**RiESTech**
*Recent in Engineering Science and Technology*

MBI

*Article*

# Design of a Heavy-Duty Manual Turntable for Heavy Material Handling Activities to Reduce the Potential Risk of Musculoskeletal Disorders (MSDs)

**Ari Dwiyanto [1,*], Agus Edy Pramono [1], Aminudin Zuhri [2]**

[1] Master's Program in Applied Manufacturing Technology Engineering, Politeknik Negeri Jakarta, Indonesia
[2] Department of Materials Science and Engineering, National Dong Hwa University, Taiwan
* Correspondence: agus.edypramono@mesin.pnj.ac.id

**Abstract:** Heavy material handling and rotation activities in the fabrication area are still performed manually using a conventional worktable without a material rotation system. This condition requires the observed operator to bend, twist the body, and repeatedly lift and reposition the material during the work process. These non-neutral working postures have the potential to cause Musculoskeletal Disorders (MSDs), particularly in the neck, shoulders, lower back, arms, and wrists due to excessive and repetitive physical loading. Therefore, this study aims to analyze ergonomic risks in heavy material handling activities and design a Heavy-Duty Manual Turntable to improve operator working posture. The methods used include field observation, work posture documentation, Nordic Body Map (NBM) analysis, posture angle measurement, ergonomic evaluation using Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA), anthropometric analysis, CAD-based design simulation, and simple biomechanical analysis. The NBM screening was completed by one observed operator and identified complaints in the neck, shoulders, lower back, upper arms, wrists, and lower legs. The initial condition had a RULA score of 6–7 and a REBA score of 9–11. The proposed solution is a Heavy-Duty Manual Turntable Model VP1-R with 360° rotational capability and an adjustable working height. Based on the proposed posture simulation, the estimated RULA score decreased to 2–3 and the estimated REBA score decreased to 2–3. The simplified biomechanical comparison also indicated an approximately 45% reduction in the lower-back moment. Because the post-design assessment was based on CAD simulation and not on a fabricated prototype, these results should be interpreted as preliminary design estimates. This study presents an ergonomic assistive-device design that can be used as a basis for prototype development and field testing.

**Keywords:** Ergonomics; RULA; REBA; Nordic Body Map; Anthropometry; Manual turntable; CAD simulation

**Citation:** Dwiyanto, A., Pramono, A. E., Zuhri, A. (2026). Design of a Heavy-Duty Manual Turntable for Heavy Material Handling Activities to Reduce the Potential Risk of Musculoskeletal Disorders (MSDs). Recent in Engineering Science and Technology, 4(3), 155–164. Retrieved from https://www.mbi-journals. com /index.php/riestech/article/view/154.

Academic Editor: Noor Hidayati

Received: 11 May 2026
Accepted: 17 June 2026
Published: 31 July 2026



## 1. Introduction

Manual handling of heavy materials remains common in manufacturing and fabrication activities [1,2]. These activities involve lifting, twisting, bending, and maintaining static postures for certain periods, thereby increasing the risk of Musculoskeletal Disorders (MSDs). According to the National Institute for Occupational Safety and Health (NIOSH), MSDs are disorders affecting muscles, tendons, ligaments, nerves, and joints caused by exposure to ergonomic risk factors such as non-neutral postures, excessive force, repetitive movements, and static working positions [17].

Ergonomic posture analysis has been conducted using the Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), and Ovako Working Analysis System (OWAS) methods [1,9]. The RULA method is used to evaluate upper-limb, neck, and trunk postures during work activities [13]. The REBA method evaluates whole-body posture and also considers load, coupling, and activity factors [6]. Recent studies have also used image- and sensor-based joint-angle measurements to support RULA and REBA assessment [3,4].

In the actual fabrication process, operators perform heavy material handling and repositioning activities using conventional worktables without a material rotation mechanism. The dimensions and weight of the workpiece require the operator to reposition the material manually during the work process. This condition forces the operator to work in a bent posture, twist the body, partially lift the material, and maintain static postures for certain periods. Preliminary observations also indicate that the operator has difficulty reaching specific processing areas because the existing table cannot rotate the workpiece. These activities increase biomechanical loading and may raise the risk of MSDs due to non-neutral working postures [12]. Recent industrial intervention and field-evaluation studies likewise support workstation redesign and adjustable equipment as practical controls for reducing musculoskeletal risk [5,8].

Several previous studies have applied RULA, REBA, and NBM to evaluate ergonomic risk in manual material handling activities [1,2,9,10]. These methods are useful for identifying risk, but the observed fabrication process also requires a practical device that can rotate a heavy workpiece and maintain an appropriate working height. Therefore, the research gap addressed in this study is the design and simulation-based ergonomic evaluation of a manually controlled heavy-duty turntable for the observed task.

Based on the literature review, this study aims to identify musculoskeletal complaints using NBM, analyze ergonomic risks using RULA and REBA, determine the main design dimensions from the available operator anthropometric data, and redesign a Heavy-Duty Manual Turntable equipped with a 360° material rotation system and adjustable working-height features. The proposed design is evaluated through CAD-based posture simulation and a simplified biomechanical comparison; therefore, the post-design results are not presented as field-tested effectiveness.

The observed posture shown in Figure 1 illustrates the main problems identified in the initial process, including trunk and neck flexion, elevated arms, wrist flexion, and an unstable standing position.

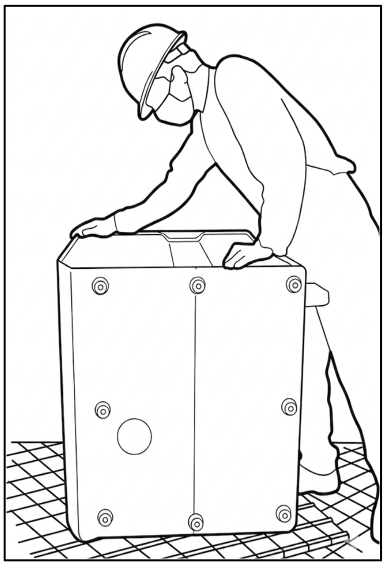

**Figure 1.** Non-neutral working posture observed in the initial process

## 2. Materials and Methods

This study uses a descriptive quantitative approach to analyze ergonomic risks in heavy material handling activities and to design a rotary turntable assistive device to improve the operator's working posture. The study focuses on one observed operator and one representative heavy material handling task in a fabrication area. The proposed condition was evaluated through CAD-based posture simulation; a fabricated prototype was not tested in this study.

### 2.1. Research Tools and Materials

The tools used in this study included a smartphone camera for work posture documentation, posture angle measurement software, CAD software for assistive device design, and assessment sheets for Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), and Nordic Body Map (NBM).

The research materials consisted of the observed operator's heavy material handling activity, the available operator anthropometric data, and the design of the Heavy-Duty Manual Turntable Model VP1-R.

### 2.2. Research Method

The study began with direct observation of the operator's work activities to identify postures that pose a risk of MSDs. The observation covered lifting, moving, reaching, and rotating the heavy workpiece. Photo and video documentation were then used to obtain body-posture angles. The posture shown in Figure 2 was selected because it represents the main non-neutral positions found during the task and was used for the subsequent angle measurement and RULA–REBA scoring.

**Figure 2.** Representative initial posture used for angle measurement and ergonomic assessment

The observed operator completed the NBM questionnaire (n = 1) to identify body regions that felt uncomfortable during the task. Because the questionnaire involved one operator, the results are reported descriptively and are not expressed as complaint prevalence. Posture angles of the neck, trunk, upper arm, lower arm, and wrist were measured from the visual documentation using posture-angle measurement software. Figure 3 shows the posture-angle measurement used in the assessment.

The measured posture angles were analyzed using RULA and REBA. RULA was used to assess the upper limbs, neck, trunk, and legs [13], while REBA was used to assess whole-body posture together with load/force, coupling, and activity [6]. The available anthropometric measurements were then used to determine the proposed working height and reach of the assistive device.

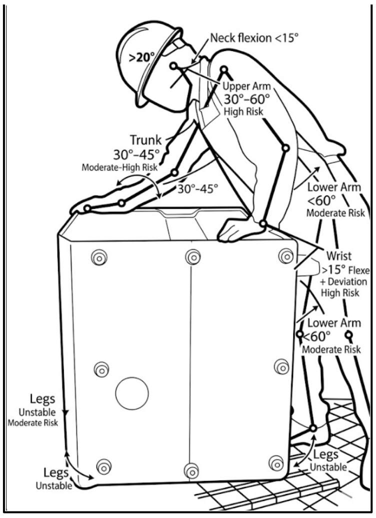


**Figure 3.** Posture-angle measurement of the representative initial condition

### 2.3. NBM, RULA, REBA, and Anthropometric Procedures

The Nordic Body Map is a body-region questionnaire used to identify perceived musculoskeletal discomfort [11]. In this study, the questionnaire was completed by the observed operator after the work activity. The results were used only to identify complaint locations and were not used to estimate prevalence among workers.

RULA assesses the upper arm, lower arm, wrist, neck, trunk, and legs, followed by adjustments for muscle use and force. The final score ranges from 1 to 7; higher scores indicate a greater need for corrective action [13].

REBA assesses the neck, trunk, legs, upper arm, lower arm, and wrist, and then adds load/force, coupling, and activity scores. The final score ranges from 1 to 15; higher scores indicate a higher ergonomic risk and a more urgent need for corrective action [6].

The anthropometric inputs used in the design were the observed operator's standing elbow height of 105 cm and forward arm reach of 68 cm. These values were treated as individual measurements, not as population averages. The proposed platform-height range of 100–110 cm was selected as an adjustable range around the measured elbow height.

The Heavy-Duty Manual Turntable Model VP1-R was developed in CAD and the proposed operator posture was simulated using the same body-segment variables applied in the initial RULA and REBA assessments. The simplified biomechanical comparison used the load, horizontal distance, and trunk-angle values already presented in the study.

All post-design posture scores and biomechanical values in this article are simulation-based estimates. They were not obtained from a fabricated prototype or from a second field measurement.

### 2.4. Analysis Techniques

The analysis techniques used in this study were:

1. Working posture analysis using RULA and REBA for the initial documented posture and the proposed simulated posture;
2. Descriptive musculoskeletal complaint analysis using NBM for the observed operator (n = 1);
3. Operator-specific anthropometric analysis using standing elbow height and forward arm reach;
4. A simplified biomechanical comparison of the estimated lower-back moment; and
5. Comparative analysis of the documented initial condition and the CAD-simulated proposed condition.

The biomechanical comparison was used to estimate changes in lower-back loading associated with the initial and proposed scenarios. It was treated as a simplified engineering comparison rather than a direct measurement of spinal load or a complete application of the Revised NIOSH Lifting Equation [18].

### 2.5. Research Methodology Steps

The research stages are summarized in Figure 4, starting with observation and posture documentation, followed by NBM, posture-angle measurement, RULA–REBA assessment, anthropometric analysis, turntable design, CAD posture simulation, and simplified biomechanical comparison.

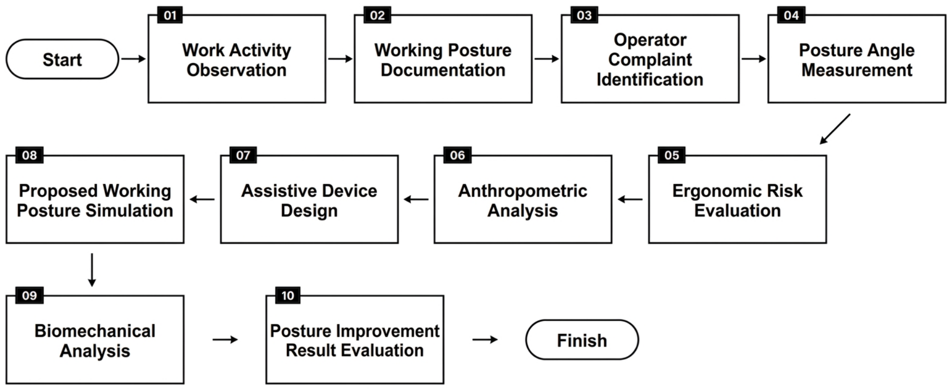


**Figure 4.** Research methodology flowchart

## 3. Results and Discussion

The observation results showed that the operator performed heavy material handling and workpiece repositioning manually. The representative posture in Figure 2 involved trunk and neck flexion, upper-arm elevation, wrist deviation, and unstable lower-limb support. These conditions indicate a non-neutral posture that may increase musculoskeletal loading during the task [1,9,14].

### 3.1. Operator Complaint Analysis

The NBM questionnaire was completed by the observed operator (n = 1). The reported complaints were located in the following body regions:

- Lower back;
- Neck, shoulders, and upper arms;
- Wrists and lower legs.

The complaint locations are consistent with the body segments loaded in the posture shown in Figure 2. Because the NBM involved one operator, the findings are interpreted as a description of the observed task and not as a percentage of workers with complaints.

### 3.2 Posture Angle Analysis

The posture-angle measurements shown in Figure 3 produced the following initial values:

- Neck flexion: approximately 35°;
- Trunk flexion: approximately 35°;
- Upper-arm flexion: approximately 45°;
- Lower-arm flexion: approximately 50°;
- Wrist flexion: approximately 25° with deviation.

These angle values were used as the scoring inputs for Table 1. The combined deviations of the trunk, neck, upper arm, and wrist explain the high initial RULA and REBA scores.

**Table 1.** RULA score calculation for the representative initial condition

| Component | Condition | Score |
|---|---|---|
| Upper Arm | ±45° | 3 |
| Lower Arm | ±50° | 2 |
| Wrist Position | ±25° + deviation | 3 |
| Wrist Twist | Near end range | 2 |
| Neck Position | ±35° | 3 |
| Trunk Position | ±35° | 3 |
| Legs | Unstable | 1 |

Final RULA score = 6–7 (changes required soon to immediately)

The RULA assessment resulted in a score range of 6–7. A score of 6 indicates that investigation and change are required soon, whereas a score of 7 indicates that investigation and change are required immediately [13].

The RULA result is consistent with the NBM complaint locations, particularly the neck, shoulders, lower back, upper arms, and wrists. This agreement is descriptive because the study involved one observed operator.

### 3.3. Ergonomic Risk Evaluation

The initial RULA and REBA results were:

- RULA score = 6–7;
- REBA score = 9–11.

**Table 2.** REBA component scores for the initial and simulated proposed conditions

| REBA component | Initial condition | Score | Simulated proposed condition | Score |
|---|---|---|---|---|
| Neck | ≈35° flexion | 2 | <15° flexion | 1 |
| Trunk | ≈35° flexion | 3 | <10° flexion | 1 |
| Legs | Unstable/asymmetrical | 2 | Stable support | 1 |
| Load/force | 50 kg workpiece; partial lifting | 3 | No manual lifting during rotation | 0 |
| Upper arm | ≈45° flexion | 2–3 | <20° flexion | 1 |
| Lower arm | ≈50° flexion | 2 | ≈90° flexion | 1 |
| Wrist | ≈25° with deviation | 2–3 | ≈5° deviation | 1 |
| Coupling/activity | Constrained; repeated repositioning | 1–2 | Controlled rotation | 0–1 |
| Final REBA score | High to very high risk | 9–11 | Low risk (estimated) | 2–3 |

Table 2 presents the REBA components used for the initial posture and the proposed CAD-simulated posture. The initial score of 9–11 indicates high to very high risk. The proposed score of 2–3 is an estimate based on the simulated posture and should not be interpreted as a result of field implementation.

### 3.4. Anthropometric Analysis

The design dimensions were based on the observed operator's standing elbow height of 105 cm and forward arm reach of 68 cm. The term "average" was removed because the study did not use a population sample. The proposed platform was designed to be adjustable from 100 to 110 cm, providing an adjustment range around the measured elbow height.

**Table 3.** Operator anthropometric inputs and proposed working height

| Parameter | Initial condition | Proposed condition | Design basis |
|---|---|---|---|
| **Observed operator standing elbow height** | **105 cm** | **105 cm** | **Direct measurement (n = 1)** |
| **Working platform height** | **75 cm** | **Adjustable 100–110 cm** | **±5 cm around measured elbow height** |
| **Observed forward arm reach** | **68 cm** | **68 cm** | **Direct measurement (n = 1)** |
| **Upper-arm flexion angle** | **45°** | **<20°** | **RULA–REBA posture target** |
| **Trunk flexion angle** | **35°** | **<10°** | **RULA–REBA posture target** |

### 3.5. Design Simulation and Posture Improvement

The Heavy-Duty Manual Turntable Model VP1-R was designed with 360° rotation capability, an adjustable work platform, and a foot-pedal system to facilitate material rotation without requiring the operator to partially lift the workpiece. These features address the trunk twisting, reaching, and lifting observed in the initial process.

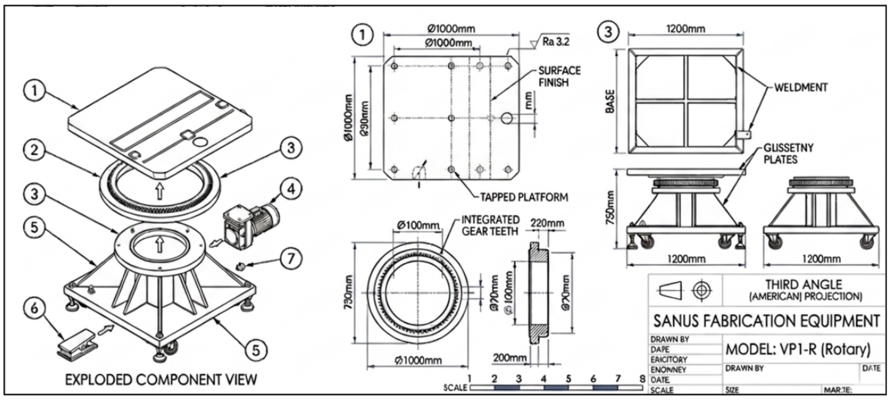


**Figure 5.** Heavy-Duty Manual Turntable Model VP1-R: components and principal dimensions

The modification of the Heavy-Duty Manual Turntable Model VP1-R was intended to improve the operator's working posture through a 360° material rotation system and adjustable work-area height. The main modifications included the manual rotation mechanism, platform-height adjustment based on the available operator anthropometric data, and a foot-pedal system. The design shown in Figure 5 is a CAD proposal and was not fabricated during this study.

The posture shown in Figure 6 was generated through CAD simulation using the proposed dimensions. The simulation was used to estimate changes in posture angles and ergonomic scores; it was not a post-implementation measurement.

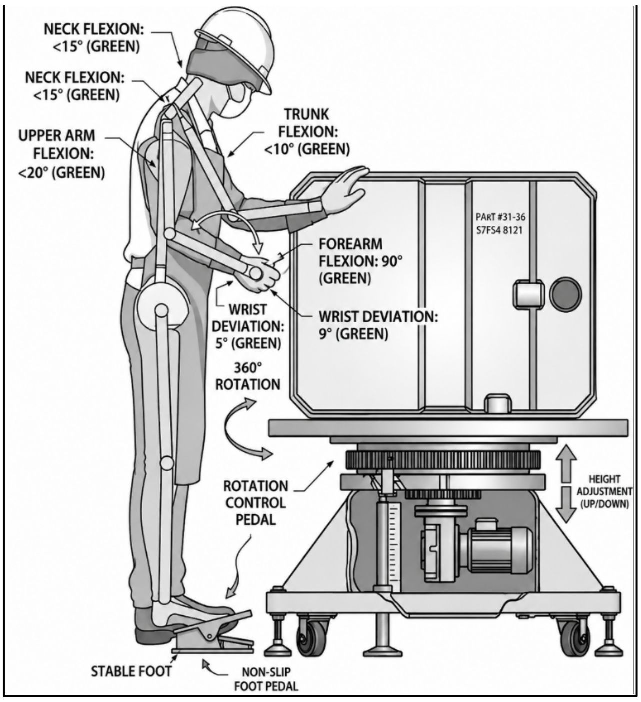


**Figure 6.** CAD-simulated working posture using the proposed turntable

### 3.6. Working Posture Analysis After Using the Heavy-Duty Manual Turntable Model VP1-R

Based on the CAD posture simulation, the proposed condition showed a more upright trunk, lower neck flexion, reduced upper-arm elevation, a more neutral wrist, and more stable foot support than the initial condition. These changes occurred because the workpiece could be rotated toward the operator and the working height could be adjusted.

The simulated posture showed neck flexion of less than 15°, trunk flexion of less than 10°, upper-arm flexion of less than 20°, lower-arm flexion of approximately 90°, and wrist deviation of approximately 5°. These values, shown in Figure 6, were used to estimate the post-design RULA and REBA scores. More neutral postures are associated with lower ergonomic loading [12].

The foot-pedal concept allows rotation control without using the hands and may help the operator maintain a more stable stance. However, pedal force, slip resistance, braking, and locking reliability still require verification during prototype testing.

Using the simulated posture angles, the estimated RULA score decreased from 6–7 to 2–3 and the estimated REBA score decreased from 9–11 to 2–3. The REBA component scores are presented in Table 2. These results indicate a lower predicted ergonomic risk, but they do not establish actual effectiveness because no prototype was tested.

The simulation supports the design approach of reducing reach, trunk flexion, body rotation, upper-arm elevation, and wrist deviation. The proposed design therefore requires prototype fabrication and field validation before conclusions are generalized.

### 3.7. Biomechanical Analysis

The simplified biomechanical comparison estimated a lower L5/S1 moment for the proposed condition because the simulated task removed manual lifting during rotation and reduced the horizontal distance and trunk-flexion angle.

Using the scenario values in Table 4, the estimated lower-back moment decreased from 312 Nm to 172 Nm, or approximately 45%. This value is a simplified engineering estimate and should not be interpreted as a directly measured spinal load or as a complete Revised NIOSH Lifting Equation analysis [18].

**Table 4.** Simplified comparison of estimated lower-back moments (L5/S1)

| Condition | Lifting Force | Horizontal Distance | Trunk Angle | Moment (Nm) | Reduction |
|---|---|---|---|---|---|
| Initial Condition | 50 kg | 40 cm | 35° | 312 | - |
| Using Turntable | 0 kg | 20 cm | <10° | 172 | -45% |

## 4. Conclusions

The results of this study indicate that the observed heavy material handling task has a high ergonomic risk based on RULA and REBA. The operator worked in a non-neutral posture characterized by trunk flexion, upper-arm elevation, wrist deviation, and unstable foot support. The NBM questionnaire completed by the observed operator identified complaints in the neck, shoulders, lower back, upper arms, wrists, and lower legs. The initial assessment produced a RULA score of 6–7 and a REBA score of 9–11, indicating that corrective action was required.

To address these issues, a Heavy-Duty Manual Turntable Model VP1-R was designed with a 360° material rotation system, an adjustable 100–110 cm working height, and a foot-pedal mechanism. The CAD-simulated posture produced estimated RULA and REBA scores of 2–3. The simplified biomechanical comparison also indicated an approximately 45% reduction in the estimated lower-back moment. These results support continued prototype development, but they do not demonstrate field effectiveness.

This study is limited to one observed operator, a CAD-simulated proposed posture, and a simplified biomechanical comparison. Future studies should fabricate and test the VP1-R prototype, verify structural capacity and locking safety, measure pedal and rotation forces, repeat the RULA and REBA assessments during actual use, and involve additional operators before the findings are generalized to other industrial settings.

**Acknowledgments:**

The author would like to express sincere gratitude to Politeknik Negeri Jakarta for providing academic support, facilities, and an educational environment that greatly contributed to the completion of this research. The author also extends heartfelt appreciation to all lecturers who have shared their knowledge, guidance, experience, and valuable insights throughout the learning process. Their dedication and support have played an important role in the development of the author’s academic understanding and research abilities.

In addition, the author would like to thank all individuals who directly or indirectly contributed to this study, whether through technical assistance, constructive discussions, or moral support during the research and preparation of this paper.

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

## References

[1] D. Kee, “Systematic Comparison of OWAS, RULA, and REBA Based on a Literature Review,” International Journal of Environmental Research and Public Health, vol. 19, no. 1, 595, 2022, doi: 10.3390/ijerph19010595.

[2] A. S. Rezki, A. H. Maksum, D. Herwanto, and M. T. Rahmat, “Analisis Risiko Postur Kerja dengan Metode Nordic Body Map, RULA dan REBA pada Proses Manual Material Handling Pabrik Kecap,” Jurnal Media Teknik dan Sistem Industri, vol. 7, no. 2, pp. 86–94, 2023, doi: 10.35194/jmtsi.v7i2.2677.

[3] P. Paudel, Y.-J. Kwon, D.-H. Kim, and K.-H. Choi, “Industrial Ergonomics Risk Analysis Based on 3D-Human Pose Estimation,” Electronics, vol. 11, no. 20, 3403, 2022, doi: 10.3390/electronics11203403.

[4] W. F. Senjaya, B. N. Yahya, and S.-L. Lee, "Sensor-Based Motion Tracking System Evaluation for RULA in Assembly Task," Sensors, vol. 22, no. 22, 8898, 2022, doi: 10.3390/s22228898.

[5] M. Rostami, A. Choobineh, M. Shakerian, M. Faraji, and H. Modarresifar, "Assessing the effectiveness of an ergonomics intervention program with a participatory approach: Ergonomics settlement in an Iranian steel industry," *International Archives of Occupational and Environmental Health*, vol. 95, no. 5, pp. 953–964, 2022, doi: 10.1007/s00420-021-01811-x.

[6] Ö. Ayvaz, B. A. Özyıldırım, H. İşsever, G. Öztan, M. Atak, and S. Özel, "Ergonomic risk assessment of working postures of nurses working in a medical faculty hospital with REBA and RULA methods," *Science Progress*, vol. 106, no. 4, Art. no. 00368504231216540, 2023, doi: 10.1177/00368504231216540.

[7] R. Darussalam, "Analisis Penilaian Postur Kerja Karyawan dengan Menggunakan Metode NBM, RULA dan REBA," Jurnal Indonesia Sosial Sains, vol. 3, no. 9, pp. 1278–1285, 2022, doi: 10.59141/jiss.v3i09.706.

[8] J. G. Ramsey and S. M. Hatcher, *Ergonomic and Musculoskeletal Evaluation of Distribution Tasks at a Logistics Agency in California*, NIOSH Health Hazard Evaluation Report 2019-0024-3398, Cincinnati, OH, USA, 2024.

[9] D. Kee, "Comparison of OWAS, RULA, and REBA for assessing potential work-related musculoskeletal disorders," *International Journal of Industrial Ergonomics*, vol. 83, 103139, 2021, doi: 10.1016/j.ergon.2021.103139.

[10] N. R. Kodle, S. P. Bhosle, and V. B. Pansare, "Ergonomic Risk Assessment of Tasks Performed by Workers in Granite and Marble Units Using REBA," Materials Today: Proceedings, vol. 72, pp. 1903–1916, 2023.

[11] M. E. Beatrix and A. W. Wijayanto, "Posture Analysis Using the Rapid Entire Body Assessment (REBA) & Nordic Body Map (NBM) Methods to Reduce the Risk of Musculoskeletal Disorders (MSDs) in Automotive Company," *International Journal of Advances in Scientific Research and Engineering*, vol. 9, no. 2, pp. 29–35, 2023, doi: 10.31695/IJASRE.2023.9.2.4.

[12] C. M. Lind, F. Abtahi, and M. Forsman, "Wearable Motion Capture Devices for the Prevention of Work-Related Musculoskeletal Disorders in Ergonomics—An Overview of Current Applications, Challenges, and Future Opportunities," *Sensors*, vol. 23, no. 9, Art. no. 4259, 2023, doi: 10.3390/s23094259.

[13] K. Sirikasemsuk, P. Kittipanya-Ngam, D. Luanwiset, and K. Leerojanaprapa, "Work posture risk comparison of RULA and REBA based on measures of assessment-score variability: A case study of the metal coating industry in Thailand," *International Journal of Innovative Research and Scientific Studies*, vol. 7, no. 3, pp. 926–935, 2024, doi: 10.53894/ijirss.v7i3.2978.

[14] F. Motta, T. Varrecchia, G. Chini, A. Ranavolo, and M. Galli, "The Use of Wearable Systems for Assessing Work-Related Risks Related to the Musculoskeletal System—A Systematic Review," *International Journal of Environmental Research and Public Health*, vol. 21, no. 12, Art. no. 1567, 2024, doi: 10.3390/ijerph21121567.

[15] M. K. A. Serunting and H. Hz, "Analisis risiko ergonomi pada karyawan bengkel utama yang mengalami keluhan Musculoskeletal Disorders di PT Bukit Asam Tanjung Enim," *Jurnal Ilmu Kesehatan Masyarakat*, vol. 3, no. 2, pp. 58–66, 2017.

[16] D. Suryanto and R. A. F. Ginanjar, "Hubungan risiko ergonomi dengan keluhan Musculoskeletal Disorders (MSDs) pada pekerja informal bengkel las," *Jurnal Ilmu Kesehatan Masyarakat*, vol. 3, pp. 196–202, 2019.

[17] National Institute for Occupational Safety and Health, "About Ergonomics and Work-Related Musculoskeletal Disorders," *Centers for Disease Control and Prevention*, Feb. 21, 2024. Accessed: Aug. 7, 2026.

[18] T. R. Waters, V. Putz-Anderson, and A. Garg, *Applications Manual for the Revised NIOSH Lifting Equation*, DHHS (NIOSH) Publication No. 94-110, revised Sept. 2021, doi: 10.26616/NIOSHPUB94110revised092021.