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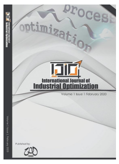

Occupational health risk assessment of manufacturing workers using the hand activity level method

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Repetitive manual handling tasks in industrial settings often expose workers to musculoskeletal risks, particularly when performed without ergonomic consideration. At PT. ABC, production workers are routinely engaged in lifting and assembling heavy components, raising concerns about their long-term health and safety. To address this issue, a structured assessment using the ACGIH TLV for Hand Activity Level (HAL) was conducted to evaluate biomechanical exposure and identify ergonomic risks. This study contributes by applying a quantitative, evidence-based framework to assess real workplace conditions and offer actionable insights for intervention. It also demonstrates how HAL and Borg CR-10 metrics can be integrated into practical ergonomic evaluations in industrial environments. The research involved five workers from the concrete production division. Data were collected through direct observation and video analysis to determine hand movement frequency and peak force levels. The HAL values and Borg CR-10 scores were used to calculate the Exposure Ratio (ER) for each worker, serving as the main indicator of ergonomic risk. Results revealed that all five workers had ER values ranging from 1.18 to 1.30, exceeding the ACGIH TLV threshold of 1.0. This indicates a consistently high risk for work-related musculoskeletal disorders (WMSDs). Frequent lifting of 12–13 kg loads combined with moderate-to-high hand activity and poor posture contributed to elevated strain levels. These findings confirm that the existing work system places employees at risk and highlight the need for immediate ergonomic improvements. Moreover, the HAL-ER assessment framework used in this study provides structured data that can be utilized in simulation-based planning or optimization models. By integrating these metrics into ergonomic redesign scenarios such as task reallocation, force-load balancing, or layout planning future studies can enhance both worker safety and operational efficiency.

1. Introduction

Work-related musculoskeletal disorders (WMSDs) remain the leading cause of lost workdays and compensation costs in labor-intensive industries [1]. Recent epidemiological surveys place the one year prevalence of upper limb and back pain among production line personnel between 53 % and 90 %, with assembly and machining jobs consistently within the highest risk strata [2]–[4]. Such injuries degrade workers' quality of life, inflate absenteeism, and as reported in multinational reviews reduce manufacturing throughput by up to 12 % annually [4], [5].

The manufacturing sector plays a pivotal role in supporting economic development across numerous nations [6], [7]. It not only provides employment to a vast number of workers but also functions as a key contributor to national economic progress [8]. Nevertheless, alongside its economic benefits, this sector grapples with critical challenges related to occupational health and safety [9]. Tasks commonly performed in manufacturing such as manual lifting, pushing, pulling, frequent bending, and prolonged static postures can lead to substantial ergonomic hazards [10]. These physically demanding conditions have drawn global attention, as musculoskeletal disorders (MSDs) continue to be a major factor behind absenteeism and declines in workplace productivity [11], [12]. Based on reports from the International Labour Organization (ILO), millions of non-fatal occupational accidents occur around the world each year, with a significant portion attributed to musculoskeletal disorders (MSDs) resulting from inadequate ergonomic practices [13]. In the Indonesian context, data reveals a high incidence of muscle related injuries among workers, affecting various parts of the body approximately 20% in the shoulders, 80% in the neck, 40% in the upper back, 20% in the mid-back, 40% in the lower back, 20% in the hips, 40% in the thighs, 60% in the knees, and as high as 80% in the calves [14].

PT. ABC is a company that produces concrete for toll road construction projects in East Java, Indonesia. The company's production process is still performed manually, including the lifting and placement of finished concrete products, which are carried by workers without the aid of mechanical equipment. Each concrete block weighs approximately 12 to 13 kilograms, and workers are required to lift around 10 blocks in order to fill the transport area before the materials are loaded onto trucks for delivery to the toll road construction sites. The time needed to lift these 10 concrete blocks typically ranges from 20 to 30 minutes.

Beyond its health implications, MSDs also have significant implications for industrial optimization [15], [16]. Studies have demonstrated that ergonomic inefficiencies due to repetitive strain and poor posture can lead to measurable losses in productivity, increased operational costs, and quality issues due to human error [17]. For instance, it is estimated that MSD-related absenteeism and compensation claims may cost manufacturing firms up to 10% of their operating budget annually [18], [19]. Addressing ergonomic risks thus becomes not only a health imperative, but also a strategic necessity to enhance throughput and reduce downtime [16], [20].

Moreover, quantitative ergonomic metrics such as the HAL-based Exposure Ratio (ER) have growing relevance in simulation and optimization domains [21]. HAL-ER values can serve as key input variables in digital twin simulations or multi-criteria decision-making (MCDM) frameworks that aim to redesign work systems while balancing cost, efficiency, and worker safety [22]. Integration with tools such as Analytic Hierarchy Process (AHP) or Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) allows stakeholders to systematically prioritize interventions based on risk severity and feasibility [23].

The American Conference of Governmental Industrial Hygienists (ACGIH) offers precisely such criteria through its Threshold Limit Value for Hand Activity Level (TLV-HAL) [24]. The TLV combines a 0–10 hand-activity scale with a normalized peak-force rating, generating an exposure ratio that predicts the probability of upper-extremity disorders [25]. Validation studies including the 2018 revision that tightened acceptable force–frequency combinations have confirmed its predictive power across automotive, electronics, and food-processing lines [26]–[28]. Despite its international uptake, use of the TLV-HAL in Indonesian manufacturing is extremely limited.

More than two decades of research has explored TLV-HAL validity, optimization, and integration with intervention strategies. Prospective cohorts have linked exposure ratios > 1.0 to a two to four fold increase in incident carpal tunnel syndrome and tendonitis [29]. while simulation studies show the 2018 limits reduce false-negative risk classification by 18 % compared with the

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2001 version [30]. Field applications span automotive assembly, electronics soldering, metal stamping, garment manufacture, and food processing [31]–[34]. Researchers have further shown that integrating TLV-HAL outputs with digital human modelling or vision-based motion capture enhances risk-mapping accuracy and guides low-cost engineering fixes [35]. However, no prior study has combined the revised TLV-HAL, detailed force measurements, and pragmatic intervention planning within an Indonesian high-throughput manufacturing setting, leaving a critical research gap.

To close that gap, this study will quantify hand activity exposure in representative PT. ABC workstations using the 2018 ACGIH TLV-HAL, classify tasks by risk level, and propose the hand tools to reduce exposure ratios below the Action Limit within one production cycle. The contribution of the research is a field validated, reproducible framework that couples TLV-HAL diagnostics with actionable design and organizational solutions for Indonesian manufacturing environments, thereby advancing local ergonomic practice and offering a template for comparable plants across Southeast Asia.

2. Method

2.1. Problem statement

This study employs a quantitative observational approach to assess occupational health risks associated with repetitive manual tasks performed by workers at PT. ABC, a concrete manufacturing company in East Java, Indonesia. The selection of this approach is based on the need to objectively quantify physical workload parameters specifically hand activity level and applied force using standardized and validated tools to ensure the accuracy, reliability, and generalizability of the findings.

The ACGIH TLV for Hand Activity Level (HAL) was chosen as the main assessment method due to its wide acceptance in occupational health research and practice for evaluating upper extremity risks in repetitive work environments. The method combines two critical variables hand activity (frequency of repetitive motion) and normalized peak force (force exerted during task execution) to compute an exposure ratio. This exposure ratio categorizes the level of risk into zones (below AL, between AL and TLV, and above TLV), providing a clear basis for ergonomic intervention prioritization. The use of this model aligns with recent revisions (2018 update) which offer improved predictive capability for musculoskeletal disorder development compared to earlier versions.

Data were collected through direct field observation and video recordings of workers performing typical manual handling tasks, such as lifting and placing concrete blocks weighing 12–13 kg. Each worker was observed while completing a full cycle of repetitive lifting (10 concrete blocks), and the duration of task completion (20–30 minutes) was recorded to calculate the hand activity level (HAL scale). Force exertion was estimated using the Borg CR-10 scale with worker self-reporting supported by trained observers, enabling normalized peak force calculation in accordance with ACGIH guidelines.

The rationale for using video analysis and observational techniques is to increase objectivity and allow repeated review of task sequences for precise scoring of frequency and posture. Meanwhile, the Borg CR-10 scale is a validated subjective measure that has been widely used in ergonomic studies to assess perceived exertion in industrial settings. The combination of these techniques ensures both the consistency and ecological validity of data in the specific context of Indonesian manual labor.

By applying these methods, the study ensures a structured and scientifically grounded analysis of ergonomic risks, supporting the development of targeted and evidence-based interventions. This methodological framework also allows for the replication of the study in similar industrial settings, thereby contributing to broader occupational health improvements in Southeast Asia. The methodological rigor enables readers and stakeholders to critically assess the study's validity and reliability in relation to its objectives and contributions.

Fig. 1 illustrates a worker manually lifting a concrete block during the production process. This activity was documented as part of the observational study and subsequently analyzed using the Hand Activity Level (HAL) method to quantify hand movement frequency and peak force, which were then used to calculate the Exposure Ratio (ER) as an indicator of ergonomic risk.

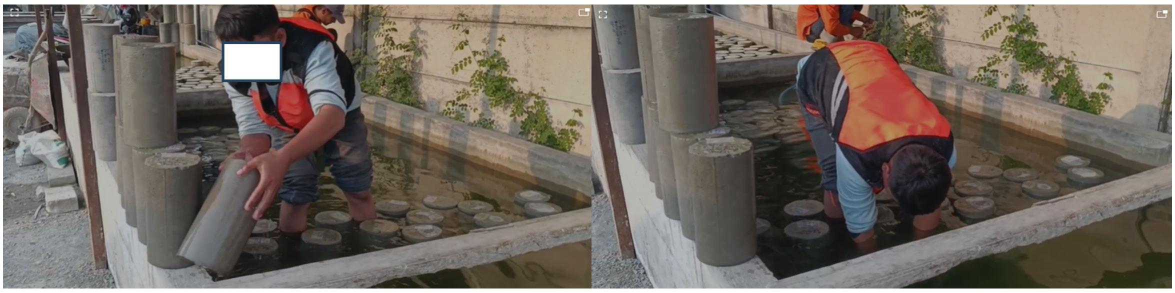

Fig. 1. Body Posture of Workers

2.2. Research Methodology

This study adopts a quantitative observational research design to assess occupational health risks associated with repetitive manual material handling tasks among workers at PT. ABC, a concrete manufacturing company in East Java, Indonesia. The study aims to identify ergonomic risks using the ACGIH Threshold Limit Value (TLV) for Hand Activity Level (HAL) method, which provides a standardized, validated framework for evaluating upper extremity workload.

2.3. Research Design

A cross-sectional observational design was used to evaluate the exposure levels of workers engaged in repetitive lifting and placement of concrete blocks. The design is appropriate because it allows for the analysis of current working conditions, exposure intensities, and ergonomic risk levels in a real-time industrial setting without interfering with the actual workflow.

While the current study adopts a cross-sectional observational approach for risk assessment, future extensions of this research will involve comparative simulations of current vs. improved work methods. This will allow modeling the ergonomic impact of alternative task designs using discrete event simulation or digital human modeling tools. Such integration aligns with the journal's optimization focus and enhances decision-making on intervention strategies.

2.4. Population and Sampling

The population in this study includes all production workers involved in manual handling processes at PT. ABC. Purposive sampling was employed to select 5 workers from the production line who regularly perform lifting and placing of concrete blocks weighing approximately 12–13 kg. These workers were selected based on inclusion criteria such as age (18–50 years), minimum work experience (≥ 6 months), and daily engagement in the repetitive lifting task.

2.5. Data Collection Procedures

In this study, several methods were employed to collect data relevant to evaluating ergonomic risks using the ACGIH TLV for Hand Activity Level (HAL). Data collection began with video observation, where each worker's lifting activity was recorded using a digital camera. The recordings captured the complete movement cycle involved in lifting and placing 10 concrete blocks, which represent a standard workload cycle at PT. ABC. The video footage enabled detailed motion analysis, allowing for accurate determination of hand movement frequency.

Following the video observation, a time study was conducted to measure the duration required for each worker to complete the lifting of 10 concrete blocks. This time data was then used to calculate the repetition rate, expressed as the number of lifting motions per minute. The repetition rate is essential for assigning a Hand Activity Level (HAL) score, as stipulated in the ACGIH TLV for HAL methodology.

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To estimate the level of physical effort exerted by the workers during lifting, the study employed the Borg CR-10 scale, a validated tool for measuring perceived exertion. Workers were asked to rate the intensity of the force they applied using this scale. Their responses were supported and validated by observations from trained ergonomists, ensuring that the force estimations reflected realistic workload conditions.

Finally, the collected HAL scores and normalized peak force values were plotted onto the ACGIH TLV for HAL graph (2018 version**)** to calculate the Exposure Ratio**.** This ratio was used to classify the ergonomic risk level of each worker's task. Based on the position of the plotted values on the graph, the worker's exposure was categorized into one of three risk levels: (1) below the Action Limit, indicating a safe zone; (2) between the Action Limit and the Threshold Limit Value (TLV), representing a moderate or increased risk; or (3) above the TLV, indicating high ergonomic risk. This classification provides a clear foundation for recommending targeted ergonomic interventions.

2.6. Data Analysis

The quantitative data collected in this study were analyzed through a series of structured steps. The first step involved the calculation of the repetition rate, which corresponds to the Hand Activity Level (HAL). This was determined by analyzing the video recordings and time measurements to calculate the number of lifting actions performed per minute. Each worker's lifting cycle was timed, and the frequency of hand motions was derived to assign a HAL score based on ACGIH guidelines.

Following this, the normalized peak force was estimated using the Borg CR-10 scale**.** Workers provided their perceived exertion scores during the lifting task, and these scores were further validated through expert observation. The force ratings were then converted into normalized values, as specified by the ACGIH TLV for HAL framework, to ensure comparability and consistency across subjects.

Once both the HAL scores and normalized force values were obtained, the data were plotted on the ACGIH TLV for HAL chart (2018 version) to compute the exposure ratio**.** This ratio served as the basis for risk classification, enabling researchers to categorize each worker's exposure into three defined risk zones: below the Action Limit (safe), between the Action Limit and the Threshold Limit Value (increased risk), or above the TLV (high risk). This classification helped identify which tasks presented significant ergonomic hazards requiring intervention.

As an optional stage, descriptive statistical analysis was also conducted to summarize the main variables. Measures such as the mean and standard deviation were used to describe the distribution of repetition rates, perceived force ratings, and exposure categories among the observed workers. If the sample size permits, further inferential statistical analysis such as correlation tests between hand activity level and force, or between exposure scores and duration of work may be carried out to explore deeper relationships within the data.

Furthermore, the collected HAL and normalized force data can serve as input for predictive modeling in future research. By training classification models such as Support Vector Machines (SVM) or Neural Networks, risk levels could be automatically predicted based on posture, repetition rate, and lifting force. This would enable ergonomic assessments to scale efficiently across larger populations.

Additionally, applying data mining or clustering algorithms on larger ergonomic datasets could uncover patterns and risk-prone task profiles, offering the potential for early-warning systems and adaptive interventions. Integrating these computational approaches aligns well with the journal's emphasis on industrial optimization and simulation-based analysis.

2.7. Validity and Reliability

To ensure the validity of the collected data, several methodological controls were implemented throughout the research process. Observations of worker activities were conducted on multiple occasions to capture consistent patterns of motion and task execution. Each set of observations was independently reviewed and cross-validated by two trained ergonomic experts to minimize subjectivity and strengthen the accuracy of the assessments. Additionally, the use of the Borg CR-10 scales for estimating perceived exertion was supported by its extensive validation in previous ergonomic research across various industrial sectors, lending further credibility to the force measurement approach.

In terms of reliability, standardized procedures were applied consistently to all participants. Each worker followed the same task protocol under similar conditions, ensuring uniformity in data collection. The use of video recordings also contributed significantly to the reliability of the analysis, as it allowed researchers to replay and re-examine the lifting sequences as needed. This reduced the potential for observational bias and enabled precise, repeatable measurement of hand activity and postural patterns. Through these methodological safeguards, both the internal consistency and reproducibility of the study's findings were effectively maintained.

To strengthen generalizability, the study also proposes the use of simulation models in future work to replicate ergonomic scenarios with larger virtual populations. This allows sensitivity testing of various intervention strategies under controlled assumptions, thus supporting more robust recommendations.

3. Results and Discussion

The main findings of this study indicate that all observed workers had exposure ratios (ER) ranging from 1,18 to 1,30, exceeding the ACGIH TLV threshold of 1,0. These elevated values suggest a high level of ergonomic risk primarily due to high-frequency lifting activities, moderate to high force exertion, and forward-bending postures. These risks are confirmed through structured observations and validated ergonomic scales.

This study focused on five workers from the production line at PT. ABC, a manufacturing company. Each participant was responsible for manually handling concrete materials used in highway construction, specifically in the production of precast concrete components for toll road infrastructure with weighing around 12 to 13 kilograms. These tasks were performed repetitively, without the aid of mechanical tools, and often involved a forward-bending posture that could contribute to physical strain. Observations were carried out during a typical work cycle for each individual, using video recordings and structured ergonomic assessments.

For each worker, data were collected on the frequency of dominant hand movements per minute, and peak force was assessed using the Borg CR-10 scale, as per the ACGIH TLV for Hand Activity Level (HAL) methodology. These values were used to calculate the Exposure Ratio (ER), the key indicator of biomechanical risk in repetitive manual tasks [36]. The average frequency of hand movements was 11,2 movements per minute, with a standard deviation of ±1,1. Based on the ACGIH HAL rating scale, this corresponds to a HAL score between 4.5 and 5.0, with a mean HAL of 4.8. All workers repeatedly lifted 12–13 kg loads, without any assistive equipment, while maintaining a moderately stooped posture. Given these working conditions, a Borg CR-10 score of 6.5 was assigned to represent the peak force exerted by each worker.

To quantify the ergonomic risk, the Exposure Ratio (ER) was calculated by integrating the perceived force (Borg CR-10) and the hand activity level (HAL) into the following Equation (1):

$$ER = \frac{force(BorgCR - 10)}{10 - HAL} \tag{1}$$

As seen in Table 1, the average frequency of hand movements was 11.2 movements per minute, with a standard deviation of ±1.1. Based on the ACGIH HAL rating scale, this corresponds to a HAL score between 4.5 and 5.0, with a mean HAL of 4.8. All workers repeatedly lifted 12–13 kg loads, without any assistive equipment, while maintaining a moderately stooped posture. Given these working conditions, a Borg CR-10 score of 6.5 was assigned to represent the peak force exerted by each worker.

Table 1. Exposures Risk Summary Based on HAL and Borg CR-10 For Production Line Workers

No	Worker	Movement Frequency (per min)	HAL (0–10)	Borg CR-10 (Force)	Exposure Ratio (ER)	Risk Category
1	Mr. A	12	5	6.5	1.30	High
2	Mr. B	10	4.5	6.5	1.18	High
3	Mr. C	12	5	6.5	1.30	High
4	Mr. D	12	5	6.5	1.30	High
5	Mr. E	10	4.5	6.5	1.18	High

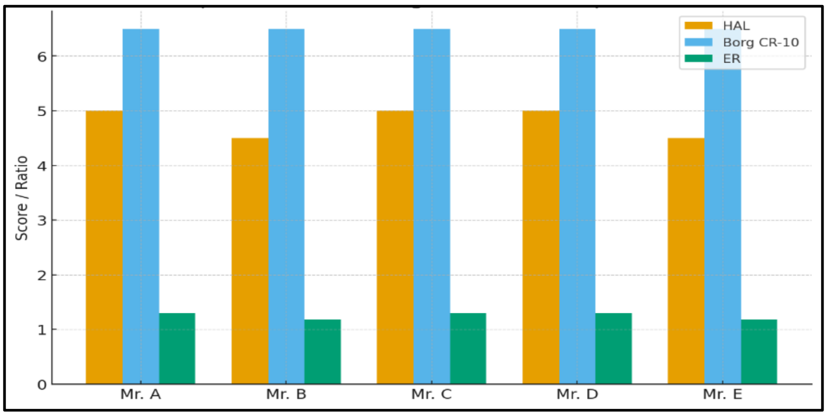

Fig. 2. Exposures Risk Summary Based on HAL and Borg CR-10

All five workers (100%) had ER values greater than 1.0, which, according to ACGIH 2018 standards, places them firmly in the high-risk category. None of the participants fell within the safe or intermediate "action limit" zones. These results indicate that all workers are exposed to ergonomic risks that exceed the recommended safety thresholds, highlighting the need for immediate attention to task design and workplace ergonomics.

The following figures present the conclusion in graphical form. As seen in Fig. 2, the bar chart illustrates the Exposure Ratio (ER) of each worker compared to the TLV threshold (1.0), clearly showing that all workers exceeded the acceptable limit and are therefore classified as high risk. The pie chart further emphasizes this result, indicating that 100% of the observed workers fall into the high-risk category. These visualizations strengthen the conclusion that ergonomic interventions are urgently required.

As seen in Fig 3, the data clearly show that the assembly workers at PT. ABC are exposed to a level of physical strain that goes beyond safe limits. The combination of lifting heavy components (12–13 kg), moving the hands frequently (10–12 times per minute), and doing so with poor posture (forward bending) leads to continuous stress on the muscles and tendons in the upper body. This cumulative strain puts workers at risk of developing injuries over time.

From an ergonomic standpoint, a HAL score close to 5.0 already suggests limited time for muscle recovery. When coupled with a Borg CR-10 score of 6.5 indicating fairly heavy perceived effort this workload, if sustained over an entire shift, significantly increases the likelihood of musculoskeletal disorders like tendinitis or carpal tunnel syndrome.

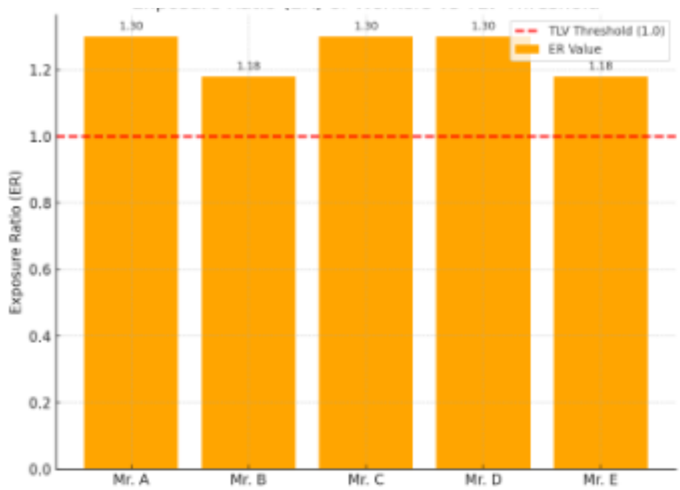

Fig. 3. All Workers Category

The findings of this study are comparable to results from another empirical research. For instance, research found that workers with ER values above 1.2 had higher prevalence of upper-limb WMSDs, despite the implementation of job rotation. These similarities strengthen the generalizability of the HAL-ER method across industrial settings [37],[38]. For instance, a research conducted a study on construction and manufacturing workers using ACGIH HAL and RULA methods, and found that those with ER values above 1,2 had significantly higher incidences of upper-limb musculoskeletal disorders, despite implementation of job rotation strategies [39]. Likewise, other research examined repetitive motion tasks in industrial settings and confirmed that workers exceeding the TLV threshold for ER consistently reported high levels of wrist and shoulder discomfort [40]. These contemporary studies align with our findings and reinforce that the observed ER range in our sample (1.18–1.30) represents a high-risk profile consistent with recent ergonomic evidence.

In practical terms, this study emphasizes the urgent need for ergonomic improvements. Introducing mechanical aids, such as hoists or pneumatic tools, could reduce the physical effort required and bring down Borg scores by 1.5 to 2 points. Adding job rotation or brief recovery breaks every 30 minutes could also lower HAL scores and, in turn, the overall ER.

On a theoretical level, our findings reinforce the cumulative load theory which states that small increases in movement frequency or applied force can sharply raise injury risk. This highlights the importance of designing tasks to match individual capacity and ensuring that repetitive jobs are structured with recovery in mind.

The implication of these findings extends beyond ergonomic assessment. The structured data collected in this study HAL scores, force levels, and postural observations can be used as input variables in future predictive models. Machine learning approaches such as neural networks or support vector machines (SVM) can help classify ergonomic risk more efficiently and adaptively across diverse work settings. By integrating such computational tools, stakeholders can develop proactive interventions, optimize work design, and reduce long-term costs associated with WMSDs.

One limitation of this study is the small sample size (n = 5), which limits the generalizability of the findings. Additionally, force levels were estimated subjectively using the Borg scale, without validation from objective tools such as dynamometers or electromyography (EMG). Future research should involve larger sample sizes, utilize objective measurement instruments, and track the impact of ergonomic interventions over longer periods to determine whether ER values and related injury risks can be significantly reduced.

4. Conclusion

This study has shown that all observed workers at PT. ABC are exposed to high ergonomic risk, as indicated by Exposure Ratios that consistently exceed ACGIH's TLV threshold. The combination of repetitive lifting, heavy loads, and non-neutral posture clearly places long-term strain on the body, increasing the likelihood of musculoskeletal injuries. Despite this, the findings also offer practical and achievable solutions such as using assistive tools, implementing short recovery breaks, and rotating tasks that could significantly reduce physical demands and improve workplace safety. These insights not only confirm the concerns raised at the beginning of the study but also point toward the importance of designing work environments that prioritize human health. Moving forward, this research provides a solid foundation for future studies and real-world improvements that can create safer, more sustainable, and worker-friendly industries. Furthermore, the quantitative results of this study particularly the HAL scores and Exposure Ratios can serve as valuable input parameters in the development of future simulation or optimization models. For instance, simulation-based layout planning tools could be employed to redesign workstations for reduced physical load, while metaheuristic algorithms such as genetic algorithms or particle swarm optimization may assist in force-load balancing, task scheduling, or ergonomic tool assignment. These approaches could enhance decision-making for intervention planning and maximize both worker well-being and operational efficiency.

Supplementary Materials: The following supporting information can be seen at Figure 1,2,3.

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Conflicts of Interest: The authors declare no conflict of interest.

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