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Mitigating Ergonomic Risks through Lean Ergonomics and Karakuri Kaizen Using NBM and RULA: A Case Study of Visual Inspection Operators in Automotive Manufacturing

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Abstract: This research is aimed at the reduction of ergonomic risk factors and complaints of work-related musculoskeletal disorder (WMSDs) among visual inspection operators in the automotive component industry using the integration of Lean Ergonomics and Karakuri Kaizen. A case study was carried out at PT Kanemitsu SGS Indonesia focusing on five visual inspection operators. Ergonomic risk factors were analyzed using the Nordic Body Map (NBM) to evaluate musculoskeletal discomfort and the Rapid Upper Limb Assessment (RULA) for working postures. Primary assessments revealed the presence of significant ergonomic risk factors which resulted in the average NBM score of 62.6 and RULA score of 7 which indicates the presence of risk factors regarding working posture and action required correction on an urgent basis. Ergonomic modifications were accomplished by workstation redesigning based on the principles of anthropometry, which is the science of design and proportions of the human body, layout optimization, and integration of gravity-assisted Karakuri mechanisms to alleviate manual lifting and forward bending. The post-intervention assessment revealed the ergonomic risk factors have been significantly minimized and the NBM score and RULA score are now 28.8 and 3 respectively. Also, there was more than 75% reduction in the frequency of forward bending, which decreased from more than 80 occurrences per shift to less than 20. As such, the application of the two concepts in tandem suggests they may provide a viable and cost-effective solution to the balance of ergonomics and sustainable improvement to the comfort and productivity of the systems workers use in the automotive industry manual visual inspection systems.

Keywords: Karakuri Kaizen, Lean Ergonomics, Musculoskeletal Disorders, Nordic Body Map, Rapid Upper Limb Assessment

Introduction

The automotive manufacturing sector still depends very much on all types of manual work. This is particularly evident with the use of manual labor for visual inspections and the handling of materials (Joe McKendrick — Senior Contributor, 2023), (Ayu Paramudita, Putri Hera Lusmana, Lani Amaliah, Ayunitasanti, 2024). All work of this type is virtually guaranteed to be repetitive and will require workers to be standing for long periods of time. This type of work will require workers to assume potentially dangerous postures that will expose workers to the risk of many work-related musculoskeletal disorders (WMSDs) (edited by E. N. Corlett, John R. Wilson, 1995), (Dul & Weerdmeester, 2008), (World Health Organization (WHO), 2020). The challenges posed by these types of ergonomics issues will affect the health and comfort of workers and will negatively impact productivity, the quality

of the products being produced, and the operational sustainability of the sector (edited by E. N. Corlett, John R. Wilson, 1995), (A et al, 2020), (Brito et al, 2018).

Earlier research has shown more use of the Nordic Body Map (NBM) and the Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) tools to assess the risks of WMSDs in industrial settings (Brito et al, 2018), (Anggraeni, 2015), (Widya et al, 2023), (Lynn & Corlett, 1993), (Adiyanto et al, 2022). Some research has also looked at Lean Manufacturing and Kaizen as strategies to improve productivity and reduce non-value-added activities (A et al, 2020), (Colim et al, 2021), (Mozzi et al, 2019), (Kurganov et al, 2021), (Eliasson et al, 2022). However, the majority of these studies have focused on ergonomics and lean implementation in isolation. There is still very little research focusing on the integration of Lean Ergonomics with Karakuri Kaizen in visual inspection processes in the automotive component industry (Colim et al, 2021), (Imansuri et al, 2024), (Brito et al, 2018).

Most studies related to ergonomics and lean thinking have focused on assembly work or general material handling tasks, while visual inspection activities are often overlooked (Tarwaka & Bakri, 2016), (GÜRSOY ÖZCAN, 2022), (Kartika & Mukhtar, 2023), (Adiyanto et al, 2022). Visual inspection is characterized by bending, reaching, and repetitive static postures, which present certain unique risks in terms of ergonomics (edited by E. N. Corlett, John R. Wilson, 1995), (Lynn & Corlett, 1993). Furthermore, there is very little literature on the combined use of NBM and RULA in Lean-based manufacturing, as well as the use of Karakuri Kaizen as a low-cost ergonomic intervention (GÜRSOY ÖZCAN, 2022), (Imansuri et al, 2024), (Dul & Weerdmeester, 2008).

Keeping the identified research gap in mind, this study intends to:

1) analyze the levels of ergonomic risk and the associated musculoskeletal discomfort of visual inspection operators using NBM and RULA methods (Tarwaka & Bakri, 2016), (Lynn & Corlett, 1993), and
2) analyze the impacts of the combining Lean Ergonomics and Karakuri Kaizen on the reduction of ergonomic risk and the enhancement of work efficiency, in the field of automotive component manufacturing (Tarwaka & Bakri, 2016), (GÜRSOY ÖZCAN, 2022), (MacHado et al, 2023).

This paper also provides constructive contributions to theory and practice with the empirical results demonstrating that the integration of Lean Ergonomics and Karakuri Kaizen can effectively mitigate ergonomic risks at low capital cost without the need for advanced automation technology (GÜRSOY ÖZCAN, 2022), (Imansuri et al, 2024), (MacHado et al, 2023), (Brito et al, 2018). The results can provide instructive assistance to production professionals, especially SMEs, to create cost-effective and sustainable ergonomic improvements in labor-intensive production settings (Adiyanto et al, 2022), (Exegens Team, 2019), (2002, غلامحسین).

Methodology

Research Design

The descriptive current Semi Quantitative Research Design was used in this study according to accepted guidelines from the American National Standards Institute for an Ergonomics Assessment in Industrial settings. The research design uses two internationally accepted ergonomic assessment tools which include the Nordic Body Map (NBM) and Rapid Upper Limb Assessment (RULA) for evaluating musculoskeletal complaints and postural risks (MacHado et al, 2023), (Lynn & Corlett, 1993). The assessment method follows expert-recommended guidelines for industrial ergonomic assessments which apply to manual work environments (Tarwaka & Bakri, 2016).

Research Site and Participants

This research was carried out in PT Kanemitsu SGS Indonesia, a company that produces automotive parts in Bekasi, Indonesia. The research involved\ContractsFive workers who did visual inspection tasks. This number of participants was adequate for a detailed observational ergonomic study focusing on workers' posture analysis and movement repetition. Even though the number of workers in this study is small, a small number of workers has effectively been used in previous ergonomic studies focusing on workers' postures (Anggraeni, 2015), and the effectiveness of workstation modification (Adiyanto et al, 2022) of workers in industries. The use of a S/NBM and RULA ergonomic tool in previous studies has proved the validity of ergonomic studies even if there are a few workers. To achieve uniformity in all workers' responses, all workers have the same job description and cycles.

Data Collection Procedures

1. Nordic Body Map (NBM) Assessment

The Nordic Body Map functioned as an approved assessment tool which used its 28 anatomical regions to evaluate musculoskeletal complaints (edited by E. N. Corlett, John R. Wilson, 1995). The NBM functions as a standard research instrument in manufacturing ergonomics to assess discomfort levels and identify critical body areas (Primasari & Kurnianingtyas, 2022), (Widya et al, 2023). The four-point pain scale allowed researchers to measure pain levels which followed the quantification methods defined by Indonesian ergonomic assessment standards. To measure the level of discomfort each participant had according to the Indonesian Guidelines for Industrial Ergonomic Assessment a four-point pain scale was employed.

2. Rapid Upper Limb Assessment (RULA)

RULA was used to evaluate postural load based on the angles and orientation of the neck, trunk, upper arm, lower arm, and wrist (Lynn & Corlett, 1993). RULA is a first-level screening tool recognized under ISO and CEN ergonomic assessment principles for non-cyclic industrial tasks. The method follows the same procedures which ergonomics experts

use to evaluate workplaces in automotive and electronics manufacturing facilities (GÜRSOY ÖZCAN, 2022), (Kartika & Mukhtar, 2023).

3. Motion Observation and Work Task Analysis

Task analyses were performed using direct observations with video recording to document operator activity and workstation interaction. Evaluating reach distances, bending frequency, and layout of the workstation were conducted using Lean Work Design Principles (Kurganov et al, 2021) and Ergonomic Motion Analysis Frameworks (Ashary Aznam et al, 2017). A comprehensive analysis was conducted to identify areas in the inspection process where there are ergonomic risks and/or non-value added activities.

4. Intervention Design

a. Lean Ergonomics Design Framework

The intervention used Lean Ergonomics principles which united waste reduction methods with ergonomic risk reduction techniques (Tarwaka & Bakri, 2016). The research employed three main tools which consisted of work sequence mapping and 5S-based material organization and anthropometric-based workstation height and reach zone redesign (Pheasant, Stephen, Haslegrave, 2018). The method follows evidence which demonstrates that human-oriented lean design systems decrease worker exhaustion while creating better production workflows (MacHado et al, 2023).

b. Karakuri Kaizen Mechanism Development

Karakuri kaizen is an example of low-cost mechanical support developed through frugal engineering principles, using gravity, springs and simple mechanical linkages with no additional power source (GÜRSOY ÖZCAN, 2022), (Exegens Team, 2019). This application is prevalent in the Toyota Production System for the reduction of operator workload, including decreased trunk flexion and increased material handling efficiency. The result of this type of mechanical aid to support the inspection process was to increase the efficiency of inspection and provide operators with a safer, ergonomic working environment.

5. Implementation and Evaluation Procedures

a. Pre-Intervention Assessment

The assessment process began with NBM scoring followed by RULA evaluation and bending frequency measurement and workstation motion documentation. The assessment procedures follow established ergonomic risk evaluation methods which researchers use before starting their redesign work (World Health Organization (WHO), 2020).

b. Intervention Implementation

1) The steps taken in the implementation of this intervention have included:
2) Adjusting workstation height to fit operators based on their anthropometry,

3) Improved material positioning through the identification of optimum reach zones and implementing a 5S organizational system, and
4) The use of a Karakuri-assisted material transfer mechanism to assist in moving materials associated with and for inspection tasks.

To facilitate material movement with the inspection task, a Karakuri-assisted material transfer mechanism was used.

Research studies show that manufacturing lines can minimize worker postural risks through ergonomic-lean interventions according to(GÜRSOY ÖZCAN, 2022) and (Kartika & Mukhtar, 2023).

c. Post-Intervention Assessment

The same NBM and RULA assessments were conducted again one week following the system deployment. The study maintains a follow-up duration which matches the ergonomic adaptation periods found in similar industrial research (MacHado et al, 2023).

6. Data Analysis

The research team applied descriptive statistics to find average values and identify which body regions caused the most discomfort by analyzing NBM scores. The RULA scores received their interpretation from established risk action levels which served as the basis for assessment. Pre- and post-intervention results were compared to determine the effectiveness of improvements. The research team conducted thematic analysis of the qualitative feedback which operators provided.

The sample size was too small for inferential statistical analysis; therefore, descriptive statistics were utilized to identify trends and changes in levels of ergonomic risk before and after the intervention.

7. Ethical Considerations

All research participants provided their consent before beginning the study. The research study conducted no invasive medical tests while following all necessary workplace safety protocols. The research study protected participant anonymity through established ethical protocols which apply to workplace assessment investigations.

The limitations of this study include the relatively small sample size. Nevertheless, by utilizing comprehensive observational ergonomic assessment methods and workstation-specific analyses, an analysis of a smaller sample size provides an in-depth look at either posture-related hazards or the efficacy of an intervention. Future research will benefit from involving larger numbers of participants and using more extended observation periods to allow for better generalization of results.

Results and Discussion

Pre-Intervention Assessment

The Nordic Body Map (NBM) and Rapid Upper Limb Assessment (RULA) tools enabled the first ergonomic assessment to determine how visual inspection operators experience musculoskeletal discomfort and face postural risks. The initial assessment showed that operators who carried out visual inspections were repeating the same movements over and over with their upper bodies, bending at the waist and reaching for items, all of which increased the risk of developing musculoskeletal disorders.

1. Nordic Body Map (NBM) Results

The baseline assessment of participants using the Nordic Body Map indicated that the areas of discomfort noted by the greatest number of participants were the lower back (80%), right shoulder (60%) and neck (60%). Most of the reported discomfort occurred as a result of picking repetitive items, bending forward, holding their arms in a static position for a long period of time while completing visual inspections.

Table 1. Summary of Pre-Intervention NBM Scores

No	Method	Aspects Evaluated	General Results (5 Operators)	Risk Category
1	Nordic Body Map (NBM)	The most common complaints are in the lower back (80%), right shoulder (60%), and neck (60%).	The majority of operators experienced complaints in the upper body area with moderate to high levels of discomfort, due to repetitive activities when picking products from stacks of boxes and moving them to the inspection table.	Medium to High
2	Rapid Upper Limb Assessment (RULA)	The work position shows the neck leaning slightly forward and the back bending slightly when picking up products. The	Immediate corrective action is needed to reduce ergonomic risks, especially	High

No	Method	Aspects Evaluated	General Results (5 Operators)	Risk Category
		average RULA score was 5.6 out of 7.	during the product retrieval phase.	

Table 2 shows the results from the pre-intervention assessments of RULA and NBM, which demonstrate that visual inspection operators were at a moderate to high ergonomic risk for musculoskeletal disorders.

2. RULA Results

The pre-intervention analysis using the RULA assessment identified that the visual inspection operators tended to assume a non-neutral posture involving the flexion of the neck, bending, and the elevation of the upper limbs while performing the retrieval of products. The average value of the RULA score was 5.6, thus making the Ergonomic Risk Level as High and establishing the need for an urgent corrective ergonomic action. Figure 1 below illustrates the results obtained using the pre-intervention RULA assessment.

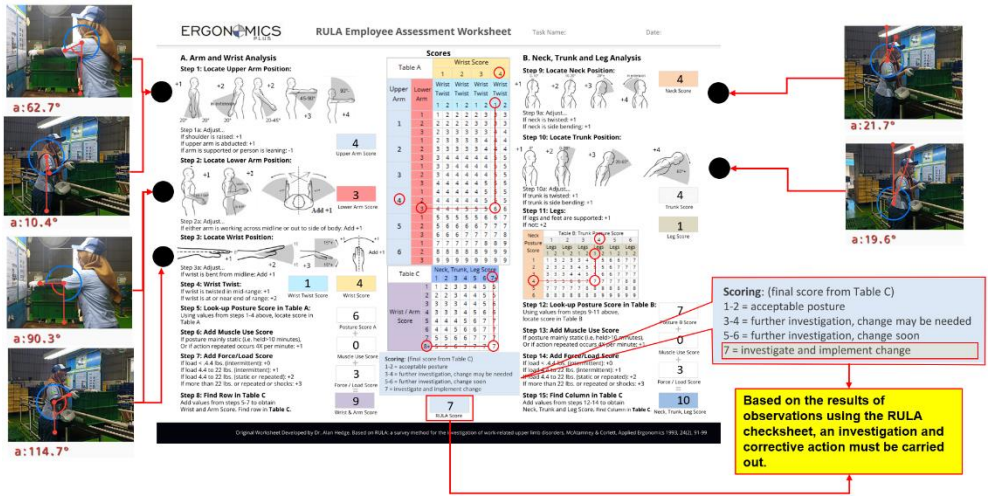

Figure 1. Pre-Intervention RULA Score Summary

Identification of Critical Motions

Through direct observation and picture analysis, critical ergonomic hazard contributors were identified. They include:

1) over 80 forward bending occurrences in a work shift,
2) reach distances in excess of recommended anthropometric standards,
3) low stacking height boxes containing product, and
4) poor workstation organization resulting in unnecessary repetition

Such results support an article by Wilson & Corlett (edited by E. N. Corlett, John R. Wilson, 1995), in which they emphasized that trunk bending and using upper limb strength are core contributors to increased risk of developing WMSD.

Workstation Improvement Through Lean Ergonomics and Karakuri Kaizen

An integrated improvement intervention was developed using Lean Ergonomics and Karakuri Kaizen principles. Improvements included:

1) Work area reconfiguration (5S and layout optimization)
2) The design of anthropometric dimensions resulted in shorter reach distances
3) Gravity-assisted Karakuri mechanisms to eliminate manual lifting and bending
4) Adjustment of box and table height
5) Elimination of non-value-added movements

The implemented interventions follow previous studies which showed Karakuri Kaizen methods decrease workplace ergonomic hazards while creating more efficient production workflows (GÜRSOY ÖZCAN, 2022), (Imansuri et al, 2024).

An integrated workstation enhancement technique called Lean Ergonomics & Karakuri Kaizen design principles were developed. This worked on workstation organization by 5S implementation, reach zone based on anthropometrics principles, using Karakuri devices to support reduced lifting, box & table height modification, and reduction of non-value-adding steps. The purpose of all these modifications was to reduce nonproductive operations and maintain constant working positions of operators during inspection operations.

Figure 2 above shows a new workstation design facilitated by Lean Ergonomics and Karakuri Kaizen.

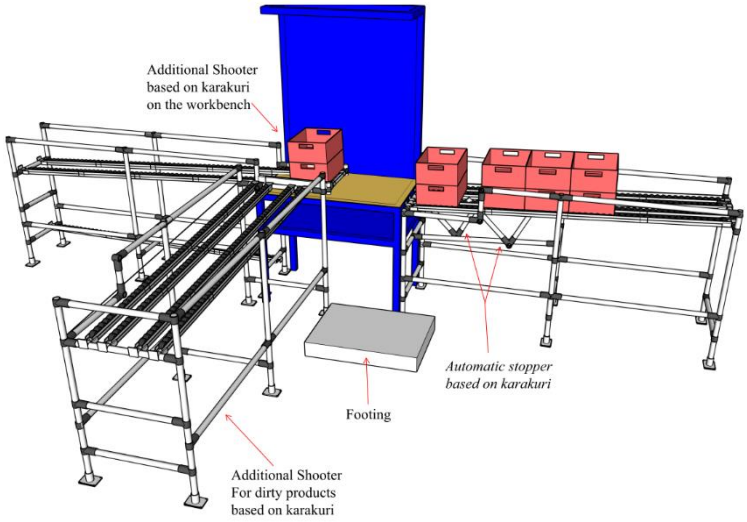

Figure 2. Redesigned Workstation Incorporating Lean Ergonomics and Karakuri Kaizen

Post-Intervention Measurements

Intervention remeasures were completed after one week because of the redesigned workstation and included RULA and NBM.

1. Post-Intervention NBM

After the implementation of the ergonomic interventions, the Nordic Body Map scores improved; the average Nordic Body Map score fell from 62.6 to 28.8, showing that the musculoskeletal discomfort had been greatly reduced. The results showed that the greatest improvements had been realized in the lower back, shoulder, and neck.

Table 2. Comparison of NBM Scores Before and After Intervention

Condition	Mean NBM Score	Discomfort Level
Before improvement	62.6	Moderate–High
After improvement	28.8	Low

2. Post-Intervention RULA

After the workstation revision RULA score showed:

Initial score of 7, then a very high risk,

Post revision score of 3, low risk

It was intended that the post-intervention RULA assessment resulted in a significant decrease in the mean score from 7 (very high risk, Action Level 3) to 3 (low risk, Action Level 1). This shift means that the modified workstation was able to reduce the level of postural risks to an acceptable degree and thus did not necessitate corrective actions.

Table 3. RULA Score Comparison Before and After Intervention

Assessment Stage	RULA Score	Action Level	Risk Category
Before improvement	7	Action Level 3	Very high risk
After improvement	3	Action Level 1	Low risk

5. Reduction in Repetitive and Awkward Motion

A dramatic decrease in repetitive forward bending was recorded following the workstation modification. As can be seen in Figure 3, the incidence of forward bending motions reduced from an average of 80 occurrences per shift to an average of 20 occurrences per shift, which corresponds to a decrease of 75%.

Additionally, extreme angles in postural positions were decreased by over 40% to minimize operator fatigue and facilitate better workflow stability. Operators also benefited from reduced physical strain and smoother flowing products, signifying the elimination of non-value added actions through proper ergonomic design.

the same improvements in elimination of awkward and repeated movements have also been observed by previous studies, including Widya et al. (2023), Adiyanto et al. (2022),

and Mozzi et al. (2020). These studies are relevant in proving the reliability and validity of current findings regarding Lean Ergonomics.

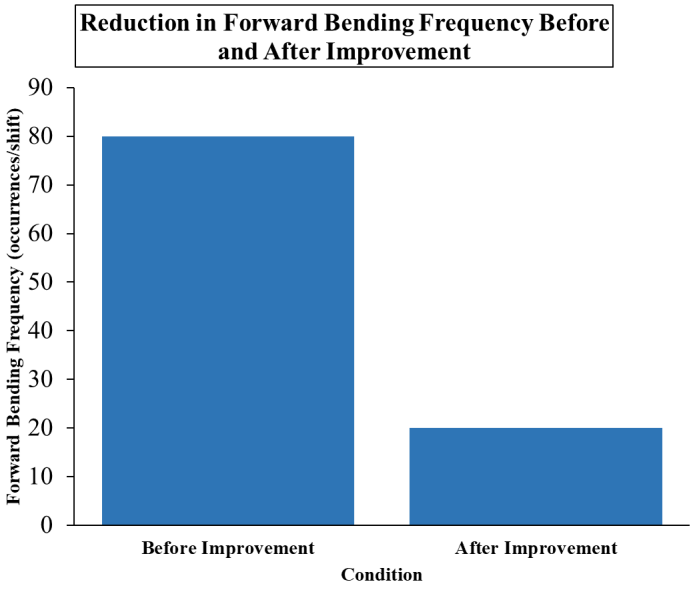

Figure 3. Comparison of forward bending frequency before and after workstation improvement.

Discussion

Findings from this research show that implementation of both Lean Ergonomics and Karakuri Kaizen is an effective way to reduce the risk of Musculoskeletal Disorder among visual inspection operators in automotive components production. Pre-intervention analysis among these operators indicated a high level of exposure to poor working postures in terms of both high scores of NBM and RULA risk level.

Following workstation modifications based on anthropometric considerations and usage of Karakuri systems for material handling, marked improvements were noted. The average score for NBM reduced from 62.6 to 28.8, which further shows a marked reduction in RULA scores from 7 to 3, thus establishing a change from high to low-risk working postures. Moreover, the incidence of recurrent bending in a forward direction is less than 20 in a working shift, thus establishing efficiency in maintaining an operator posture.

Unlike in the study conducted by Gürsoy Özcan in 2022, wherein an experiment proved the effectiveness of Karakuri Kaizen in reducing ergonomic risk in assembling operations using semi-automated systems, in this study, it can be observed that a degree of risk reduction can be achieved in visual inspection without using any form of powered automation.

Moreover, the obtained decreases in NBM and RULA scores are in support of some studies conducted by Widya et al. (2023) and Adiyanto et al. (2022), in which they used ergonomic evaluation methods in addition to implementation of process improvements. Nevertheless, in contrast to these studies, this research combines Lean Ergonomics with Karakuri Kaizen, where both issues concerning work in inspection tasks the reduction of ergonomics risk and work efficiency are tackled accordingly.

From a theoretical viewpoint, these results support the view that a Lean Ergonomics approach is a socio-technical system rather than simply an efficiency-led strategy. The incorporation of an ergonomic philosophy in a Lean design shows that both increased efficiency and better working conditions are not opposing aims but rather complementary outcomes. Karakuri Kaizen acts in this case as a mediator tool which matches human physiological capabilities with a Lean work-flow system through a low-energy and human-centered approach.

From a management point of view, the results of this research indicate that a considerable increase in ergonomic benefits and productivity can be obtained without depending on high automation or capital expenditure. The combination of Lean Ergonomics and Karakuri Kaizen is beneficial to manufacturing managers in improving the welfare of workers while ensuring productivity is not adversely affected. The proposed program may be more effective for small to medium-scale manufacturing companies as they have constraints on budget expenditure.

In practical terms, this research work shows which benefits may be successfully obtained using frugal engineering solutions for improving ergonomics and working methods without necessarily using advanced automation methods. This can be especially relevant for small and medium-sized enterprises in the production field in a laborious environment. Further research suggestions are described in the following paragraph for future research work concerning this topic.

Conclusion

This case demonstrates that integration of Lean Ergonomics with Karakuri Kaizen is an effective and sustainable strategy towards minimizing WMSD risk in visual inspection tasks in automotive component production. The intervention strategy, which used workstation modification based on anthropometric principles and gravity-assisted Karakuri systems, proved effective in optimizing working positions, minimizing repetition, and improving working stability.

Practically speaking, it can be observed that meaningful ergonomics and operational gains can be realized with minimal cost using human-centered solutions in engineering without needing any form of powered automation. Such an intervention strategy will prove most beneficial in a labor-driven production setting or small and medium enterprises.

Of course, this study also has a number of shortcomings, including a small sample size and a short observation time after intervention implementation. Although this intensive observation technique gives a good idea of posture, it may not be very reliable in terms of generalization of results.

Future studies need to cover a larger sample of participants and a more extended time span in order to improve the level of generalizability. Secondly, it would be a good idea to incorporate wearable sensors/motion capture technology in order to confirm objectively the improvements in postural orientation and assess in a broad manner the level of ergonomic adjustment during a variety of inspection and labor-intensive manufacturing operations.

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