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Integrating RNLE and REBA to Evaluate Manual Handling Risks among Semiconductor Technicians

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Abstract:
Manual handling of wafer pods persists in semiconductor fabrication despite high levels of automation, exposing technicians to work-related musculoskeletal disorders (WMSDs). This case study evaluated ergonomic risks associated with lift-and-load wafer pod tasks in the Fab Integration Department of a semiconductor facility in northern Malaysia. Eight technicians performing routine transfers from upper and lower trolley levels to tool loading ports were assessed using direct observation, task analysis, and physical measurements. Lifting demands were quantified using the Revised NIOSH Lifting Equation (RNLE) to determine the Recommended Weight Limit (RWL) and Lifting Index (LI), while postural risk was evaluated using the Rapid Entire Body Assessment (REBA). RNLE analysis showed LI values ranging from 1.01 to 2.00, indicating increased to high lifting risk, particularly for lower trolley tasks. Excessive horizontal reach and asymmetric trunk rotation were identified as the main contributors, reflected by reductions in the Horizontal Multiplier (HM) and Asymmetry Multiplier (AM). Postural assessment revealed high REBA risk levels (scores 6–8) associated with trunk flexion, neck extension, and asymmetric lifting. Based on these findings, targeted ergonomic interventions were proposed, including limiting twisting angles, maintaining safe horizontal reach distances, adopting squatting techniques for low-level lifting, and providing ergonomics training. The integrated RNLE–REBA approach offers a practical framework for identifying high-risk manual handling tasks in semiconductor manufacturing. Future research should extend this assessment to other departments and evaluate digital ergonomic monitoring tools for continuous risk management.

Keywords: Work-related musculoskeletal disorders (WMSDs); Ergonomic risk assessment; Semiconductor wafer fabrication; Revised NIOSH Lifting Equation (RNLE); Rapid Entire Body Assessment (REBA)

1. INTRODUCTION

Ergonomics is essential in designing workplaces that align with human physical capabilities to reduce the risk of work-related musculoskeletal disorders (WMSDs). WMSDs are widespread across manufacturing sectors, often resulting from repetitive motions, awkward postures, and manual handling. These issues lead not only to physical pain but also to higher absenteeism rates and reduced productivity, imposing substantial economic and operational burdens (1). In the semiconductor wafer fabrication industry, the risk of WMSDs is especially pronounced. Despite high levels of automation, technicians are still required to perform manual tasks such as lifting and loading wafer pods, which involve repetitive motions and awkward postural adjustments in cleanroom conditions (2). These biomechanical strains commonly affect the lower back, shoulders, neck, and upper limbs, ultimately reducing workforce efficiency and productivity in precision-focused manufacturing environments (3). Review of ABC Semiconductor's internal health data reveals a pronounced increase in WMSD cases with the Fab Integration Department reporting the highest incidence. This trisected trend highlights how specific job activities, most notably pod handling, contribute to injury risk among wafer fab technicians.

In Malaysia, there is limited empirical research addressing ergonomics within the semiconductor sector. A pivotal study of 906 female semiconductor technicians across Peninsular Malaysia found high prevalence rates of musculoskeletal pain particularly in the lower limbs, neck/shoulders, and upper back with strong correlations to prolonged standing, repetitive hand movement, and manual lifting (4). These findings discover a research gap: despite the industry's scale and workforce health concerns, ergonomics-focused assessments and intervention strategies are underrepresented in Malaysia's semiconductor context. Therefore, this study addresses these gaps by applying validated ergonomic assessment tools which are Revised NIOSH Lifting Equation (RNLE) and Rapid Entire Limb Assessment (REBA) to evaluate the ergonomic risks inherent in wafer pod handling. Therefore, this study aims to quantify ergonomic risk during wafer pod handling using the RNLE and REBA methods and to propose feasible control strategies to reduce WMSD risk among semiconductor technicians.

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Musculoskeletal disorders (MSDs) are a significant global occupational health issue that affects technician productivity and quality of life. The World Health Organization (WHO) identifies MSDs as one of the leading causes of disability worldwide, commonly involving the lower back, shoulders, neck, and upper limbs, often resulting from repetitive work, awkward postures, and manual handling tasks. In Malaysia, the prevalence of MSDs among industrial technicians is notably high. Chee *et al*. (4) reported that 45.4% of semiconductor technicians experienced musculoskeletal pain, particularly in the lower back (18.7%) and shoulders (21.8%), due to prolonged standing, repetitive tasks, and manual lifting. Similarly, a recent study found that 93.1% of factory technicians reported MSD symptoms in the past year, with lower back pain being the most common complaint (5).

The primary risk factors associated with MSDs include awkward or sustained postures, repetitive movements, and manual material handling. In semiconductor wafer fabrication, despite high levels of automation, technicians remain exposed to physically demanding tasks such as repetitive wafer pod handling, which involve bending, twisting, and lifting motions that place substantial biomechanical stress on the musculoskeletal system (6). Ergonomic risk assessment tools such as the RNLE and REBA are widely used to evaluate physical risk factors in manufacturing environments. RNLE calculates the Recommended Weight Limit (RWL) and Lifting Index (LI) to assess manual lifting safety, while REBA provides a whole-body postural assessment, scoring risk levels based on trunk, neck, leg, and arm positions, force, and activity type (7, 8). Studies applying RNLE and REBA in manufacturing have demonstrated their effectiveness in quantifying risk and guiding interventions. For example, research in electronics and assembly industries reported high-risk findings (LI > 1.0; REBA scores 7–11) associated with manual handling and awkward postures, leading to targeted ergonomic interventions such as workstation redesign, optimized reach distances, and training, which successfully reduced risk levels (6). However, few studies have applied RNLE and REBA concurrently in Malaysian semiconductor wafer fabrication. Addressing this gap is crucial to developing evidence-based ergonomic interventions that reduce MSD prevalence and improve technician health in high-precision manufacturing.

2. METHODOLOGY

A total of eight technicians from the Fab Integration Department of ABC Semiconductor were assessed in this study. Participants were selected using purposive sampling based on their routine involvement in wafer pod lift-and-load activities and their availability during the observation period. Prior to data collection, all technicians were briefed on the study objectives, procedures, and confidentiality measures, and written informed consent was obtained. The study was conducted as an internal industrial ergonomics assessment with organizational permission and informed consent. Observations and measurements were carried out over representative task cycles across trolley-to-tool transfers involving both upper and lower shelf levels.

The study adopted a case study research design, beginning with a review of historical records of reported and confirmed musculoskeletal disorder (MSD) cases within the company. This preliminary review provided an overview of work activities, body regions, and tasks most frequently associated with ergonomic issues. Based on this information, critical MSD risk areas were identified to ensure that subsequent ergonomic evaluations focused on workstations and activities with the greatest potential impact on technicians' health and safety. Following the identification stage, a detailed ergonomic assessment was conducted at the selected work area using two complementary approaches: psychophysical assessment and postural analysis. The RNLE was applied to evaluate manual handling tasks and to determine the Recommended Weight Limit (RWL) and Lifting Index (LI), which quantify the level of biomechanical stress associated with lifting activities. In parallel, the Rapid Entire Body Assessment (REBA) method was used to evaluate awkward, asymmetric, and sustained working postures that may contribute to discomfort or injury. Data collection was performed through a combination of interviews, direct observations, task analysis, and physical measurements. Task-related data included workstation layout, lifting distances and heights, asymmetric angles, task frequency, duration, and working capacity. A smartphone camera was used to capture images of technicians' working postures and movements associated with wafer pod transfer tasks. Angular measurements of trunk, neck, and limb positions during lift-and-load activities were obtained using a manual goniometer. A measuring tape was used to collect dimensional inputs required for the RNLE, including horizontal distance (H), vertical height (V), vertical travel distance (D), and asymmetry angle (A). The RWL was calculated using Equation 1, where the Load Constant (LC) is set at 23 kg, as recommended in the RNLE guidelines (7, 9, 10):

$$RWL = LC \times HM \times DM \times FM \times AM \times CM \quad (1)$$

$$LI = \frac{Actual\ Load}{RWL} \quad (2)$$

An LI value of less than 1 indicates low risk of WMSDs, values between 1 and less than 2 indicate increased risk, and values greater than 2 indicate a high risk of WMSDs. All assessment results were compiled into a comprehensive ergonomic risk evaluation, enabling the identification of key contributing factors and providing a robust basis for the development of targeted control measures. Although the sample size was limited, repeated observations across multiple task cycles and shelf configurations ensured adequate representation of typical wafer pod handling exposures.

3. RESULT AND DISCUSSION

3.1 Job Analysis

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Job analysis is the analysis on the job scope which involves identification of work operations and obliged tasks that must be performed by the technicians during their working time. In Fab Integration department at ABC company, the job involves task lifting of wafer pods from the trolley and loading to the tool continuously for 8-hour working shift. This task of lift/ load objects often ends up with issues such as asymmetric lifting and loading movement of wafer pods from the trolley to the tool as illustrated in Figure 1. Based on Figure 1, technicians load 10 kg of wafer pod from upper layer and lower layer of a trolley to assigned tools in 8-hour shift. The height of the upper trolley layer was 88 cm, and lower layer was 40 cm. The height of loading tools was 120 cm and 115 cm. Technician twists at the origin and destination of lift with asymmetrical angle of various degrees. The loads were held at different distances by each technician. Consider the grip from upper trolley to loading pod is good and from lower trolley is fair. Thus, this difference in holding loads at different distance results in asymmetric lifting and loading movement of wafer pod 1, 2 ,3 from the trolley to the tool among the Fab Integration technicians at ABC company. This eventually raises the risk of developing WSMD's and causing high number of low back pain cases reported from Fab Integration technicians at this industry for three years continuously.

The Fab Integration tools and trolleys that are used in the lift/ load task have their own specifications which require different tasks that need to be performed by the technicians as in Figure 2. Each tool has own sample, height for loading port and its own loading capacity. However, all the tools that are present in this department have similar loading capacity of 2 pods and height of loading port where 115 to 120 cm. Table 1 summarizes the lifting frequency for each tool which directly influences the RNLE Frequency Multiplier.

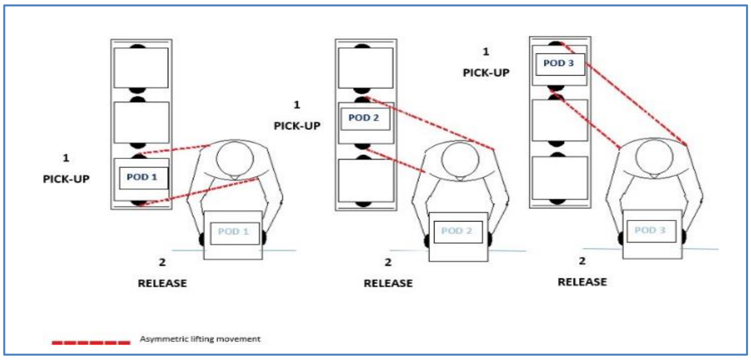

Figure 1. Asymmetric lifting and loading movement of pod 1, 2 ,3 from trolley to tool (upper view).

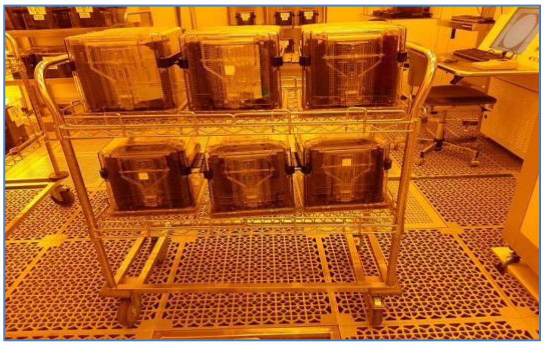

Figure 2. Fab integration trolley.

Table 1. Frequency (lifts/min) for tools in Fab integration.

FREQUENCY	KLA 01	KLA 04	F1DIAM01	F1DIAM02	P1BFKL01	P1DFKL01
	*These 4 tools allocated for one technician in 8-hour working shift				*These 2 tools allocated for one technician in 8-hour working shift	
(lifts/8hour)	50	50	60	60	80	80
(lifts/hour)	6.25	6.25	7.5	7.5	10	10
(lifts/min)	0.1	0.1	0.13	0.13	0.17	0.17
Technician Frequency (Lift/min)	0.5	0.5	0.5	0.5	0.3	0.3

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3.2 Ergonomic Risk Evaluation of Wafer Pod Handling Using RNLE and REBA

Table 2 presents a consolidated summary of ergonomic risk associated with wafer pod lift-and-load tasks, combining results from the RNLE and posture assessment using the REBA. Four representative task conditions (T1–T4) were evaluated based on trolley height (upper or lower) and tool group, with a constant load of 10 kg across all tasks. From the RNLE perspective, the Recommended Weight Limit (RWL) varied across tasks, reflecting differences in lifting geometry and task demands. Tasks involving lower trolley handling (T2 and T4) generally exhibited lower minimum RWL values compared to upper trolley tasks (T1 and T3), indicating less favorable lifting conditions due to increased horizontal reach, trunk flexion, and asymmetric postures. These reductions in RWL directly influenced the Lifting Index (LI) values, which ranged from 0.64 to 2.00 across all task conditions. Among the four tasks, T4 (lower trolley for P1DFKL01/P1BKL01 tools) demonstrated the highest ergonomic risk, with LI values ranging from 1.01 to 2.00 and a mean LI of approximately 1.35. LI values exceeding 1.0 indicate increased risk of low-back injury, while values approaching or exceeding 2.0 suggest a high level of biomechanical stress requiring prompt intervention. In contrast, upper trolley tasks (T1 and T3) generally showed lower mean LI values (≈0.92 and ≈1.05, respectively), although some observations still exceeded the recommended threshold. Postural risk assessment using REBA revealed consistently elevated risk levels across all tasks. REBA scores ranged from 6 to 8, corresponding to high to very high-risk categories, indicating that corrective actions are necessary. Tasks involving lower trolley handling (T2 and T4) recorded the highest REBA scores (7–8), reflecting the combined effects of deep trunk flexion, neck extension, and asymmetric postures during lifting and placement at the tool loading port. Lower trolley lift-and-load tasks pose substantially greater ergonomic risk than upper trolley tasks, as evidenced by both higher LI values and elevated REBA scores. The combined RNLE–REBA analysis highlights that ergonomic risk is driven not only by load weight, which remained constant, but primarily by task geometry, horizontal reach, asymmetry, and working posture.

The combined RNLE and REBA results (Table 2) clearly indicate that lower trolley wafer pod handling tasks represent the highest ergonomic risk and should be prioritized for engineering and administrative control measures. Chee *et al.* (2004) reported that prolonged standing, repetitive hand movements, and manual lifting are major contributors to WMSDs in Malaysian semiconductor facilities. The present study supports these findings by showing elevated LI values (>1.0) and high REBA scores (6–8) during wafer pod handling tasks, indicating increased biomechanical load and sustained awkward postures associated with manual lifting while standing.

Table 2. Summary of RNLE and posture risk from REBA.

Task ID	Task description	Tool group	Load (kg)	RWL range (kg)	LI range	Mean LI	REBA score (range)	REBA- risk level
T1	Upper trolley → tool	KLA01, KLA04, F1DIAM01, F1DIAM02	10	~8.7–15.7	0.64–1.15	~0.92	6–7	High
T2	Lower trolley → tool	KLA01, KLA04, F1DIAM01, F1DIAM02	10	~8.3–13.2	0.76–1.21	~0.97	7	High
T3	Upper trolley → tool	P1DFKL01, P1BKL01	10	~9.0–14.0	0.85–1.30	~1.05	6	High
T4	Lower trolley → tool	P1DFKL01, P1BKL01	10	~7.5–12.0	1.01–2.00	~1.35	7–8	High to Very High

3.3 Ergonomic Risk Control and Action

Preventing WMSDs occurrence by adjusting few variables in RNLE is another proposed ergonomic risk control and action that can be taken by Fab Integration department of ABC company. These variables have huge influence on the occurrence of WMSDs among technicians. The value of these variables should not exceed 1.0. There is positive evidence to link that it can result in the occurrence of WMSDs among the technicians as the weight the technician can carry has exceeded which eventually can cause back pain or back bone injuries for the value of more than 1.0. Thus, adjustments need to be made to reduce the prevalence of WMSDs among technicians. In this study, the asymmetric angles of twisting when lift/ load wafer pods to loading port set to 60˚ (Figure 3). A green floor marking tape stick at 60˚ of angle on the floor and trolley will be moved by technician for each time lift the wafer pod from trolley. This tape shall be a guiding spot for the technicians to know how to set the twisting angle to 60˚ in handling the pod.

The horizontal distance of the load from the technician's spine should be maintained within a safe range to prevent discomfort and reduce the risk of work-related musculoskeletal disorders (WMSDs) (Figure 4). One practical method to achieve this is by applying a red tape marker on the workstation surface, which serves as a visual guide to help technicians keep the horizontal reach within the recommended range of 15 cm to 25 cm. By limiting excessive reaching, this approach helps reduce spinal load and lowers the likelihood of WMSDs. However, while 25 cm is commonly accepted as an upper limit, Waters *et al.* (7) noted that the maximum Horizontal Distance (H) of 25 inches (63 cm) used in the Revised NIOSH Lifting Equation may still be too great for shorter technicians, especially during asymmetric lifting. When loads are handled beyond 25 cm from the body, the ankles cannot produce sufficient vertical force without compromising balance, further increasing the risk of injury. Supporting this, a case study by (11) found that tasks involving loads placed at long horizontal distances from the technician's midpoint resulted in LI values greater than 1.0, indicating unacceptable lifting demands. As a result, their ergonomic intervention strategies focused on reducing the horizontal distance of the load at both the origin and destination of the lift to minimize lifting strain and enhance safety.

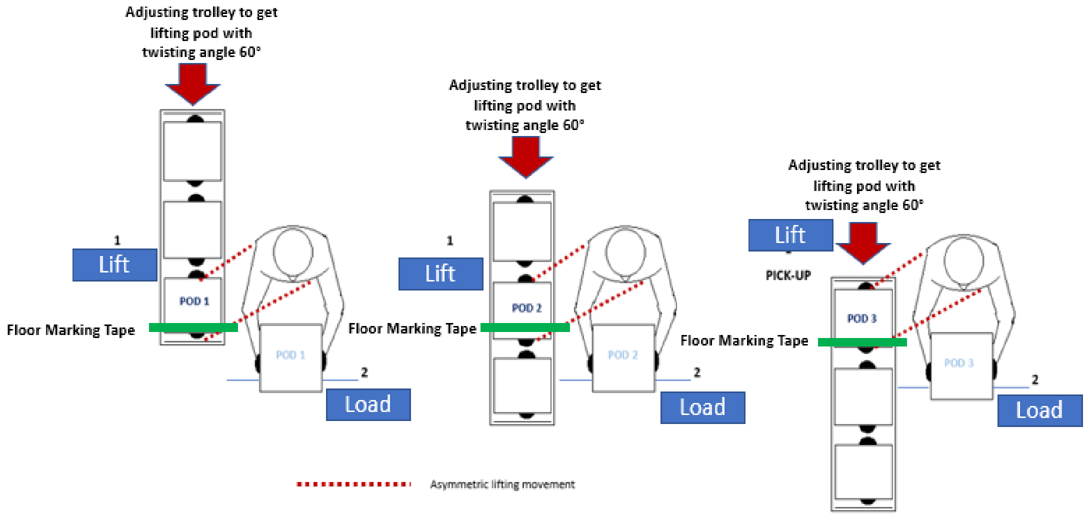

Figure 3. New asymmetric lifting practice for lifting or loading wafer pods from trolley to loading port, with 60° rotation marker for improved posture control.

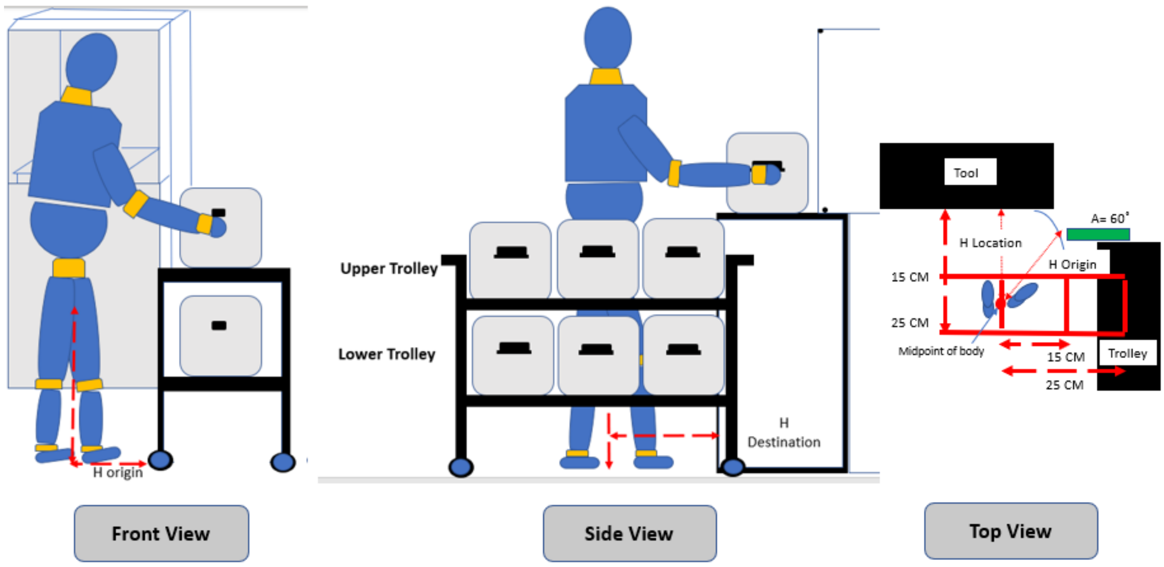

Figure 4. Red floor marking tape to set horizontal location from tools and trolley between 15 cm and 25 cm.

One of the proposed ergonomic risk control measures to reduce the prevalence of WMSDs in the Fab Integration Department of ABC Company is to improve working postures identified through the REBA assessment. Since poor posture was one of the major ergonomic risk factors contributing directly to WMSDs, corrective postures were introduced to minimize strain on the body. A corrected version of this posture was developed to reduce upper/lower body and trunk flexion by encouraging a more neutral posture.

The revised working posture shown in Figure 5 was recommended to minimize excessive reach and trunk flexion. Several specific guidelines were introduced: (1) the technician's body should be positioned closer to the wafer pod, (2) the arms and elbows should be kept close to the body with minimal flexion, (3) the back should remain straight by engaging the core muscles, and (4) the technician should stand at the center of the trolley and look forward to reduce neck and trunk flexion. By implementing these adjustments, spinal load can be reduced, thereby lowering the risk of WMSDs. For the posture which involved lifting wafer pods from the lower layer of the trolley, it was found to cause the highest prevalence of lower back discomfort due to excessive bending. This extreme trunk and neck flexion significantly increased ergonomic risk. Therefore, as shown in Figure 6, squatting was recommended as a safer posture when lifting loads from low heights. In addition, proper lifting techniques and ergonomics training were provided to increase technicians' awareness of safe movement patterns. This recommendation is consistent with several researchers. Ahmad & Muzammil (12) reported that the Revised NIOSH Lifting Equation (RNLE) is effective in identifying tasks that impose high spinal loads, and that squatting is an appropriate strategy to reduce risk during low-level lifting. Besides, Ranavolo *et al.* (13) also introduces a dynamic LI like the NIOSH LI, showing that small changes in lifting posture (including horizontal distance) immediately increase LI and Proud *et al.* (14) mention that maximum lift capacity conditions being significantly different from heavier load conditions is representative that the kinematics of a lift do change consistently when a participant's load is increased.

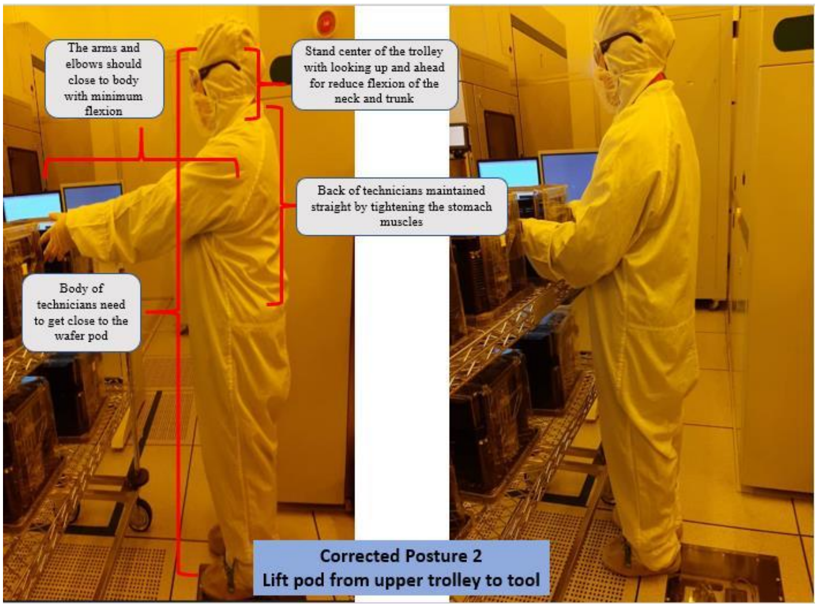

Figure 5. Corrected working posture (lift pod from upper trolley to tool).

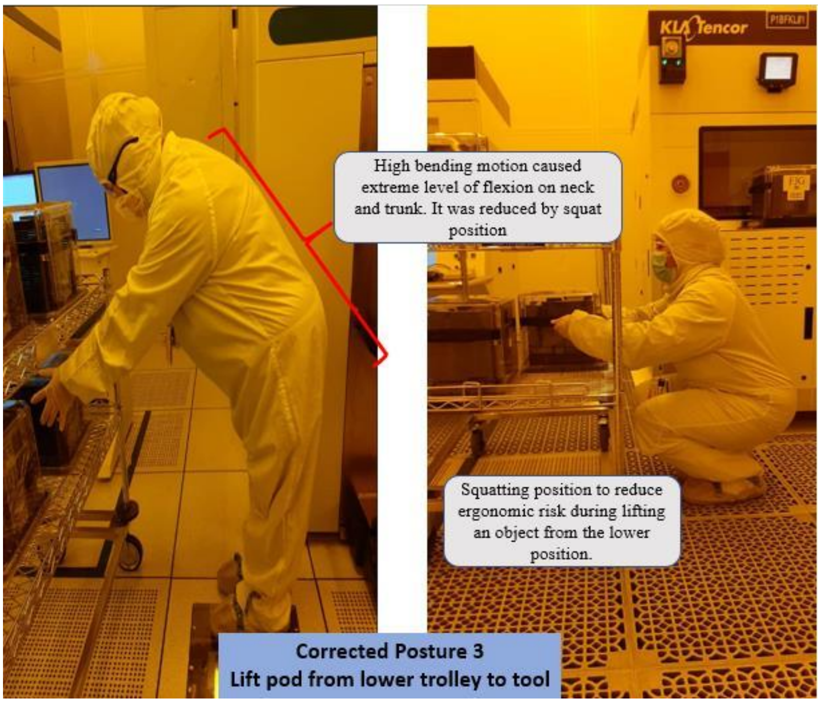

Figure 6. Corrected working posture (lift pod from lower trolley to tool).

Based on the REBA assessment findings, the awkward working postures identified in the selected tasks were corrected by reducing excessive flexion in the upper extremities, particularly at the arms, wrists, neck, and trunk. These interventions align with NIOSH's hierarchy of controls by prioritizing engineering measures (workstation layout cues, reach and rotation constraints) and administrative measures (posture guidance and ergonomics training) to reduce exposure to WMSD risk factors. The corrected posture resulted in a low risk for REBA reassessment with score of 3. Technicians were instructed to lift the load closer to the body and minimize the horizontal distance between the body, trolley, and tool during lift/load activities to reduce biomechanical strain. In addition to postural corrections, several variables in the RNLE were also adjusted to further prevent WMSDs. The results indicated that the Horizontal Multiplier (HM) and Asymmetry Multiplier (AM) were the primary contributors to high Lifting Index values, leading to increased WMSD risk in this working population. This finding was aligned with (15) where they concluded in their study that the lifting factors and equation multipliers from RNLE is critical for evaluating the risk estimates of manual lifting. Therefore, the intervention that being suggested must be reflected to the related multiplier. Ergonomic interventions were implemented by limiting twisting angles to a maximum of 60° and maintaining the horizontal reach within a range of 15 cm to 25 cm when lifting wafer pods from the trolley to the loading port. These combined modifications in posture and task parameters are expected to effectively reduce spinal load and lower the overall risk of WMSDs among technicians.

4. CONCLUSION

This study integrated the RNLE and REBA to evaluate ergonomic risks associated with wafer pod lift-and-load tasks among semiconductor technicians. The findings revealed that several task conditions, particularly lower trolley handling, resulted in elevated LI values (up to 2.00) and high REBA scores (6–8), indicating increased biomechanical loading and high postural risk despite a constant load weight. Excessive horizontal reach and asymmetric trunk rotation were identified as the primary contributors to elevated risk, reflected by reductions in the HM and AM in the RNLE analysis. Based on these results, targeted ergonomic interventions focusing on posture correction, limiting twisting angles, and maintaining safe horizontal reach distances were proposed, aligning with engineering and administrative controls to reduce WMSD risk. Future research should extend this assessment to other departments within semiconductor fabrication facilities and evaluate the effectiveness of digital ergonomic monitoring tools, such as wearable sensors or real-time posture tracking systems, to support continuous risk monitoring and intervention validation.

AUTHORSHIP CONTRIBUTION STATEMENT

Asuvani Nadarajan: data collection, data analysis, writing - original draft. Nooraizedfiza Zainon: risk assessment, methodology design, supervision, writing – review & editing. Muhammad Syahril Bahari: Conceptualization, literature review, validation, writing – review & editing. Norashiken Othman: instrumentation setup, data acquisition. Marina Marzuki: resource coordination, writing – review & editing.

DATA AVAILABILITY

The data supporting the findings of this study are subject to third-party restrictions. As the data are owned and controlled by an external organization, the authors are not permitted to share the data publicly.

DECLARATION OF COMPETING INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

DECLARATION OF GENERATIVE AI

The authors acknowledge the use of generative AI tools for language refinement, including grammar correction and sentence structure improvement from the original report.

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