids to reduce excessive grip force and upper-limb loading, (d) Work-rest organization-implementation of scheduled active rest breaks (10-15 min) incorporating stretching exercises targeting major muscle groups, and (e) Worker education-short daily briefings and training sessions on ergonomic principles, safe postures, and early recognition of musculoskeletal symptoms. The intervention was implemented following the Plan-Do-Check-Act (PDCA) cycle to ensure systematic execution and continuous improvement. Worker feedback was actively incorporated during the "Check" phase to refine intervention measures, consistent with recent recommendations for participatory ergonomic interventions in small-scale industries (Sadeghi et al., 2025; Benson et al., 2024).

2.4. Ergonomic Risk Assessment

Ergonomic risk levels were assessed using the RULA and REBA methods. These observational tools were selected due to their proven validity and reliability in evaluating postural risks in manual and craft-based work environments (Hita-Gutierrez et al., 2020). Postural assessments were conducted during typical production activities and analyzed from video recordings to minimize observer bias. RULA scores were used to assess upper-limb postural load, while REBA scores evaluated whole-body postural risk. Risk levels were categorized according to standard scoring criteria to identify low, medium, and high ergonomic risk.

2.5. Health Outcomes

2.5.1 Musculoskeletal Complaints

Musculoskeletal complaints were assessed using the NBM questionnaire, which evaluates discomfort across 28 anatomical regions. Participants rated the intensity of discomfort using a five-point Likert scale ranging from 1 = not painful to 5 = very painful. The NBM has been widely used in ergonomic studies and is recognized for its sensitivity in detecting changes in musculoskeletal symptoms following intervention (Vosoughi et al., 2024; Umyati et al., 2023).

2.5.2 Work Fatigue

Work fatigue was measured using the Borg Rating of Perceived Exertion (RPE) scale, which captures subjective perceptions of physical effort and fatigue. Fatigue was analyzed across activity-related, motivational, and physical aspects, reflecting the multidimensional nature of work fatigue. Participants completed fatigue assessments at the end of the workday to capture cumulative workload effects. Assessments were conducted at three time points: one month before intervention (baseline), one month after intervention, and eight months after intervention, allowing evaluation of both immediate and sustained intervention effects.

2.6. Data Analysis

Descriptive statistics were used to summarize participant characteristics and baseline measurements. Changes in ergonomic risk scores (RULA, REBA), musculoskeletal complaints (NBM), and fatigue levels (Borg) across production stages and time points were analyzed using a repeated-measures analysis of variance (RM-ANOVA). Where appropriate, post hoc pairwise comparisons were conducted to identify differences between specific stages and measurement times. To complement statistical significance testing, effect sizes were reported using eta squared (η^2) for the overall model and Cohen's d for pairwise comparisons. Statistical significance was set at $p < 0.05$, and p-values were reported in a standardized format (e.g., $p = 0.001$). All analyses were conducted in accordance with best practices in ergonomic intervention research.

3. Results and Discussion

3.1. Participant Flow and Follow-Up

A total of 152 workers who met the inclusion criteria completed the baseline assessment and were allocated into three groups according to the main production stages: fibre extraction, cleaning and drying (Group 1, $n = 51$), sorting and manual spinning (Group 2, $n = 50$), and weaving and finishing (Group 3, $n = 51$). All participants completed the one-month follow-up assessment. At the eight-month follow-up, complete data were obtained from most participants, and the small amount of attrition did not affect group comparability. Baseline characteristics, including age, anthropometric measures, work experience, blood pressure, and baseline ergonomic and health outcome scores, did not differ significantly between groups ($p > 0.05$), indicating comparable baseline conditions.

3.2. Changes in Ergonomic Risk Scores (RULA And REBA)

At baseline, workers in all production stages were exposed to moderate to high ergonomic risk, as shown by the mean RULA and REBA scores (Table 2). Group 1 and Group 3 had relatively higher RULA scores, whereas Group 2 had higher REBA scores. After the ergonomic intervention, both RULA and REBA scores decreased significantly at the one-month follow-up in all groups ($p < 0.05$). These improvements were maintained or further increased at the eight-month follow-up. The largest reduction was observed in Group 3. Fig. 3 presents the integrated RULA and REBA assessment before and after the intervention.

Panel A; RULA (Upper limb)
- Neck flexion 30-40°
- Trunk flexion 20-30°
- Upper arm flex/abd 45-60°
- Wrist wxt/deviation 25-30°

RULA = 6-7 (High risk)

Panel B; REBA (Whole body)
- Neck flexion 35°
- Trunk flexion 30-45°
- Leg unsupported/squat
- Load 5-10 kg

REBA = 8-9 (High risk)

High ergonomic risk | Musculoskeletal complaints | Fatigue

Panel C; RULA (Upper limb)
- Neck < 10° (neutral)
- Trunk < 10°
- Upper arm < 20°
- Wrist < 15°

RULA = 4 (Moderate risk)

Panel D; REBA (Whole body)
- Neck < 10°
- Trunk upright
- Leg supported sitting
- Minimal load

REBA = 4-5 (Low-moderate)

Reduced ergonomic risk | Reduced musculoskeletal | Reduced fatigue

Fig. 3. Integrated RULA and REBA ergonomic assessment before and after ergonomic intervention

Fig. 3 also shows a reduction in postural angles and biomechanical loading after the intervention. Before the intervention, workers commonly showed excessive neck and trunk flexion, elevated upper limbs, and unsupported lower extremities, resulting in high RULA (6-7) and REBA (8-9) scores. After the intervention, postural alignment improved, with lower joint angles and reduced loading, corresponding to lower RULA (4) and REBA (4-5) scores.

3.3. Changes in Musculoskeletal Complaints and Work Fatigue

Baseline Nordic Body Map (NBM) scores indicated moderate musculoskeletal complaints in all groups. The most frequently reported discomfort involved the neck, shoulders, lower back, wrists, and lower extremities. Group 1 reported greater discomfort in the upper limbs and lower back, while Group 3 reported more discomfort in the neck and shoulders. After the intervention, NBM scores decreased significantly at both follow-up assessments in all groups ($p < 0.05$). The greatest reduction was observed at the eight-month follow-up. Fig. 4a shows the changes in musculoskeletal complaints across the production-stage groups. Workers also reported moderate levels of perceived work fatigue at baseline. Group 1 and Group 3 had higher Borg RPE scores than Group 2. After the intervention, Borg RPE scores decreased significantly at the one-month follow-up in all groups ($p < 0.05$), and these reductions were sustained at the eight-month follow-up. Fig. 4b shows the changes in work fatigue before and after the intervention.

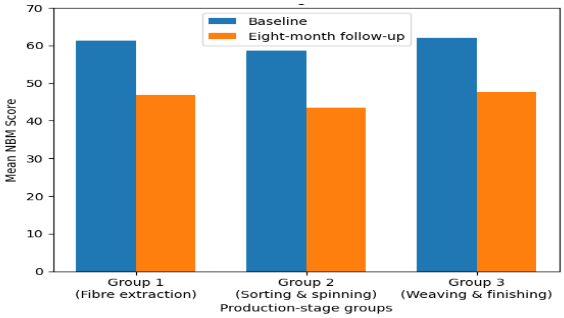

Fig. 4a. Changes in musculoskeletal complaints

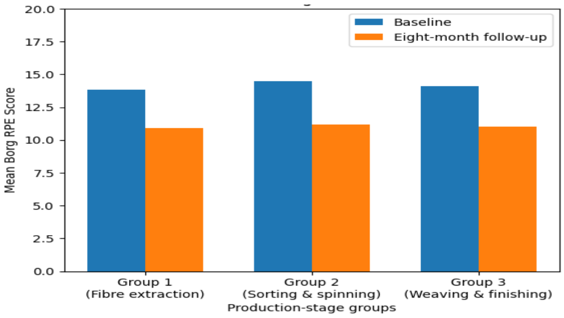

Fig. 4b. Changes in work fatigue

The significant decline in mean Borg RPE scores at the eight-month follow-up indicates improved workload tolerance and reduced physiological strain during routine tasks, which is consistent with recent findings showing that ergonomics-driven reductions in postural load, forceful exertions, and task repetition are closely associated with lower perceived exertion and fatigue (Campana et al., 2025; Dias et al., 2023). This aligns with contemporary evidence that well-designed ergonomic interventions can enhance energy efficiency and delay fatigue accumulation by improving biomechanical alignment and reducing unnecessary muscular activation (Muttaqin, 2025).

The statistically significant decrease in RPE scores ($p < 0.05$) across all production stages further underscores the robustness of the intervention, reinforcing current ergonomic theory that perceived exertion is a sensitive and integrative indicator of physical workload improvements, particularly in heterogeneous and labor-intensive traditional industries. Table 3 shows the changes in ergonomic risk, musculoskeletal complaints, and work fatigue together with effect sizes. In addition to significance testing, effect sizes were calculated to estimate the magnitude of the intervention effect. Partial eta squared (η^2) was used for repeated-measures analysis, and Cohen's d was used to estimate within-group pre–post differences. Effect sizes were interpreted as small ($\eta^2 \approx 0.01$; $d \approx 0.2$), medium ($\eta^2 \approx 0.06$; $d \approx 0.5$), and large ($\eta^2 \geq 0.14$; $d \geq 0.8$). All outcomes showed large effect sizes, indicating that the intervention had substantial practical significance.

Table 3. Changes in ergonomic risk, musculoskeletal complaints, and work fatigue with effect sizes

Variable	Group	Baseline Mean ± SD	Eight-month Mean ± SD	p-value	η^2 (partial)	Cohen's d
RULA	Group 1	6.8 ± 0.9	4.9 ± 0.7	<0.001	0.32	2.35
	Group 2	6.5 ± 0.8	4.7 ± 0.6	<0.001	0.30	2.50
	Group 3	6.9 ± 1.0	4.6 ± 0.7	<0.001	0.35	2.52
REBA	Group 1	8.2 ± 1.1	5.6 ± 0.8	<0.001	0.34	2.61
	Group 2	7.9 ± 1.0	5.3 ± 0.7	<0.001	0.33	2.78
	Group 3	8.4 ± 1.2	5.2 ± 0.8	<0.001	0.36	2.79
NBM	Group 1	61.3 ± 9.2	46.9 ± 8.4	<0.001	0.28	1.62
	Group 2	58.6 ± 8.7	43.4 ± 6.1	<0.001	0.31	1.98
	Group 3	62.1 ± 9.6	47.6 ± 7.2	<0.001	0.29	1.69
Borg RPE	Group 1	13.8 ± 2.1	10.9 ± 1.7	<0.001	0.26	1.52
	Group 2	14.5 ± 2.3	11.2 ± 1.8	<0.001	0.29	1.60
	Group 3	14.1 ± 2.2	11.0 ± 1.6	<0.001	0.27	1.58

All outcomes demonstrated large effect sizes, indicating strong practical significance of the ergonomic intervention. Table 4 shows significant reductions in cumulative fatigue, activity-related fatigue, motivational fatigue, and physical fatigue in all groups at the eight-month follow-up ($p < 0.001$). Effect sizes were in the moderate to large range across all fatigue dimensions.

Table 4. Changes in cumulative fatigue and fatigue dimensions with effect sizes

Fatigue dimension	Group	Baseline Mean ± SD	Eight-month Mean ± SD	*p*-value	η^2 (partial)	Cohen's d
Cumulative fatigue	Group 1	65.2 ± 16.1	49.6 ± 14.9	<0.001	0.30	1.02
	Group 2	81.4 ± 18.3	64.2 ± 16.8	<0.001	0.33	0.99
	Group 3	68.5 ± 15.6	52.7 ± 14.1	<0.001	0.31	1.06
Activity fatigue	Group 1	21.9 ± 6.1	16.3 ± 5.2	<0.001	0.24	0.98
	Group 2	28.4 ± 7.2	21.8 ± 6.1	<0.001	0.27	0.97
	Group 3	23.1 ± 6.5	17.5 ± 5.4	<0.001	0.25	0.91
Motivational fatigue	Group 1	21.4 ± 5.8	15.8 ± 5.0	<0.001	0.23	0.99
	Group 2	27.1 ± 6.9	20.6 ± 5.9	<0.001	0.26	1.02
	Group 3	22.6 ± 6.1	16.9 ± 5.1	<0.001	0.24	0.97
Physical fatigue	Group 1	21.9 ± 6.3	17.5 ± 5.4	<0.001	0.22	0.74
	Group 2	25.9 ± 7.1	21.8 ± 6.3	<0.001	0.23	0.61
	Group 3	22.8 ± 6.5	18.3 ± 5.6	<0.001	0.22	0.73

Table 5 further shows that activity-related, motivational, and physical fatigue symptoms were lower at the eight-month follow-up than at the one-month follow-up in all production-stage groups ($p < 0.05$). Before the intervention, fatigue symptoms commonly appeared after 3-4 hours of continuous work. After the intervention, fatigue was generally reported after 5-6 hours of work.

Table 5. Fatigue at work at the one- and eight-month follow-ups

Statement	G1/ fs	G1/ f (%)	*p*-value	G2/ fs	G2/ f (%)	*p*-value	G3/ fs	G3/ f (%)	*p*-value
A. Activity-related fatigue									
Feel tired all over the body	2.9	27 (53%)	0.041*	3.1	29 (58%)	0.033*	3.0	28 (55%)	0.038*
Heavy legs	2.8	25 (49%)	0.044*	3.0	28 (56%)	0.029*	2.9	27 (53%)	0.035*
Want to lie down	2.7	24 (47%)	0.048*	2.9	26 (52%)	0.031*	2.8	25 (49%)	0.037*
Easily exhausted	2.9	26 (51%)	0.042*	3.1	28 (56%)	0.028*	3.0	27 (53%)	0.034*
B. Motivational fatigue									
Difficulty concentrating	2.8	25 (49%)	0.036*	3.0	27 (54%)	0.024*	2.9	26 (51%)	0.029*
Difficulty thinking clearly	2.7	24 (47%)	0.039*	2.9	26 (52%)	0.026*	2.8	25 (49%)	0.031*
Feeling nervous	2.6	23 (45%)	0.041*	2.8	25 (50%)	0.027*	2.7	24 (47%)	0.033*
Unable to control work attitude	2.6	22 (43%)	0.043*	2.8	24 (48%)	0.029*	2.7	23 (45%)	0.035*
C. Physical fatigue									
Headache	2.6	23 (45%)	0.040*	2.8	25 (50%)	0.028*	2.7	24 (47%)	0.034*
Back pain	3.1	28 (55%)	0.032*	3.3	30 (60%)	0.021*	3.2	29 (57%)	0.026*
Constant thirst at work	3.0	27 (53%)	0.035*	3.2	29 (58%)	0.023*	3.1	28 (55%)	0.029*
Feel unwell despite being healthy	2.5	22 (43%)	0.044*	2.7	24 (48%)	0.030*	2.6	23 (45%)	0.036*

Overall fatigue (Borg RPE)

Group	One-month fs (Mean ± SD)	Eight-month fs (Mean ± SD)	f (%)	p-value
Group 1 Fibre extraction, cleaning & drying	13.1 ± 1.9	10.9 ± 1.7	51 (100%)	<0.001
Group 2 Sorting & manual spinning	13.7 ± 2.0	11.2 ± 1.8	50 (100%)	<0.001
Group 3 Weaving & finishing	13.4 ± 2.0	11.0 ± 1.6	51 (100%)	<0.001

Notes:
fs = mean fatigue score (Likert/Borg-derived item score); f = number of workers reporting moderate–high fatigue; % = proportion of workers per group; p-value = comparison between one- and eight-month follow-ups; * Significant at $p < 0.05$.
(fs = mean fatigue score; f = number of workers reporting moderate–high fatigue; % = percentage of workers; p-value = comparison between one- and eight-month follow-ups); G1=Group 1, G2=Group 2, G3=Group 3.

Table 5 demonstrates significant reductions in activity-related, motivational, and physical fatigue across all production-stage groups at the eight-month follow-up ($p < 0.05$), while no consistent reductions were observed at the one-month follow-up. Prior to ergonomic intervention, fatigue symptoms commonly emerged after approximately 3-4 hours of continuous work, coinciding with the onset of musculoskeletal complaints in the neck, back, waist, and lower extremities. Workers reported feelings of whole-body tiredness, heavy legs, reduced concentration, and the desire to lie down, indicating cumulative physical and mental workload.

3.4. Effectiveness of Ergonomic Intervention in Reducing Ergonomic Risk

This study showed that the ergonomic intervention reduced ergonomic risk, musculoskeletal complaints, and perceived work fatigue across all production stages. The consistent decrease in RULA and REBA scores indicates that the intervention improved working posture and reduced biomechanical loading. These findings are consistent with previous studies showing that workstation adjustment and posture improvement can reduce ergonomic risk in manual occupations. The greatest improvement was observed in Group 3. This may be related to the nature of weaving and finishing tasks, where workstation modification and posture correction could be implemented more directly and consistently. These findings align with recent intervention studies reporting that task-specific ergonomic modifications, including workstation adjustment and posture improvement, effectively reduce biomechanical loading in manual and craft-based occupations (Adjei et al., 2025; Motta et al., 2024; Hilmi et al., 2024). The observed improvements across all production stages suggest that the participatory ergonomic approach adopted in this study successfully addressed both common and task-specific risk factors. In particular, reductions in upper-limb and trunk loading indicate that relatively low-cost interventions can yield meaningful ergonomic benefits in traditional industries with limited technological resources.

3.5. Reduction in Musculoskeletal Complaints Across Production Stages

he marked reduction in musculoskeletal complaints across all production stages provides strong evidence that the ergonomic intervention effectively mitigated work-related musculoskeletal disorders (WMSDs). Nordic Body Map (NBM) scores declined from 61.3 to 46.9 in Group 1, from 58.6 to 43.4 in Group 2, and from 62.1 to 47.6 in Group 3 at the eight-month follow-up, with all changes statistically significant ($p < 0.001$). These sustained reductions indicate that the intervention produced not only short-term symptom relief but also durable improvements in musculoskeletal health, which is a key indicator of successful ergonomic design in manual work systems (Rahmahwati, 2021). The findings are consistent with recent studies showing that reduced postural load leads to better musculoskeletal outcomes (Gaunekar, 2025; Krishnanmoorthy et al., 2025). They also support evidence that ergonomics interventions are most effective when tailored to task-specific demands within a unified intervention framework, particularly in traditional craft industries (Martínez, 2025).

3.6. Impact of Ergonomic Intervention on Work Fatigue

Work fatigue, a critical occupational health outcome, improved markedly following the ergonomic intervention. Borg RPE scores decreased from 13.8-14.5 at baseline to 10.9-11.2 at the eight-month follow-up, indicating a clear reduction in perceived physical effort during routine tasks. This finding is consistent with previous studies showing that improved postural alignment, reduced static loading, and structured work-rest schedules can lower fatigue and enhance work endurance (Suarbawa et al., 2026; Almenar-Arasanz et al., 2025; Greig et al., 2025). In the present study, the parallel reduction in ergonomic risk, musculoskeletal complaints, and fatigue supports the cumulative exposure pathway, in which sustained biomechanical stress contributes simultaneously to physical discomfort and fatigue. Although no significant overall reduction in fatigue was observed at the one-month follow-up, early improvements in bodily heaviness and mental strain suggested initial adaptation.

By eight months, fatigue declined significantly across all groups ($p < 0.05$), and fatigue onset was delayed from 3-4 hours to 5-6 hours. The reduction in fatigue occurred alongside the reduction in ergonomic risk and musculoskeletal complaints. This supports the view that these outcomes are closely related. When biomechanical stress is reduced, workers are likely to experience less discomfort and lower perceived exertion. The largest relative improvement was seen in motivational fatigue. This may reflect the participatory nature of the intervention, which encouraged worker involvement and improved engagement with safer work practices.

3.7. Implications for Traditional Craft Industries

These findings are important for traditional fibre-based craft industries, where work is still highly manual and often based on inherited practices. In such settings, low-cost ergonomic improvements can produce meaningful health benefits without disrupting production. This study also shows the value of combining objective ergonomic assessments (RULA and REBA) with subjective health indicators (NBM and Borg RPE). This approach provides a more complete evaluation of intervention outcomes and may be useful in similar small-scale industries. Overall, this study contributes novel evidence demonstrating that ergonomic intervention can effectively reduce ergonomic risk, musculoskeletal complaints, and work-related fatigue in a traditional abaca banana fibre carpet craft industry. By addressing a sector that remains underrepresented in ergonomic research, the findings support the broader application of ergonomic principles to improve worker health and sustainability in traditional craft-based industries.

5. Conclusion

This study demonstrates that ergonomic intervention can effectively reduce ergonomic risk, musculoskeletal complaints, and work-related fatigue among workers in the Abaca banana fibre carpet craft industry. The sustained improvements observed after the intervention indicate that participatory, task-specific, and low-cost ergonomic strategies can be successfully implemented in traditional manual production settings. These findings have practical relevance for improving worker health and supporting more sustainable production processes in craft-based industries. More importantly, this study contributes conceptually to ergonomic intervention research by showing that participatory ergonomics should be understood not only as a means of correcting posture or modifying workstations, but also as an integrated framework through which reductions in biomechanical exposure can lead to broader improvements in musculoskeletal health, perceived work capacity, and occupational well-being.

Several limitations should be acknowledged. First, the absence of a non-intervention control group limits causal inference, although the longitudinal design and consistent improvements across multiple outcomes strengthen the observed associations. Second, reliance on self-reported measures for musculoskeletal complaints and fatigue may introduce reporting bias, although validated instruments were used. Future research should consider controlled intervention designs, longer follow-up periods, and integration of objective physiological fatigue indicators. Additionally, economic evaluations of ergonomic interventions could provide valuable insight into cost-benefit considerations for small-scale industries.

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