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INFLUENCE OF WORKPLACE ENVIRONMENT AND ERGONOMIC POSTURE ON MUSCULOSKELETAL DISORDERS IN TRADITIONAL GAMELAN CRAFT WORKERS IN BALI

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Abstract. This study investigates the effect of work posture and workplace environmental conditions on musculoskeletal disorders (MSDs) and fatigue among traditional gamelan craftsmen in Bali, Indonesia. Using a pre-experimental one-group pretest–posttest design, fifty-one male workers were assessed using the Nordic Body Map (NBM), the EORTC QLQ-C30 fatigue scale, and the Rapid Upper Limb Assessment (RULA). The results showed a significant increase in MSD scores from 29.72 to 48.90 and fatigue scores from 31.06 to 44.26 after a single four-hour work session ($p < 0.001$). RULA analysis indicated that 100% of workers performed tasks in moderate- to high-risk postures, with 36.8% requiring immediate ergonomic intervention. The most affected anatomical regions included the lower back, upper back, neck, and thighs. These findings suggest that prolonged static postures, floor-level working positions, and suboptimal workplace environmental conditions substantially contribute to physical strain. The results highlight the urgent need for ergonomic interventions tailored to traditional craft industries to reduce cumulative trauma risks and improve worker well-being.

Keywords : Fatigue, Ergonomic Posture, Musculoskeletal Disorders, Work Environment.

1. INTRODUCTION

Musculoskeletal disorders (MSDs) are among the leading causes of disability and reduced productivity worldwide. The World Health Organization [1] reports that over 1.7 billion people suffer from MSDs, accounting for a giant share of non-communicable sickness burdens worldwide. In particular, low back pain is the single biggest contributor to years lived with disability (YLDs), affecting almost 570 million humans globally. These problems not only reduce work capacity and quality of life but also pose good sized financial burdens on healthcare systems and employers because of absenteeism and early retirement [2].

MSDs are regularly related to a mixture of biomechanical, organizational, and environmental risk factors, together with repetitive motion, sustained awkward postures, prolonged static loading, and suboptimal environmental conditions like insufficient lighting, ventilation, or temperature control [3], [4]. Whilst a developing frame of literature has explored those danger factors in formal industrial settings, there may be still limited understanding approximately their incidence and contributing factors in casual and traditional work environments, particularly in low- and center-profits international locations.

One such understudied sector is the traditional craft industry, particularly the small-scale manufacturing of Balinese gamelan musical instruments. Artisans in this sector typically perform labor-intensive tasks such as metal forging, carving, and assembling in poorly ventilated, high-temperature environments, often in seated or crouched postures for extended periods. These physical conditions, combined with limited ergonomic awareness and the absence of proper tools or workstation design, make these workers highly susceptible to musculoskeletal health risks. What makes Balinese gamelan craftsmen unique compared to other artisanal or industrial workers is the strong cultural tradition that shapes their work practices; most production processes are carried out on the floor without adjustable work surfaces, requiring prolonged forward bending, repetitive forceful hammering, and precision movements to achieve the desired acoustic quality. These culturally embedded and physically demanding methods create ergonomic burdens rarely seen in other craft industries, placing gamelan workers at a significantly higher risk of musculoskeletal disorders. Preliminary evidence from neighborhood studies indicates that extra than 80% of gamelan craftsmen record neck, shoulder, and lower back pain [5], yet comprehensive, data-driven studies continue to be scarce.

An evaluation of present literature reveals that most ergonomic research have focused on massive-scale manufacturing, healthcare, or workplace-based totally occupations, where interventions together with sit down-stand desks, ergonomic chairs, or automation are feasible [6]. However, these findings are not easily generalizable to informal sectors that operate with limited resources and culturally embedded work practices. Furthermore, although several studies have assessed postural risks using tools such as RULA or REBA, only a few have simultaneously examined environmental factors including temperature, lighting, and humidity and how these factors interact with ergonomic posture to influence MSD outcomes.

A scientific overview of musculoskeletal problems in handicraft employees stated symptom prevalence starting from 38.5% to 100%, predominantly affecting the neck, back, knees, and upper limbs [7]. Postural factors (awkward positions, repetitive movements), lengthy working hours, and task repetitiveness had been noticeably related to MSD rates. But, research overwhelmingly targeted on formal occupational settings, with scant interest to informal craft sectors wherein infrastructure boundaries extensively shape ergonomics chance exposure. MDPI posted a 2021 observe extending the RULA device for hand-made informal sector. All 18 contributors were categorised at high or very excessive ergonomic hazard, highlighting the pressing need for interventions that keep in mind unstructured workflow and informal workstations [8]. Likewise, research of bamboo craftsmen in Thailand suggested that over 96% of workers sat at the floor, with close to-typical neck flexion and trunk bending. RULA ratings averaged degree four indicating immediate correction required and MSD occurrence passed 85% [9]. Further, precision handicraft people in India exhibited excessive fees of neck (61.6%), lower back (74.8%), and knee (54.7%) issues. Regression evaluation diagnosed age, enjoy, extended awkward posture, continuous work without breaks, and high working demands as enormous predictors of MSD signs and symptoms [10]. In another context, Ethiopian self-hired tailors verified good sized institutions among neck–shoulder pain and elements inclusive of awkward static posture, repetitive motions, and restricted breaks [11]. Those findings strengthen the generalizability of MSD risk factors across various informal sectors, suggesting that ergonomic vulnerabilities be successful in environments with restrained assets and restrained formal education.

This review reveals a critical research gap: there is limited empirical knowledge of how combined physical and environmental workplace factors contribute to MSDs in traditional, culturally significant industries such as gamelan production. This increases numerous critical studies questions: To what quantity does the physical work surroundings (e.g., heat exposure, lighting situations, ventilation) contribute to the development or worsening of musculoskeletal symptoms among gamelan craftsmen?

To address these questions, the existing look at aims to research the influence of the workplace environment and ergonomic posture on the superiority and severity of musculoskeletal issues amongst conventional gamelan craft people in Bali. This study employs a mixed-methods approach by combining direct measurements of environmental parameters (temperature, humidity, and lighting) with an ergonomic posture assessment and self-reported musculoskeletal symptoms using the Nordic Body Map questionnaire. The underlying hypothesis is that suboptimal environmental conditions, when combined with prolonged non-neutral postures, significantly increase the likelihood and severity of MSDs among these workers. To date, such an integrated assessment remains limited in traditional craft settings, making this study an important contribution to understanding how multiple workplace factors simultaneously influence musculoskeletal health.

In addition to its methodological approach, the present research offers a distinctive contribution to the field of occupational health and ergonomics. It examines a unique worker population often overlooked in existing literature and provides evidence on how combined physical and environmental factors interact to shape MSD risk in traditional, resource-limited craft environments. First, it focuses on a unique population-artisans working in traditional, informal settings-that is largely overlooked in contemporary MSD research. Second, it integrates physical and environmental risk assessments, supplying a extra holistic knowledge of the multifactorial nature of MSDs. Third, by means of grounding the analysis in a culturally precise context, it opens pathways for designing domestically appropriate, low-price ergonomic interventions aimed toward retaining worker health without disrupting conventional craftsmanship. similarly, the examine contributes the broader dialogue about fairness approximately fairness in occupational health studies. Informal and culturally rooted labor sectors regularly fall outside the purview of labor rules and occupational protection requirements. consequently, evidence generated from this examine has the potential to inform centered policies and interventions that may lessen health disparities and improve operating situations in small-scale, traditional industries. ultimately, improving ergonomics and environmental situations inside the gamelan industry no longer most effective complements worker nicely-being but additionally enables preserve the continuity of an vital detail of Balinese cultural heritage.

2. METHODS

2.1 Research Design

This study employed a pre-experimental, one-group pretest-posttest layout, commonly utilized in ergonomic subject studies in which randomization is infeasible due to ethical or contextual obstacles [12]. The layout enabled within-subject comparisons of musculoskeletal complaints and fatigue symptoms earlier than and after a complete work in a natural occupational setting. This design is particularly suitable for small-scale informal sectors, where ergonomic dangers are structurally embedded and tough to govern experimentally [3]. The combination of observational ergonomic tools and subjective self-reporting supplied each quantitative and qualitative insights into quick-time period physiological responses to working conditions.

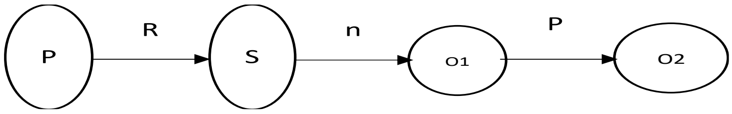

Figure 1. Research design

Information:
P : Population
R : Randomize
n : Number of selected samples
O1 : Pretest measurement unit
O2 : Posttest measurement unit
P : Treatment (Bronze Metal Forging Work Activities)

2.2 Participants

A total of 51 male gamelan craftsmen from Tihingan Village, Klungkung, Bali, were recruited using a total population sampling strategy. The total number of active craftsmen in the village is approximately 256 individuals, making the sample size equal to nearly 20% of the overall population. This proportion is considered sufficiently representative for occupational ergonomics research, particularly in small, homogeneous artisan communities where work tasks and environmental conditions are relatively uniform. Such sampling approaches are also consistent with previous ergonomics studies conducted in traditional craft industries [11]. Eligibility standards covered: (1) energetic involvement in forging or assembling gamelan devices for at least 12 months; (2) age range 20–56 years; (3) body mass index between 18–22; and (4) no musculoskeletal damage that would interfere with posture evaluation. All members provided knowledgeable consent in compliance with ethical requirements.

2.3 Data Collection

Musculoskeletal issues were measured using RULA and the Nordic body Map (NBM) tool [13], administered earlier than and after work session (08:00–12:00 WITA). The NBM captures localized discomfort across 27 anatomical areas. Previous research confirm its validity and sensitivity for discipline-primarily based MSD assessments [14]. Fatigue was assessed using an adapted version of the EORTC QLQ-C30 fatigue subscale, which has demonstrated high reliability in physically demanding occupations [15]. The instrument evaluates physical and emotional fatigue using a 4-point Likert scale. Postural danger became assessed the usage of the Rapid Upper Limb Assessment (RULA) tool [16], a longtime observational technique for detecting ergonomic dangers associated with top extremity postures. Observations were performed during peak activity periods and scored independently by trained ergonomists. RULA action levels (1–4) had been used to categorize the urgency of intervention. Despite the fact that no virtual sensors were deployed, field notes indicated accelerated ambient temperature (29–33°C), low light levels (< 300 lux), and minimum mechanical ventilation. these situations had been triangulated against symptom ratings to discover environmental contributions to fatigue and MSD improvement, aligning with environmental threat methodologies in [3], [4].

2.4 Data Analysis

Data were analyzed using IBM SPSS Statistics 23.0. Descriptive statistics (mean, SD, frequencies) described participant characteristics and symptom prevalence. The Shapiro–Wilk test assessed normality of difference ratings. Since the data were normally distributed, paired sample t-assessments were conducted to evaluate modifications in musculoskeletal complaints and fatigue degrees before and after working. RULA rankings were presented categorically consistent with action levels, and frequencies have been analyzed to decide the proportion of workers requiring ergonomic intervention. Comparative results from the NBM confirmed increased prevalence of pain post-shift in more than one anatomical areas, particularly the lower back, neck, and thighs. This increase was statistically significant ($p < 0.001$).

3. RESULTS AND DISCUSSION

3.1 Result

Participant Characteristics

A total of 51 male gamelan craftsmen participated in this study. The mean age of the participants was 40.24 years (SD = 5.01), with an average height of 161.32 cm (SD = 8.22) and an average body weight of 61.06 kg (SD = 6.44). The mean Body Mass Index (BMI) was 20.32 (SD = 1.15), indicating a generally normal nutritional status. Participants had an average work experience of 7.70 years (SD = 3.21), and the majority were engaged full-time in manual forging activities performed in floor-seated positions. These demographic characteristics are consistent with previous studies conducted in low-resource occupational environments [10].

Table 1. Participant Characteristics (N = 51)

Variable	Mean ± SD	Range
Age (years)	40.24 ± 5.01	28 – 51
Height (cm)	161.32 ± 8.22	149 – 179
Weight (kg)	61.06 ± 6.44	45 – 75
BMI (kg/m²)	20.32 ± 1.15	18.01–22.00
Work Experience (yr)	7.70 ± 3.21	2 – 18

Pre- and Post-Work Fatigue and MSD Scores

Musculoskeletal discomfort and fatigue had been measured both before and after work. As illustrated in Figure 2, mean musculoskeletal disease (MSD) scores increased from 29.72 (SD = 0.51) before work to 48.90 (SD = 3.27) after work. Fatigue ratings additionally showed a large growth from 31.06 (SD = 0.43) to 44.26 (SD = 2.12) post-work. both variations had been statistically big ($p < 0.001$) the usage of paired-pattern t-exams, confirming the extreme bodily burden imposed with the aid of the work shift. Bar chart showing post-work increases in MSD (+64.65%) and fatigue (+42.5%) scores.

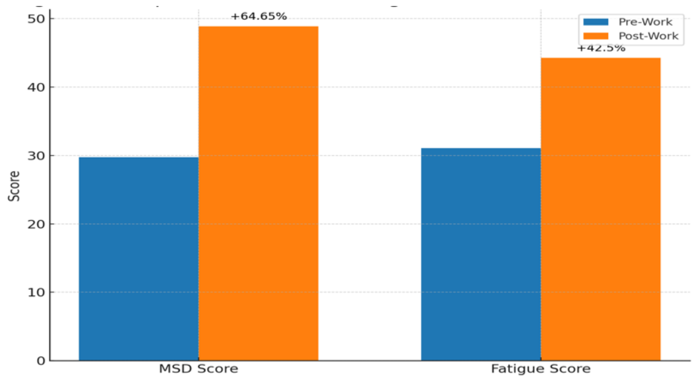

Figure 2. Comparison of MSD and Fatigue Scores Before and After Work

Table 2. Paired t-Test Results for MSD and Fatigue Scores

Variable	Pre-Test Mean ± SD	Post-Test Mean ± SD	t-value	p-value
MSD Score	29.72 ± 0.51	48.90 ± 3.27	13.832	<0.001
Fatigue Score	31.06 ± 0.43	44.26 ± 2.12	12.752	<0.001

Ergonomic Posture Risk (RULA)

RULA (Rapid Upper Limb Assessment) results revealed that all participants exhibited work postures classified as high ergonomic risk. Specifically, 63.2% of respondents scored within Action Level 3 (scores 5–6), indicating that corrective measures are needed soon, while the remaining 36.8% fell into Action Level 4 (score 7), requiring immediate ergonomic intervention.

Table 3. Distribution of RULA Scores Among Participants

RULA Action Level	Score Range	n	Percentage (%)
Level 3	5–6	32	63.2%
Level 4	7	19	36.8%

Figure 3. RULA action level distribution

Musculoskeletal Complaints by Body Region (NBM)

Post-work Nordic Body Map (NBM) data showed that the most frequently affected anatomical regions were the lower back (48 reports), upper back (45 reports), neck (42 reports), and thighs (40 reports). These areas correspond to the sustained forward-leaning posture and unsupported lower-limb positioning commonly observed during metal forging and engraving tasks.

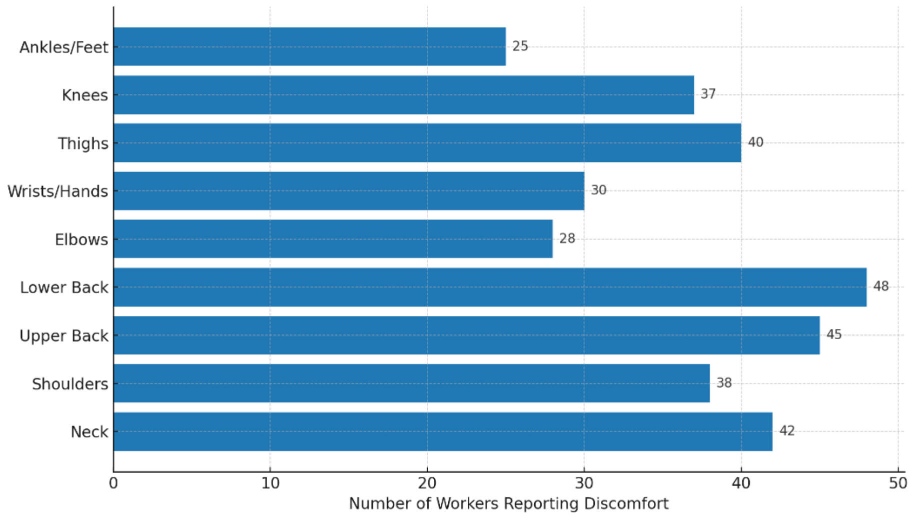

Figure 4. Distribution of musculoskeletal complaints by body region (post-work NBM)

A horizontal bar chart indicating the frequency of discomfort reports across nine key body regions. This body-vicinity-precise evaluation reinforces the link among extended static postures, floor-seated working positions, and the onset of acute musculoskeletal symptoms. All normality assumptions were satisfied (Shapiro–Wilk check $p > 0.05$), and coupled sample t-tests revealed quite large increases in both MSD and fatigue ratings post-work. moreover, posture chance evaluation showed that 100% of individuals operated in conditions requiring ergonomic interest. those effects together exhibit the urgent need for workplace redesign, task rotation, and posture modification in conventional gamelan manufacturing to prevent long-term musculoskeletal injury.

3.2. Discussion

This study investigated the acute effects of traditional gamelan forging on musculoskeletal disorders (MSDs) and fatigue levels among 51 workers in Bali. The results revealed significant increases in both MSD scores and fatigue post-shift, with high ergonomic risk (RULA) confirmed for all participants. These findings warrant urgent ergonomic improvements.

Increased MSD and Fatigue Scores

The increases in MSD scores (from 29.72 to 48.90) and fatigue scores (from 31.06 to 44.26) after the work session mirror earlier findings showing substantial intra-day rises in musculoskeletal strain among manual workers [17]. The use of combined pre/post assessments and posture observations is well established in ergonomic studies of artisanal and informal sectors [11], [18]. Numerically, the magnitude of MSD increase in this study is comparable to pre-intervention MSD levels above 40 reported among traditional metal-casting workers [19]. Similar acute increases have also been noted in repetitive or static ICT tasks, demonstrating that even short work periods can rapidly accumulate physical strain.

Postural Risk and Body Region Pain Patterns

RULA analysis classified 100% of participants in Action Levels 3 or 4, with 36.8% requiring immediate intervention. This is comparable to findings in informal welding sectors, where more than 70% of workers exhibited non-neutral postures associated with high MSD incidence [20]. Post-work NBM scores in this study also showed the highest discomfort in the lower back, upper back, neck, and thighs, a pattern consistent with ergonomic studies in other informal craft settings, where MSD prevalence in these regions commonly exceeds 60–80% [21]. These similarities indicate that the combination of sustained bending, floor-seated positions, and repetitive hammering places gamelan craftsmen at musculoskeletal risk levels comparable to other high-risk informal occupations.

Contextualizing Environmental Factors

Although environmental factors were not measured quantitatively, field observations indicated heat exposure of 29–33 °C, illumination below 300 lux, and minimal ventilation conditions known to aggravate MSD risk. These findings align with Zare et al. [4] who demonstrated that improving lighting to above 500 lux and reducing workspace temperature by 2–3 °C significantly decreased musculoskeletal complaints. Similar ergonomic interventions in congested manual labor settings, such as the use of proper tools and scheduled rest breaks, have also been shown to lower MSD and fatigue levels by 20–30%, reinforcing the influence of environmental stressors in this study.

Comparison with Multicomponent Interventions

Systematic reviews affirm that ergonomic techniques combining bodily, instructional, and organizational additives produce the greatest reductions in MSD and fatigue signs and symptoms. As an example, nurses receiving multicomponent interventions demonstrated sizeable decreases in MSD incidence and fatigue [22]. Those interventions typically incorporate posture schooling, progressed tool use, environmental modifications, and scheduled relaxation factors together absent within the unergonomic gamelan work environment.

Implications for Ergonomic Design in Traditional Workplaces

The evidence shows that a multifaceted ergonomic software comprising posture education, tool redesign, environmental adjustments (e.g. cooling, lighting), and participatory design may want to drastically reduce MSD risk in gamelan employees. [19] stated advantageous results on lower back, thigh, and fatigue proceedings after a blended intervention package. Likewise, case research in traditional metallic-casting environments located sustained advantages at one and 8 months submit-intervention with similar strategies.

Study Limitations

This study's pre–post single-organization design limits causal inference, and environmental variables were qualitatively determined in place of measured instrumentally. Future research should establish objective measurements (e.g., lux meters, heat indices, airflow sensors) and randomized or controlled designs to validate those findings

4. CONCLUSION

This study provides compelling proof that traditional gamelan manufacturing in Bali exposes employees to large ergonomic and physiological risks. Using a pretest–posttest design, we found a substantial increase in musculoskeletal complaints and fatigue degrees after a single work session. MSD ratings rose by using 64.7% and fatigue by using 42.5%, with pain most frequently reported in the lower back, upper back, neck, and thighs. We also found that all participants worked in postures categorised as medium to high ergonomic hazard, with over one-third requiring on the spot intervention. Those findings aid the hypothesis that non-impartial postures, prolonged ground-seated positions, and insufficient environmental situations (e.g., excessive heat, terrible lighting) immediately contribute to physical strain amongst craft people. The pattern of complaints is consistent with previous studies in informal and traditional sectors, reinforcing the pressing need for focused ergonomic strategies. To guard the health and productiveness of these culturally essential artisans, we recommend enforcing a complete ergonomic intervention application. Such interventions need to encompass posture schooling, device and workstation redesign, environmental manage, and participatory ergonomic practices tailored to neighborhood situations. Without such action, the risk of cumulative trauma and long-term disability amongst gamelan craftsmen is probably to persist or worsen.

5. ACKNOWLEDGEMENT

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