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Risk-Driven Ergonomic Redesign of a Woodworking CNC Workstation: WERA Analysis, Anthropometric Translation, and a Hydraulic Lift Table Proposal

Firman Ardiansyah Ekoanindiyo*
Universitas Stikubank , Indonesia

Antoni Yohanes
Universitas Stikubank , Indonesia

Zuly Budiarso
Universitas Stikubank , Indonesia

Rina Candra Noor Santi
Universitas Stikubank , Indonesia

Theresia Dwiati Wismarini
Universitas Stikubank , Indonesia

***Corresponding author:**
Firman Ardiansyah Ekoanindiyo, Universitas Stikubank , Indonesia.
✉firman@edu.unisbank.ac.id

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Abstract

Background: Wood-based manufacturing still relies on repetitive manual material handling around CNC workstations, exposing workers to awkward postures, high physical demands, and prolonged standing. At the observed workstation, the primary ergonomic problems were associated with loading, unloading, inspection, and palletizing activities rather than with the machining cycle itself.
Objective: This study aimed to address ergonomic issues associated with CNC workstation activities by proposing an ergonomic intervention involving the redesign of a CNC support workstation with a hydraulic lift table. The contribution of this study lies in integrating task-level ergonomic risk assessment with anthropometric design to develop a practical engineering proposal for wood manufacturing.
Methods: A quantitative descriptive approach was employed, incorporating direct observation, postural documentation, interviews, Nordic Body Map screening, anthropometric measurements, and the Workplace Ergonomic Risk Assessment (WERA) method. The study involved 14 workers, comprising 5 CNC operators and 9 helpers.
Results: The WERA scores were 28 for operators and 41 for helpers, indicating greater ergonomic risk exposure among helpers. The predominant risk factors were shoulder posture, neck posture, forceful exertion, repetition, and task duration. Anthropometric analysis informed the proposed design of a hydraulic lift table with a platform measuring 1,300 × 1,100 mm, an adjustable height range of 300–900 mm, and a minimum lifting capacity of 100 kg.
Conclusion: Helper tasks represent the most critical source of ergonomic risk at the CNC workstation. The proposed hydraulic lift table offers a feasible engineering intervention to reduce ergonomic risks and support occupational health and safety in wood manufacturing.

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INTRODUCTION

According to the International Labour Organization (ILO, 2019), musculoskeletal

disorders account for over 35% of work-related injuries in manufacturing. Despite the increasing adoption of computer numerical control (CNC) technology, recent ergonomic research Krishnanmoorthy et al. (2025) and Santos et al. (2025) has moved beyond simple hazard identification toward intervention-oriented design. International studies have reported that workstation redesign, assistive devices, and participatory ergonomics can reduce discomfort, biomechanical exposure, absenteeism, and productivity losses when interventions are tailored to the dominant sources of exposure rather than applied generically (Alenjareghi et al., 2026; Brosche et al., 2024; Butlewski & Broda, 2025; Marcotte et al., 2024; Mares et al., 2025; Vigoroso et al., 2025).

At the workstation level, ergonomic exposure does not arise from a single variable; rather, it results from the interaction of posture, repetition, force, contact stress, exposure duration, and workspace geometry. Manual material handling tasks remain particularly sensitive to these factors because the same task can become substantially more hazardous when the load origin is too low, the transfer distance is excessive, or workers must repeatedly accommodate unstable load heights (Arachchige et al., 2025; Ashtiani et al., 2025; Brosche et al., 2024; Marcotte et al., 2024; Musso et al., 2024; Okunola et al., 2025; Sosa et al., 2024).

This problem is particularly pronounced in wood manufacturing because sheet materials and long wooden panels are bulky, frequently repositioned, and commonly transferred between machine tables and low pallets. Recent studies of timber handling, carpentry, industrial packaging, and manual production systems consistently indicate that awkward shoulder loading, sustained trunk flexion, and repetitive board handling are among the most critical ergonomic exposure patterns in these settings (Ashtiani et al., 2025; Brunnera et al., 2024; Ciccarelli et al., 2024; Kalkis et al., 2024; Kshirsagar et al., 2025; Makris et al., 2024; Nieto et al., 2024; Okunola et al., 2025; Roy et al., 2024; Savkovi et al., 2026; Zen et al., 2024).

However, an important practical gap remains. Many studies of CNC-related work emphasize machining quality or general postural assessment, whereas fewer translate workstation risk assessment findings into dimensioned engineering interventions that can be directly implemented in industrial settings. In particular, differences in the roles of operators and helpers at woodworking CNC workstations remain underreported, even though support tasks may involve greater ergonomic exposure than machine operation itself.

To address this gap, this study investigates a woodworking CNC workstation at which operators and helpers perform repetitive material handling and inspection tasks along the production line. The study first evaluates role-specific ergonomic exposure using the Workplace Ergonomic Risk Assessment (WERA) method, supported by screening with the Nordic Body Map (NBM), and then translates the findings into a hydraulic lift table concept informed by workers' anthropometric characteristics.

This study makes three main contributions: (1) providing a role-based ergonomic assessment of a woodworking CNC workstation and identifying helper tasks as the primary target for intervention; (2) integrating WERA, NBM, and anthropometric percentile analysis into a risk-driven redesign workflow rather than treating these methods as separate assessments; and (3) developing an implementable lift table specification that translates identified ergonomic risks and measured exposure factors into workstation design parameters suitable for industrial adoption.

Accordingly, this study aims to quantify ergonomic risk at the CNC workstation using established assessment tools, identify the specific work elements and postures that contribute most to the observed risk, and translate the assessment findings into implementable design specifications for an assistive hydraulic lift table. By integrating WERA, NBM screening, and anthropometric analysis, the study establishes a risk-driven redesign framework that directly links identified ergonomic exposures to practical workstation design requirements (Zahabi et al., 2025). Additionally, research on the effects of floor inclination on torque production and postural adjustments during handwheel operations has highlighted the critical role of workspace geometry in ergonomic performance (Abautret et al., 2025). Data-driven approaches to ergonomic risk assessment have been shown to improve the identification of risks associated with complex, hand-intensive manufacturing processes, such as those found in woodworking (Krishnan et al., 2025). Research on warehouse design, particularly in high-demand environments, emphasizes the importance of ergonomic solutions for operational efficiency and worker well-being (Nasir et al.,

2024). This body of literature supports the methodology adopted in the present study, which integrates multiple ergonomic assessment tools and anthropometric data to develop effective interventions, such as hydraulic lift tables, for CNC workstations (Firescu & Filip, 2025). Furthermore, improvements in productivity and ergonomic conditions have been reported in packaging work areas, which share similarities with woodworking CNC operations (Brito et al., 2024). Research on the optimization of CNC milling parameters for material hardness and surface roughness provides another relevant example of efforts to improve machining quality and process performance (Bouriche et al., 2024). In material handling industries, ergonomic assessments and measures to mitigate musculoskeletal disorders are critical to protecting workers' long-term health (Rajesh et al., 2023). Similarly, studies of the prevalence of manual load handling and its associated pathologies among construction workers demonstrate how sustained physical strain can lead to significant long-term health consequences (Arenas et al., 2023). Assessments in the plastics manufacturing industry also highlight the importance of workstation ergonomics in reducing worker fatigue and improving performance (Sajeev & Binoosh, 2025). Therefore, ergonomic redesign is essential not only for improving occupational safety but also for enhancing overall productivity in industrial settings (Marchisio & Collao-Díaz, 2023), including CNC machining environments such as the one examined in this study. The application of ergonomic principles in manufacturing companies to increase productivity and worker satisfaction further supports the view that ergonomic improvements are integral to sustainable production systems (Syifatillah & Machfuroh, 2026).

METHOD

This research employed a quantitative descriptive design supported by direct workplace observation, task documentation, interviews, Nordic Body Map (NBM) screening, anthropometric measurements, and Working Ergonomic Risk Assessment (WERA) scoring. The methodological approach followed a sequential process: identifying areas of concentrated discomfort, evaluating task-level ergonomic exposure, translating anthropometric data into workstation design requirements, and developing a preimplementation engineering intervention for the observed CNC workstation. The study was conducted at a woodworking manufacturing company operating a computer numerical control (CNC) workstation for cutting and subsequent board handling. The observed workforce consisted of 14 workers: five CNC operators and nine helpers. Operators were primarily responsible for machine-side material handling and process monitoring, whereas helpers were more extensively involved in quality inspection, board retrieval, stacking, and pallet transfer. This distinction was important because the two roles involved different combinations of force, posture, and repetition.

Representative task cycles were documented for both roles. For operators, the cycle included receiving materials, positioning boards near the machine, transferring materials at the machine side, and handling processed boards. For helpers, the cycle included retrieving boards from the machine area, inspecting product quality, carrying or repositioning panels, and stacking them on pallets. Photographic documentation and repeated observational records were used to support consistent WERA scoring and reduce the likelihood of assigning scores based on a single, unrepresentative posture.



Figure 1. Operator posture during CNC material positioning and machine-side handling



Figure 2. Worker posture during manual board handling around the CNC workstation, showing forward reach and non-neutral upper-body posture.

As shown in Figures 1 and 2, the observed CNC workstation requires workers to interact directly with long wooden boards during positioning, transfer, and inspection activities. These visual records support the WERA scoring process by documenting postural exposures, including forward reaching, trunk inclination, and upper-limb involvement during manual material handling.

NBM screening was used as an initial assessment to identify body regions associated with recurring discomfort. Although subjective, the NBM results supported the interpretation of whether reported discomfort patterns were consistent with the ergonomic exposures observed at the CNC workstation. The screening focused on complaints involving the neck, shoulders, back, wrists, and lower limbs. WERA was used as the primary ergonomic assessment method because it considers posture, repetition, forceful exertion, contact stress, and task duration. The assessment was applied to representative activity patterns for both operators and helpers. The proposed hydraulic lift table was treated as a preimplementation engineering redesign. Accordingly, this study does not claim a measured reduction in ergonomic risk following the intervention; instead, it develops a rationale for the proposed intervention based on observed ergonomic exposures and anthropometric requirements.

Anthropometric processing focused on three dimensions directly relevant to standing material-transfer tasks: hip height, forward reach, and shoulder breadth. Hip height was used to establish the practical vertical material-transfer zone, forward reach informed the horizontal access range, and shoulder breadth informed the usable working width. Percentile selection was based on ergonomic accommodation principles rather than on a single average value. Percentile values were estimated using standard descriptive statistics. The general percentile formulation is presented in Equation (1), where (\bar{x}) denotes the sample mean, (z) denotes the standard normal deviate corresponding to the selected percentile, and (s) denotes the sample standard deviation. Anthropometric measurements were obtained using an anthropometric measuring rod with a reported precision of ±0.5 cm and an adjustable measuring tape. Measurements were taken with participants standing upright and their feet approximately shoulder-width apart. The 5th, 50th, and 95th percentiles were selected to represent different body-size ranges and inform the accommodation of a broad proportion of the workforce. However, these percentiles do not, by themselves, guarantee accommodation of 90% of workers across all design dimensions.

$$Pk = x\text{-}bar + z\ s \quad (1)$$

The total WERA score was calculated by summing the component scores specified by the assessment method. Based on the risk categories adopted in this study, scores below 20 were classified as low risk, scores from 20 to 40 as medium risk, and scores above 40 as high risk (Kalkis et al., 2024). The resulting risk classifications were interpreted alongside task observations and NBM screening results to identify the dominant sources of ergonomic exposure and establish priorities for workstation redesign. These thresholds should be verified against the specific WERA scoring protocol and reference cited in the study to ensure that the classifications are consistent with the method used.

The research design, methodology, assessment procedures, and data-collection process are presented chronologically. Where applicable, the methodological description should be supported by relevant references to establish its scientific basis and reproducibility. Each table and figure is cited in the main text before or when it is discussed. For example, Figure 1 illustrates the operator's posture during material positioning and machine-side handling. The discussion may be organized into several subsections to distinguish the research design, data-collection procedures, assessment methods, and intervention-development process.

Table 1
Research components, instruments, and outputs

Component	Description	Output in this study
Subjects	14 workers (5 operators, 9 helpers)	Observed handling tasks around the CNC station
Primary ergonomic tool	WERA posture and physical exposure assessment	Task-level ergonomic risk score
Supporting screening	Nordic Body Map	Body regions with subjective discomfort
Anthropometry	Hip height, forward reach, shoulder breadth	Percentile-based design dimensions
Intervention output	Hydraulic lift table concept	Engineering proposal for risk reduction

The analytical workflow consisted of four stages. First, NBM screening was conducted to identify the body regions associated with the most prominent discomfort complaints. Second, WERA scoring was performed for representative operator and helper task cycles. Third, anthropometric data were processed to establish the dimensional basis for the workstation redesign. Fourth, the findings were translated into a proposed hydraulic lift-table specification and an anticipated risk-reduction pathway targeting the most critical WERA variables. This workflow was designed to strengthen the practical relevance of the study. Rather than ending with an ergonomic risk classification, the study translates the assessment findings into a workstation-level intervention concept that can be reviewed, prototyped, and validated in a future preintervention–postintervention study.

RESULT

The field data clearly showed that the operator and helper were exposed to different ergonomic burdens, even though they worked in the same CNC workstation area. Operators were more directly involved in machine interaction and moderate board repositioning, whereas helpers performed more frequent retrieval, inspection, transfer, and palletizing activities. Consequently, the helper role involved greater exposure to non-neutral postures, forceful exertion, and repetitive tasks. This role-based distinction is analytically important because workstation interventions should target the dominant sources of ergonomic exposure rather than merely the job titles associated with the machine. In many manufacturing settings, attention is concentrated on the operator because the machine is regarded as the center of production. The present findings, however, reveal a different pattern: the greatest ergonomic burden was associated with the supporting manual handling tasks surrounding the CNC process.

The total WERA scores demonstrated a clear difference in ergonomic risk between the two roles. The operator obtained a total score of 28, which falls within the medium-risk category, whereas the helper obtained a score of 41, placing the helper task in the high-risk category according to the risk classification adopted in this study. The helper also recorded higher scores for shoulder posture, neck posture, forceful exertion, repetition, and task duration. These findings indicate that the highest-priority redesign intervention should focus on reducing mismatches between board-transfer height and workers' ergonomic requirements, as well as minimizing repeated handling at pallet level, rather than modifying the machining operation itself.

Table 2
Anthropometric Percentiles Used for Intervention Design

Variable	P5 (cm)	P50 (cm)	P95 (cm)
Hip height	84.79	89.43	94.07
Forward reach	71.55	75.79	80.03
Shoulder breadth	36.96	39.21	41.46

The anthropometric percentiles presented in Table 2 provided the dimensional link between ergonomic risk assessment and workstation redesign. Hip-height percentiles were used to define a practical standing transfer zone, forward reach informed the accessible horizontal interaction range, and shoulder breadth informed the platform width and allocation of usable space. This approach strengthens the engineering basis of the intervention because the lift table dimensions are derived from worker anthropometry rather than selected arbitrarily. Using anthropometric data in this manner enhances the practical applicability of the findings for practitioners. Many ergonomic studies recommend redesign in general terms, but practitioners often require specific dimensional guidance to determine whether an intervention is feasible within an existing production layout. The present study therefore translates the observed exposure problems into workstation parameters that can realistically be specified, fabricated, and tested.

The selected percentile values also reflect the principles of ergonomic accommodation. The lower-percentile hip height helps prevent an excessively high loading point for shorter workers, the median forward-reach value supports efficient interaction without requiring the platform to be positioned too far from the worker, and the higher-percentile shoulder breadth informs the provision of adequate lateral working space. The design objective is not to optimize the workstation for a single individual but to accommodate the observed range of worker dimensions within a practical industrial device.

Table 3
WERA summary for operator and helper tasks

Variable	Operator	Helper	Interpretation
Shoulder	2	5	Helper markedly higher
Wrist	3	4	Both moderate
Back	3	4	Helper higher trunk demand
Neck	3	5	Helper high due to forward flexion
Legs	3	4	Helper less stable posture
Force/load	4	5	Helper handled heavier boards
Repetition	2	5	Repetitive helper activity
Contact stress	4	4	Similar local stress
Task duration	4	5	Helper exposed longer
Total score	28	41	Operator: medium risk; Helper: high risk

Table 3 confirms that the helper task is the primary target for ergonomic redesign. Compared with the operator, the helper exhibited substantially higher scores for shoulder posture, neck posture, force/load, repetition, and task duration, whereas both roles showed comparable scores for contact stress and relatively similar scores for wrist and back posture. This pattern indicates that the workstation problem involves not only posture but also repeated interactions among load height, handling effort, and inspection-related reaching. The qualitative observations were consistent with the Nordic Body Map (NBM) screening results, which indicated recurrent complaints involving the neck, shoulders, upper back, lower back or waist, forearms, wrists, and knees. This alignment is important because it suggests that the observational risk profile is consistent with the workers' reported experiences. In other words, the measured postural and force-related exposures correspond to discomfort patterns that workers report during daily production activities.

The agreement between subjective and observational data strengthens the internal

coherence of the study. Although NBM screening alone cannot establish biomechanical risk, and WERA alone cannot fully explain individual pain perceptions, the convergence of the two methods provides a stronger basis for prioritizing interventions. In this case, both methods indicate that repeated low-level pallet handling and board transfer are among the most problematic work elements.

The present findings are also consistent with international research on industrial manual handling and workstation redesign, in which awkward shoulder loading, sustained trunk flexion, and repetitive transfer cycles are frequently identified as important ergonomic risk factors. Research in manufacturing, packaging, and woodworking-related settings similarly suggests that engineering redesign is more effective when it addresses the physical sources of exposure rather than relying exclusively on worker instruction or behavioral reminders. Accordingly, the contribution of this article extends beyond risk classification. It demonstrates a risk-driven redesign approach in which WERA identifies the dominant ergonomic exposure components, NBM screening characterizes the reported discomfort patterns, anthropometric data inform feasible workstation dimensions, and the proposed intervention is formulated as an implementable engineering concept. This integration strengthens the practical relevance of the study by linking ergonomic risk assessment directly to workstation design specifications that can be considered for implementation and subsequent empirical validation.

Table 4
Proposed Hydraulic Lift Table Specification

Component	Proposed specification	Ergonomic rationale
Platform	1300 x 1100 mm	Accommodates palletized wood boards with side tolerance
Working height	300-900 mm	Brings load closer to standing transfer zone
Lifting capacity	>= 100 kg	Exceeds observed board-and-pallet demand with safety margin
Scissor mechanism	Stabilized lifting frame	Supports smooth height adjustment and reduces manual lifting
Hydraulic system	Electric hydraulic actuator and controller	Allows controlled vertical positioning
Hose and reservoir	Approx. 1.5 m hose; 15 L reservoir	Practical layout for industrial installation

Based on the identified ergonomic risks and the proposed specifications in Table 4, a hydraulic lift table was developed as an engineering control for the CNC workstation, as illustrated in Figure 3. The design is intended to maintain the board-handling height within an appropriate ergonomic zone, reduce trunk flexion, minimize shoulder elevation, and decrease repetitive manual lifting during loading, inspection, and palletizing activities.

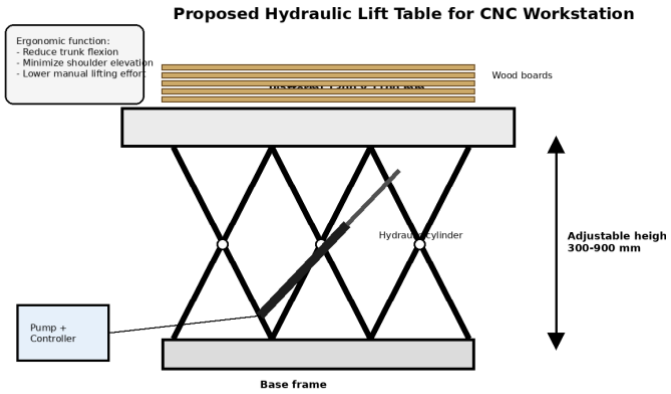


Figure 3. Proposed hydraulic lift table design for the CNC workstation to reduce trunk flexion and manual lifting effort

The hydraulic lift table specifications presented in Table 4 were developed as a preliminary industrial design concept rather than a purely illustrative sketch. The platform is intended to accommodate palletized wood boards with practical lateral clearance, the proposed working-height range is intended to keep the load closer to the standing transfer zone, and the specified lifting capacity is intended to provide a safety margin above the anticipated handling load. These features are intended to preserve compatibility with the existing production flow while reducing the need for workers to reach deeply downward during board transfer and stacking.

Operationally, the lift table would keep the top surface of the material stack closer to the intended working zone as the number of boards changes throughout the shift. Without such adjustment, workers must continually adapt to the decreasing stack height, which can progressively increase trunk flexion, shoulder reach, and lifting effort. By stabilizing the material-handling height, the proposed redesign directly addresses the source of exposure that dominated the helper task. The expected ergonomic effects can be linked to the relevant WERA assessment components. A higher transfer surface should reduce trunk flexion during loading and palletizing. Reduced reach depth should improve shoulder posture and decrease forward neck inclination during inspection. A shorter vertical lifting distance should reduce physical exertion, particularly when handling long, bulky panels. In addition, maintaining a more consistent interaction height may reduce unnecessary corrective body movements as workers adjust their positions to access a low material stack.

To further clarify the proposed mechanism of improvement, a conceptual before-and-after workstation layout is presented in Figure 4. The initial configuration depicts manual handling from low pallet positions, whereas the proposed configuration incorporates the hydraulic lift table to keep the material closer to the intended standing work zone. This comparison strengthens the engineering rationale for the intervention because the redesign directly addresses the physical source of exposure rather than relying solely on worker instruction.

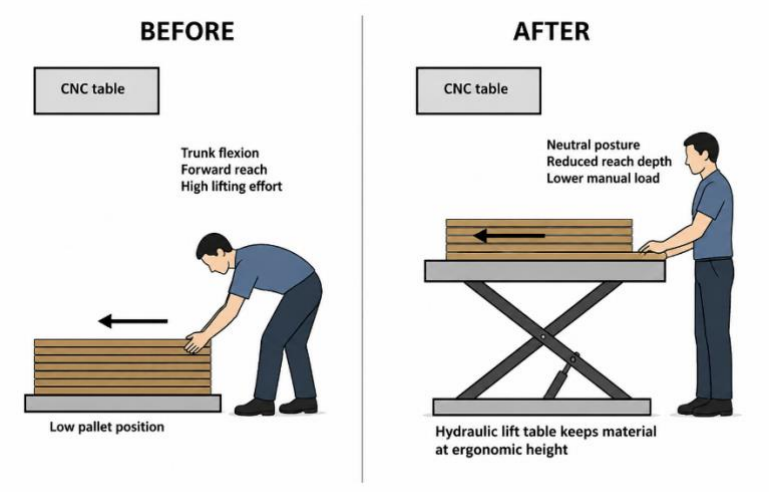


Figure 4. Before-after layout of the CNC workstation showing ergonomic improvement using the hydraulic lift table

Table 5
Expected relationship between the intervention and WERA reduction

WERA component	Observed problem	Expected effect of lift table
Back posture	Frequent bending during loading and palletizing	Lower flexion angle during transfer
Shoulder posture	Elevated shoulder while reaching over load	Reduced reach height and shoulder elevation
Neck posture	Forward head or neck while checking	Improved visual access at better

WERA component	Observed problem	Expected effect of lift table
	boards	height
Force/load	Manual lifting from low stacks	Reduced effective lifting demand
Repetition	Repeated stoop-and-lift cycle	Less severe exposure per repetition

The reduction pathway outlined in Table 5 should be interpreted as a structured ergonomic hypothesis. It does not replace empirical validation; rather, it makes the proposed mechanism of change explicit and testable. This distinction is important for publication quality because redesign proposals are stronger when they specify not only what should be changed but also which exposure variables are expected to improve and why. From a sustainable occupational health perspective, the proposed intervention has practical potential because it targets a recurring manual handling activity without requiring fundamental modifications to the CNC machine, its software, or the production sequence. However, its actual feasibility, scalability, and ergonomic effectiveness must be established through implementation and before-and-after assessment.

The redesign also has broader managerial implications. Reducing physical exposure may support more consistent work performance, limit fatigue accumulation throughout the shift, improve the consistency of quality inspections, and potentially reduce work interruptions associated with discomfort. Therefore, ergonomic redesign should be viewed not only as a safety initiative but also as a strategy for supporting production within sustainable manufacturing systems. Nevertheless, the article should be interpreted within the boundaries of its empirical evidence. The lift table remains a preimplementation proposal, and no before-and-after validation, electromyographic assessment, or productivity experiment was conducted. The study also represents a single company setting and one workstation configuration. Accordingly, the findings should be generalized cautiously and primarily regarded as an applied ergonomic framework for similar woodworking environments.

Future research should proceed in three stages. First, the proposed lift table should be prototyped and integrated into the existing workstation. Second, postimplementation WERA scores and NBM results should be compared with the baseline findings reported in the present study. Third, additional outcomes, including cycle time, operator acceptance, and material-flow compatibility, should be evaluated to determine the ergonomic benefits of the redesign alongside its operational feasibility.

CONCLUSION

Helper tasks at the studied CNC workstation presented greater ergonomic risk than operator tasks, with WERA scores of 41 and 28, respectively. According to the risk classification applied in this study, the operator task was categorized as medium risk, whereas the helper task was categorized as high risk. The dominant exposure factors for helpers involved shoulder and neck posture, forceful exertion, repetition, and task duration, particularly during board retrieval, inspection, transfer, and palletizing activities. By integrating WERA, Nordic Body Map screening, and anthropometric analysis, the study translated the identified ergonomic risks into a risk-driven workstation redesign proposal.

Based on the measured worker anthropometry and the identified workstation requirements, the proposed hydraulic lift table has a platform measuring 1,300 × 1,100 mm, an adjustable working-height range of 300–900 mm, and a lifting capacity of at least 100 kg. However, the redesign remains a preimplementation engineering proposal and has not yet been validated through before-and-after ergonomic assessment, productivity testing, or user-acceptance evaluation. Future research should therefore prototype and implement the proposed intervention and evaluate changes in WERA scores, worker discomfort, operational compatibility, and production performance.

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AUTHOR CONTRIBUTION STATEMENT

Firman Ardiansyah Ekoanindiyo contributed to the conceptualization, methodology, data analysis, and writing of the manuscript. Antoni Yohanes contributed to the research design and methodology. Zuly Budiarso contributed to data analysis and interpretation of results. Rina Candra Noor Santi contributed to data collection, data processing, and manuscript preparation. Theresia Dwiati Wismarini contributed to supervision and validation. All authors have read and approved the final version of the manuscript.

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