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Improving Labor Productivity in a Furniture Workshop through an Integrated Ergonomic Assessment Using REBA, NMQ, and 3DSSPP Simulation

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Abstract

This study presents an integrated ergonomic intervention designed to improve labor productivity in a melamine furniture workshop. Critical workstations, including cutting, drilling, and assembly, were identified based on postural risk and physical workload. To assess the workers' musculoskeletal condition, the Nordic Musculoskeletal Questionnaire (NMQ) was used, while postural risk levels were determined using the Rapid Entire Body Assessment (REBA) method. Additionally, biomechanical analysis and workstation redesign were supported through simulations with the 3D Static Strength Prediction Program (3DSSPP). Based on the ergonomic diagnosis, improvement proposals were developed, including the implementation of height-adjustable worktables, the use of lighter tools, and optimizing workspace layout to reduce awkward postures and excessive physical loads. The effectiveness of the intervention was evaluated by comparing productivity and biomechanical indicators before and after implementation. The results showed significant improvements after the ergonomic intervention. Monthly furniture production increased by 25% (from 160 to 200 units per month), while labor productivity per man-hour improved by 14%. In addition, assembly time per unit decreased by 8.5 minutes, postural risk levels were reduced, and spinal compression forces decreased from 3,350 N to 2,300 N. These findings demonstrate that affordable ergonomic improvements, supported by simulation tools, can effectively enhance both productivity and occupational health in small and medium-sized industrial workshops.

Keywords
Ergonomics, Labor productivity, REBA, Nordic Musculoskeletal Questionnaire and 3DSSPP.

1. Introduction
The melamine furniture industry plays a significant role in Peru's manufacturing sector, especially within micro and small enterprises, which represent a major source of local employment in the carpentry field. (FAO 2018). Despite their economic importance, many of these workshops operate under suboptimal ergonomic conditions, limited technological support, and poorly structured work organization (Barragán et al. 2021; Hernández et al. 2023). These deficiencies negatively impact both workers' health and operational efficiency, leading to low productivity and increased physical fatigue (Mamani 2021; Campos-Naval et al. 2025; Asish et al. 2022).

Previous studies have reported a high prevalence of musculoskeletal disorders (MSDs) among furniture manufacturing workers, particularly affecting the lower back, shoulders, and neck (Yang et al. 2022). These conditions are mainly attributed to prolonged exposure to awkward postures, manual material handling, repetitive movements, and workstations that are not adapted to workers' anthropometric characteristics, which increase physical strain and contribute to fatigue and musculoskeletal discomfort (Barragán et al. 2021; Yang et al. 2022; Sharma et al. 2023). For instance, Rodríguez-Salinas et al. (2023) found that four out of six workers assessed in a furniture manufacturing environment were exposed to high postural risk levels, with REBA scores above 9, while the remaining workers presented medium risk levels, highlighting the presence of critical ergonomic conditions. Additionally, several studies have demonstrated that ergonomic interventions can significantly improve both labor productivity and workers' physical well-being in manufacturing environments (Martinez 2025; Buarque 2015; Mares et al. 2025; Suokko 2025; Muttaquin 2025; Dewi et al. 2024).

Despite this body of evidence, the implementation of ergonomic improvements in small-scale workshops in Peru remains limited. This is largely due to a lack of technical knowledge and the misconception that ergonomic solutions are costly and only feasible for large companies. Consequently, a gap persists between current operational conditions and desirable ergonomic standards, directly impacting process performance. In the workshop analyzed in this study, an average productivity of 1.50 furniture units per labor-hour was observed, compared to an estimated sector benchmark of 1.81 units per labor-hour (Rodriguez-Salinas et al. 2023), indicating a productivity gap of 17.13%. This gap is primarily attributed to fatigue-related pauses, uncomfortable postures, excessive physical effort, and inefficient workspace layouts.

In response to this issue, this study proposes two research hypotheses: (1) ergonomic adaptation of the work environment reduces physical discomfort and absenteeism, and (2) workstation redesign decreases furniture assembly time, leading to improved labor productivity. To test these hypotheses, an integrated ergonomic assessment approach was applied. The Nordic Musculoskeletal Questionnaire (NMQ) was used to assess the prevalence and distribution of musculoskeletal symptoms, the Rapid Entire Body Assessment (REBA) method evaluated postural risk levels, and the 3D Static Strength Prediction Program (3DSSPP) simulated observed postures to quantify biomechanical loads, particularly spinal compression at the L5/S1 level.

The intervention focused on three critical process stages: cutting, drilling, and assembly, selected due to their high physical demands and frequent reports of discomfort. The implemented improvements included height-adjustable worktables, workspace redistribution, and the replacement of heavy tools with lighter alternatives better suited to workers' physical capabilities.

1.1 Objectives

- To identify critical workstations with high postural and physical workload that negatively affect labor productivity in the melamine furniture production process.
- To assess the prevalence and distribution of musculoskeletal symptoms among workers and their potential impact on work performance using the Nordic Musculoskeletal Questionnaire (NMQ).
- To evaluate postural risk levels at selected workstations using the REBA method as a basis for productivity improvement.
- To analyze biomechanical loads and postural demands through simulation using 3DSSPP to support ergonomic workstation redesign.
- To design and evaluate ergonomic improvements aimed at reducing physical load and increasing labor productivity.

2. Literature Review

2.1 Ergonomics and Labor Productivity in Manufacturing

Ergonomics has been widely recognized as a key factor influencing labor productivity, especially in manufacturing environments where manual labor and repetitive tasks are prevalent. (Dul et al. 2012; Neumann and Village 2012). Poor ergonomic conditions often lead to physical fatigue, discomfort, and musculoskeletal disorders (MSDs), which can negatively affect workers' performance by increasing error rates, generating productivity losses due to absenteeism, and reducing overall work capacity. (Greggi et al. 2024; Sundstrup et al. 2020). On the other hand, ergonomic interventions focused on workstation design, task organization, and tool adaptation have been proven to enhance operational efficiency and output rates. (Malla et al. 2022; Ünlü et al. 2024).

Several studies have demonstrated that ergonomically optimized workstations can reduce cycle times, improve task execution, and increase overall labor productivity. (Moussavi et al. 2016; Urman and Agarwal 2024). In labor-intensive manufacturing sectors, ergonomics is not only linked to occupational health but also serves as a strategic tool for productivity improvement and sustainable operations management. (Firescu and Filip 2025). By integrating ergonomic principles into the process design, companies can simultaneously improve worker well-being and operational performance, aligning human factors with productivity objectives (Goździewska-Nowicka 2024; Thomas et al. 2024).

2.2 Musculoskeletal Disorders in Furniture Manufacturing

The furniture manufacturing industry presents a high ergonomic risk due to manual material handling, prolonged standing, awkward postures, and repetitive movements. These factors contribute to a high prevalence of musculoskeletal disorders (MSDs), particularly affecting the lower back, shoulders, neck, and upper limbs. (Yang et al. 2022; Sharma et al. 2023; WHO 2022). Small-scale furniture workshops are especially vulnerable, as they often operate with limited mechanization and poorly adapted workstations. (Jain et al. 2021). Recent studies conducted in manufacturing environments have shown that workers exposed to elevated postural risk and high physical workloads report higher incidences of musculoskeletal symptoms, which are associated with reduced work capacity and frequent operational pauses due to physical discomfort (Greggi et al. 2024; Lee et al. 2023; Chen and Luo 2023).

Previous studies have emphasized the use of systematic ergonomic assessment methods to identify and quantify risk factors associated with musculoskeletal disorders in manufacturing environments. These approaches allow for the evaluation of postural load, physical demands, and task-related risks, providing objective data to support the analysis of ergonomic conditions (David 2005; Hignett and McAtamney 2000; Yazdanirad 2018).

2.3 Ergonomic Assessment Tools: REBA and NMQ

Ergonomic risk assessment tools are essential for identifying hazardous postures and physical demands in industrial tasks. The Rapid Entire Body Assessment (REBA) method is commonly used to evaluate whole-body postural risk in tasks involving dynamic movements and varied postures (Hignett and McAtamney 2000). REBA allows practitioners to classify risk levels and prioritize corrective actions based on body segment positions, applied forces, and task frequency, making it especially suited for manufacturing environments (David 2005; Hita-Gutierrez 2020; Rodriguez-Salinas 2023).

Additionally, the Nordic Musculoskeletal Questionnaire (NMQ) is a standardized tool for assessing self-reported musculoskeletal symptoms across different body regions. The NMQ has been widely applied in recent occupational health studies to identify the prevalence and distribution of MSDs and to assist in ergonomic diagnosis in industrial contexts (Crawford 2007; Kuorinka et al. 1987). Using both REBA and NMQ together provides a comprehensive ergonomic evaluation, integrating objective postural assessments with workers' perceived discomfort. Previous studies have reported the combined use of multiple ergonomic assessment tools, such as REBA, RULA, and the NMQ, to simultaneously evaluate postural risk and musculoskeletal symptoms in industrial environments (Mares et al. 2025; Yazdanirad 2018; Kittijaruwattana et al. 2023; Zhao et al. 2024).

2.4 Biomechanical Simulation in Ergonomic Analysis (3DSSPP)

Biomechanical simulation tools have gained increasing importance in ergonomic analysis by enabling the quantitative evaluation of physical loads that are difficult to assess through observational methods alone. (Ranavolo et al. 2020). The 3D Static Strength Prediction Program (3DSSPP) is a commonly used software for estimating joint forces, muscle loads, and spinal compression during static and quasi-static working postures (Chaffin 1997; Anderson and Chaffin 1986). Its application allows researchers to determine if biomechanical loads exceed recommended safety limits and to compare alternative workstation designs.

Recent ergonomic studies have emphasized that biomechanical simulations enhance the evaluation of ergonomic interventions by providing objective indicators of physical demand and spinal loading, as demonstrated in studies using musculoskeletal models to estimate compressive and shear loads in lifting tasks and assess risk levels in occupational settings (Refai et al. 2025). When combined with REBA, these simulation tools improve decision-making related to workstation redesign and task optimization, as demonstrated in studies that integrate ergonomic and biomechanical assessment tools such as REBA, RULA, and 3DSSPP to evaluate musculoskeletal risk and define intervention strategies (Mares et al. 2025; Jamshidian 2024; Silvetti et al. 2024). However, despite the benefits, the adoption of ergonomic practices in small and medium-sized enterprises remains limited due to resource constraints and low prioritization of occupational health and safety, which affects productivity and working conditions (Mukalay et al. 2025).

3. Methods

This study adopts a quantitative and applied research approach based on a case study conducted in a small-scale melamine furniture workshop. The production process is predominantly manual and involves four operators who rotate among different workstations. The workshop manufactures custom furniture units and operates under low levels of mechanization, making it suitable for ergonomic intervention analysis. The research was structured in sequential stages, including musculoskeletal symptom assessment, workstation identification, postural risk evaluation, biomechanical simulation, ergonomic redesign, and post-intervention validation. This structured approach ensured a systematic evaluation of ergonomic risk and its impact on labor productivity.

3.1 Data Collection and Work Analysis

Data collection was carried out directly in the workshop under normal operating conditions. Initial observations were conducted to understand task sequences, operator movements, and workstation characteristics. Photographs and video recordings were taken of operators while performing their regular tasks, ensuring that representative postures and work cycles were captured.

Additionally, time studies were conducted at each workstation to measure task duration and identify cycle times, particularly for furniture assembly operations. These data served as a baseline for productivity analysis and supported the identification of critical workstations with high physical demand. To ensure accuracy, 30 samples were taken across all workstations. The average cycle times per minute for each workstation, including cutting, drilling, assembly, and others, were calculated and are presented in the table below in Table 1.

Table 1. Baseline data on task duration and cycle times for each workstation

	AVERAGE
MATERIAL RECEIVING	2.50
CUTTING OF PANELS	6.15
EDGING	3.99
DRILLING AND MILLING	5.93
ASSEMBLY	7.09
ADHESIVE APPLICATION AND PRESSING	5.27
SANDING AND FINAL FINISHES	5.08
QUALITY CONTROL	1.96
PACKAGING AND STORAGE	2.02
TOTAL TIME	40.00

These values were used to determine the baseline productivity for the workshop and were essential in identifying workstations with high physical demand. By examining the cycle times, it was possible to pinpoint areas where ergonomic improvements could lead to significant time reductions, ultimately improving overall productivity.

3.2 Musculoskeletal Symptom Assessment (NMQ)

The Nordic Musculoskeletal Questionnaire (NMQ) was administered to all operators to assess the presence and distribution of musculoskeletal symptoms during the previous 12 months. The questionnaire allowed the identification of body regions most affected by discomfort and pain, providing an initial ergonomic diagnosis based on workers perceptions.

Table 2 shows that 100% of the operators reported experiencing discomfort in the neck, shoulders, upper/lower back, elbows/forearms, and wrists, indicating widespread musculoskeletal symptoms across all body regions. In terms of work limitations, 75% of the operators reported that their discomfort affected their ability to perform tasks for 1-7 days in the past year. The remaining 25% did not report any significant work limitations due to their symptoms. This suggests that while most operators were affected, a smaller proportion experienced limitations for a more extended period.

Table 2. Summary of musculoskeletal symptoms by body region

Body Region	Symptoms in the Last Year (Q4)	Work Limitations in the Last 12 Months (Q7)		Average Pain Severity (Q10)
		0 Days (%)	1-7 Days (%)	
Neck	100%	25%	75%	3.25
Shoulders	100%	25%	75%	3.5
Upper/Lower Back	100%	0%	100%	4
Elbow/Forearm	100%	0%	100%	3.75
Wrists	100%	0%	100%	4

	Neck	Shoulders	Upper/ Lower Back	Elbow/ Forearm	Wrists
Operator 1	Head inclination while performing tasks	Pressure while performing tasks	Poor posture	Use of manual tools	Repetitive tasks
Operator 2	Head lowered	Carrying panels	Movement of pieces	Repetitive movements	Wrist pressure
Operator 3	Head down	Pushing force while assembling	Curved postures	Continuous use of tools	Repetitive movements
Operator 4	Bending posture	Repetitive movements	Long periods of standing	Repetitive movements	Use of force

Regarding pain severity, these results, as shown in Table 2 and Figure 1, indicate that the lower back and wrists were the most severely affected areas, with both regions showing the highest pain severity scores of 5. This highlights the need for ergonomic interventions, particularly in these areas, to reduce discomfort and improve the operator's overall well-being.

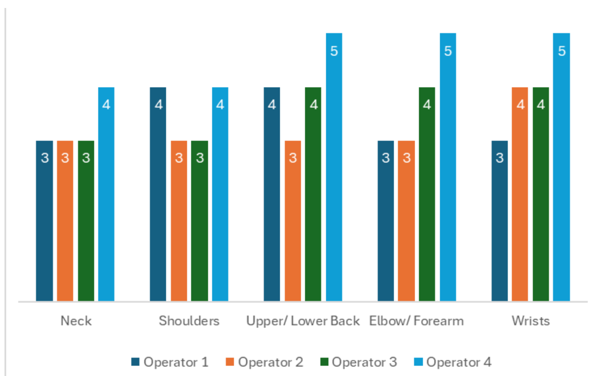

Figure 1. Pain severity levels by operator

These findings were crucial for identifying the workstations that required ergonomic analysis and redesign. The results were used to prioritize interventions at the most critical workstations to address the high prevalence of musculoskeletal symptoms and reduce the physical strain experienced by the workers.

3.3 Postural Risk Assessment using REBA

Postural risk assessment was performed using the Rapid Entire Body Assessment (REBA) method. Based on photographic and video records, representative postures were selected for each critical workstation. The evaluation considered trunk, neck, leg, and upper limb positions, as well as load handling and task frequency.

Figure 2 shows the cutting procedure and the worker's posture, with the angles identified for REBA analysis. These angles were used to evaluate postural risks and determine ergonomic improvements.

Figure 2. Cutting station

REBA scores were calculated for each selected posture and classified according to established risk levels. The assessment allowed the identification of workstations requiring immediate ergonomic intervention and provided a quantitative baseline for comparison after workstation redesign.

Figures 3 and 4 show the postures for the drilling and assembly stations, which were also among the most critical workstations analyzed. These figures provide a visual representation of the worker's posture during the tasks, which were essential for the REBA analysis.

Figure 3. Drilling station

Figure 4. Assembly station

Table 3 presents the REBA results for the cutting workstation, which is analyzed in detail in this section. Although the same procedure was applied to the drilling and assembly stations, this section focuses solely on the cutting station for a more thorough analysis.

Table 3. REBA scores for cutting workstations

Group A		
Evaluated Segment	**Justification**	**Score**
Trunk	Flexion >20° and ≤60° or extension >20°	3
	Trunk with lateral inclination or rotation	1
Neck	Flexion >20° or extension	2
	Head rotated or with lateral inclination	1
Legs	Sitting, standing, or walking with bilateral symmetrical support	1
Group B		
Evaluated Segment	**Justification**	**Score**
Arm	Extension >20° or flexion >20° and ≤45°	2
	There is a point of support or posture in favor of gravity	-1
Forearm	Flexion between 60° and 100°	1
Wrist	Flexion or extension >15°	2

Score Group A												
	Neck											
	1				2				3			
	Legs				Legs				Legs			
Trunk	1	2	3	4	1	2	3	4	1	2	3	4
1	1	2	3	4	1	2	3	4	3	3	5	6
2	2	3	4	5	3	4	5	6	4	5	6	7
3	2	4	5	6	4	5	6	7	5	6	7	8
4	3	5	6	7	5	6	7	8	6	7	8	9
5	4	6	7	8	6	7	8	9	7	8	9	9

Score Group B						
	Forearm					
	1			2		
	Wrists			Wrists		
Arm	1	2	3	1	2	3
1	1	2	2	1	2	3
2	1	2	3	2	3	4
3	3	4	5	4	5	5
4	4	5	5	5	6	7
5	6	7	8	7	8	8
6	7	8	8	8	9	9

Score Group C												
	Score Group B											
Score Group A	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Action level			
Score	**Level**	**Risk**	**Action**
1	0	Negligible	No action needed
2 or 3	1	Low	Action may be necessary
4 to 7	2	Medium	Action is necessary
8 to 10	3	High	Action should be taken as soon as possible
11 to 15	4	Very high	Immediate action is necessary

Each workstation was analyzed by assessing the worker's posture during task execution, with angles measured from photographs. These values were cross-referenced with Groups A and B, which represent the body segments involved (e.g., trunk, neck, arms). Then, the combined scores from these tables were used to calculate the final score in Group C for a comprehensive risk evaluation.

For the cutting station, the REBA score was calculated as 6, placing it in the medium risk level. This result indicates that corrective actions are necessary to reduce the ergonomic risks and improve the worker's well-being.

3.4 Biomechanical Simulation using 3DSSPP

To improve the ergonomic conditions for operators, several interventions were proposed based on biomechanical simulations conducted using the 3D Static Strength Prediction Program (3DSSPP). The analysis of postures and joint forces allowed us to identify key improvements that would reduce physical strain and enhance worker safety. These interventions were applied to critical workstations, including the cutting, drilling, and assembly stations. By simulating these ergonomic improvements, we assessed how these changes would impact joint forces and spinal compression at the L5/S1 level, ensuring that operators were placed in safer and more comfortable working conditions.

Cutting Station

At the cutting station, despite having a table with an integrated electric saw, forced postures were identified that could lead to musculoskeletal discomfort over time. To optimize working conditions, the following ergonomic improvements are proposed:

- Raising the worktable to 110 cm: This adjustment reduces the forward trunk and neck flexion of the operator, promoting a more neutral posture.
- Implementation of a sliding guide: This feature facilitates the movement of materials without excessive strain on the operator's arms, reducing the physical effort involved.
- Adjustable lateral cutting stops: Helps maintain a more balanced posture when cutting long pieces, ensuring less strain on the upper body.
- Focal lighting installation: Improves visibility, enhancing the precision of the cuts and reducing the risk of errors.
- Incorporation of saw blade safety guards: Increases safety during operation, minimizing the risk of accidents.
- Mandatory use of Personal Protective Equipment (PPE): Ensures that operators are protected by using gloves, safety glasses, ear protection, and other necessary safety gear.
- Training on correct posture techniques: Aims to educate operators on maintaining proper posture and movement to prevent musculoskeletal injuries.
- Implementation of active breaks: Encourages physical recovery throughout the workday, reducing fatigue and promoting overall well-being.

Drilling Station
In the improved scenario, it is proposed to replace the use of the handheld portable tool with a fixed drilling table featuring a built-in system, specifically designed to provide greater stability during operation. This table is equipped with an adjustable height mechanism, allowing the work surface to be adapted to the operator's anthropometry and the dimensions of the workpieces. Thanks to this modification:

- The need to hold the tool in mid-air is eliminated, significantly reducing strain on the wrists, forearms, and shoulders.
- Hand tremors are minimized by reducing the gripping effort required.
- Overall posture is improved, as the operator no longer needs to excessively lean forward.
- Compression load on the lumbar spine is reduced, minimizing the risk of musculoskeletal injuries.

Assembly Station
To reduce the musculoskeletal risks identified at the assembly station, a series of improvements are proposed aimed at optimizing working conditions and preventing forced postures:

- Ergonomic and lightweight drill: Reduces strain on the wrists and arms, minimizing fatigue during repetitive tasks.
- Adjustable worktable: Prevents forced postures and eliminates the need to work on the floor, promoting better posture and reducing physical strain.
- Progressive assembly by parts: Allows the assembly of modules on the table before final assembly, improving the overall posture of the operator and reducing unnecessary movements.
- Posture training: Encourages the correct use of tools and safe movement techniques, preventing long-term musculoskeletal issues.
- Active breaks and task rotation: Reduces fatigue and distributes physical workload between operators, allowing for recovery during work periods and minimizing the risk of overexertion.

Figure 5 presents the new workstation designs with the proposed ergonomic improvements, illustrating the correct posture and safe working conditions for operators in the cutting and assembly stations. These figures show how the operators would look while performing their tasks using the improved workstation setups, with the proper body alignment and ergonomically optimized positions.

Figure 5. Simulation of operator postures after ergonomic improvements using 3DSSPP,

3.5 Ergonomic Intervention and Validation Procedure

After conducting the biomechanical simulations, a subsequent REBA assessment was carried out to validate that the proposed ergonomic improvements were effectively implemented. This evaluation ensured that the workstation modifications, such as the adjustment of table heights and the introduction of ergonomic tools, successfully reduced postural risk and biomechanical stress for the operators.

Figure 5 was used to visualize the ergonomic improvements and postural changes, which served as the basis for conducting the REBA assessment. This enabled the validation of the proposed workstation modifications in terms of ergonomic alignment and safety.

Table 4 displays the results of the second REBA assessment conducted on the newly adjusted workstations. The results indicated a negligible risk level, meaning no immediate corrective action is required. This suggests that the ergonomic improvements were successful, as the workstations now meet the necessary ergonomic standards, reducing both postural risks and physical strain on the operators.

Table 4. REBA Results for the Cutting Station After Ergonomic Improvements

Group A		
Evaluated Segment	**Justification**	**Score**
Trunk	Upright trunk	1
Neck	Flexion between 0° and 20°	1
Legs	Sitting, standing, or walking with bilateral symmetrical support	1
Group B		
Evaluated Segment	**Justification**	**Score**
Arm	Extension >20° or flexion >20° and ≤45°	2
	There is a point of support or posture in favor of gravity	-1
Forearm	Flexion between 60° and 100°	1
Wrist	Flexion or extension >15°	1

Score Group A												
	Neck											
	1				2				3			
	Legs				Legs				Legs			
Trunk	1	2	3	4	1	2	3	4	1	2	3	4
1	1	2	3	4	1	2	3	4	3	3	5	6
2	2	3	4	5	3	4	5	6	4	5	6	7
3	2	4	5	6	4	5	6	7	5	6	7	8
4	3	5	6	7	5	6	7	8	6	7	8	9
5	4	6	7	8	6	7	8	9	7	8	9	9

Score Group B						
	Forearm					
	1			2		
	Wrists			Wrists		
Arm	1	2	3	1	2	3
1	1	2	2	1	2	3
2	1	2	3	2	3	4
3	3	4	5	4	5	5
4	4	5	5	5	6	7
5	6	7	8	7	8	8
6	7	8	8	8	9	9

Score Group C												
	Score Group B											
Score Group A	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Action level			
Score	**Level**	**Risk**	**Action**
1	0	Negligible	No action needed
2 or 3	1	Low	Action may be necessary
4 to 7	2	Medium	Action is necessary
8 to 10	3	High	Action should be taken as soon as possible
11 to 15	4	Very high	Immediate action is necessary

4. Results and Discussion

4.1 Numerical Results

The results of the ergonomic intervention showed significant improvements in both labor productivity and worker health. After the ergonomic modifications, a 14% increase in labor productivity per man-hour was observed, with output rising from 160 units per month to 200 units per month. This increase in productivity clearly demonstrates that the ergonomic improvements, such as the introduction of height-adjustable tables and ergonomically designed tools, had a clear positive impact on the operational efficiency of the workshop. This improvement is shown in Table 5, additionally, the assembly time per unit decreased by 8.5 minutes, indicating that the changes made to the workspace layout and the tools significantly reduced unnecessary physical effort and task completion time.

Table 5. Labor productivity before and after intervention

Indicator	Before the intervention	After the intervention	Variation (%)
Productivity (furniture/ Human Hour)	1.5	1.71	14%
Monthly production (Units)	160	200	25%
Assembly Time (min/unit)	40	31.5	−21.2 %

Regarding postural risk, the REBA scores for the critical workstations (cutting, drilling, and assembly) showed a significant improvement. Prior to the ergonomic intervention, the REBA scores indicated high-risk levels due to awkward postures and repetitive movements. After implementing the ergonomic improvements, the scores dropped considerably, with most postures now categorized within low to negligible-risk levels. Table 6 presents these ergonomic changes, illustrating the reduction in postural risk levels before and after the intervention. The introduction of adjustable workstations and tool design modifications were effective in reducing musculoskeletal strain and improving the operators' overall posture during their tasks.

Table 6. Postural Risk Levels (REBA Scores) Before and After Intervention

Station	Before REBA Score	Risk level Before	After REBA Score	Risk level After
Cutting	7	Medium	1	Negligible
Drilling	13	Very high	1	Negligible
Assembly	10	High	2	Low

The spinal compression at the L5/S1 level also showed a noticeable reduction. Prior to the intervention, the spinal compression force average was 3,350 N, which was above the recommended safety limits. After the implementation of ergonomic improvements, the compression force dropped to 2,267 N, aligning with ergonomic safety guidelines. Table 7 presents these results, highlighting the significant reduction in spinal compression after the ergonomic changes. This reduction in spinal compression suggests that the ergonomic adjustments were successful in mitigating the risk of long-term spinal injuries and improving workers' overall physical health.

Table 7. Spinal Compression Forces (L5/S1) Before and After Intervention

Station	Force Before (N)	Force After (N)	Reduction (%)
Cutting	3300	2300	30%
Drilling	3400	2300	32%
Assembly	3350	2200	34%
Total Average	3350	2267	32%

In addition to improving workers' well-being, these changes also had a positive impact on workshop productivity. The reduction in postural risk and spinal compression, coupled with the increase in labor productivity, demonstrates that ergonomic interventions not only make the workspace safer but also more efficient. The results support the idea that such ergonomic improvements are feasible and beneficial, even in small-scale, low-tech workshops, where the integration of ergonomic tools and practices can lead to significant benefits for both health and operational performance.

4.2 Implementation Cost Analysis

The proposed ergonomic improvements required an estimated investment of approximately USD 2,240, including height-adjustable worktables, ergonomic drills, personal protective equipment, ergonomic signage, worker training sessions, and workstation modifications. These investments support the ergonomic strategies described in the proposed improvements section, particularly workstation adaptability, task rotation optimization, and continuous ergonomics training. Despite the relatively low implementation cost, the intervention resulted in significant improvements in labor productivity, reduced assembly time, and lower biomechanical risk levels. These findings demonstrate that ergonomic interventions can be economically feasible and beneficial for small-scale manufacturing workshops.

4.3 Proposed Improvements

In addition to the implemented ergonomic interventions, further improvements are proposed to enhance both worker well-being and overall productivity in the workshop. Since workers already rotate between key stations such as cutting, drilling, and assembly, the proposed improvements aim to further optimize workstation flexibility and comfort to better suit the task variety and worker needs throughout the day.

Height-adjustable tables and ergonomically designed tools are crucial components that would allow workstations to be easily adapted to the different postures required for various tasks. By making the workspace adjustable to each task's needs, forced and repetitive postures can be minimized, reducing physical fatigue and enhancing efficiency across all stations. The ability to modify the workstation layout not only addresses ergonomic issues but also maximizes productivity, as operators can perform tasks with less strain and more precision.

In addition, while the task rotation system is already in place, a more structured approach would be beneficial to further distribute the physical workload across the different stations, especially those that require repetitive movements. By ensuring that no worker is continuously exposed to tasks that involve excessive physical effort, fatigue and the risk of musculoskeletal disorders can be further reduced. This optimized task rotation system will foster a more sustainable work environment, enabling workers to stay healthier and more productive in the long run.
Moreover, ergonomics training programs should be introduced to ensure workers understand the importance of maintaining proper posture, using tools safely, and fully benefiting from the ergonomic adjustments made. This training will not only guarantee that workers adopt best practices but will also improve overall workplace culture, promoting proactive health management and self-awareness. Training will be crucial in making the improvements sustainable, ensuring that the positive effects are long-lasting and not just a temporary adjustment.

Wider Implications: The proposed ergonomic improvements extend beyond just the immediate impact on workers' health and productivity. By fostering a safer and more efficient workspace, these interventions can help the company reduce absenteeism and lower the risk of costly worker compensation claims. Furthermore, these changes align with broader sustainability goals and corporate responsibility, as improving the health and well-being of workers can enhance employee retention, morale, and engagement. In the long term, investing in ergonomics can contribute to greater operational efficiency, reduce turnover rates, and promote a healthier workforce, creating a win-win scenario for both employers and employees.

Finally, while these improvements focus on ergonomic design and task management, the role of management in reinforcing these changes is vital. Leaders must be committed to continually monitoring the implementation of ergonomic practices, ensuring regular adjustments, and investing in employee education to adapt to evolving challenges in the workplace. This continuous feedback loop is essential for maintaining a healthy and high-performing work environment

To ensure the long-term sustainability of these ergonomic improvements, periodic ergonomic assessments, continuous worker training, and regular workstation maintenance should be maintained over time. In addition, continuous monitoring of productivity and ergonomic risk indicators will help organizations preserve the positive effects of the intervention and support ongoing workplace improvement.

5. Conclusion

This study has successfully demonstrated the positive effects of ergonomic interventions in a melamine furniture production workshop. By addressing key workstations such as cutting, drilling, and assembly, significant improvements were achieved in both worker health and productivity. Before the intervention, workers faced high levels of postural risk, particularly in the cutting and drilling stations, where REBA scores were notably high. After the implementation of height-adjustable tables, ergonomically designed tools, and optimized workspaces, the postural risk was significantly reduced, and REBA scores dropped to low and medium risk levels.

The Nordic Musculoskeletal Questionnaire (NMQ) also revealed a marked decrease in musculoskeletal discomfort, especially in the lower back and wrists, areas that were previously reported as being the most problematic. These improvements in comfort and health were not only noticed by the workers but were also validated by the decreased spinal compression measured at the L5/S1 level. The reduction in spinal compression forces from 3,350 N to 2,300 N further validated that the ergonomic changes were effective in lowering the physical strain on workers' spines, aligning with ergonomic safety guidelines.

In terms of productivity, the improvements have had a direct impact. Labor productivity increased by 14%, with output rising from 160 units per month to 200 units per month. This increase was accompanied by a reduction of 8.5 minutes per unit in the assembly time, highlighting the efficiency gains brought about by the ergonomic redesign.

Overall, the findings underscore the importance of ergonomics in improving both the health and efficiency of workers, particularly in small-scale manufacturing environments. The results of this study demonstrate that even low-cost ergonomic solutions, such as adjustable tables and ergonomic tools, can lead to substantial improvements in worker well-being and operational performance.

These findings also emphasize the need for continuous ergonomics training, periodic ergonomic assessments, and workstation maintenance to sustain the improvements achieved over time, ensure that workers adopt best ergonomic practices, and support the development of safer and more sustainable manufacturing systems. Future research could explore the long-term effects of these interventions in different industrial settings and evaluate the cost-effectiveness of implementing such solutions on a broader scale.

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