Digital Human Modelling–Driven Ergonomic Risk Assessment, Workstation Redesign, and Usability Evaluation in a Manufacturing Assembly Line

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ABSTRACT

This study applies a digital human modelling–driven approach to ergonomic risk assessment, workstation redesign, and usability evaluation in a manufacturing assembly line. Work-related musculoskeletal disorders (WMSDs) remain a major occupational health concern in manufacturing environments, particularly in standing manual assembly workstations. Inadequate workstation design often leads to awkward postures, prolonged static loading, and repetitive movements, contributing to discomfort, fatigue, and reduced productivity. This study evaluates ergonomic risks associated with working postures at a manual insert workstation in an air-conditioner manufacturing company using Digital Human Modelling (DHM) integrated with Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA). A cross-sectional assessment involving ten female operators was conducted using observational analysis, anthropometric measurement, and the Cornell Musculoskeletal Discomfort Questionnaire (CMDQ). Existing work postures were simulated in CATIA to quantify ergonomic risk levels. Based on identified risk factors, an ergonomically improved workstation was designed and re-evaluated using RULA. Results showed that the existing workstation posed medium to very high ergonomic risks (RULA scores up to 7; REBA scores up to 11), particularly affecting the neck, lower back, and lower limbs. The redesigned workstation reduced the RULA score to 3, indicating a substantial improvement in postural risk. The findings demonstrate the effectiveness of DHM-supported ergonomic interventions in reducing WMSDs risk and highlight the importance of user-centered workstation design in manufacturing settings.

Keywords: Digital Human Modelling; Ergonomics; RULA; REBA; Work-Related Musculoskeletal Disorders, Standing Assembly Workstation

INTRODUCTION

Work-related musculoskeletal disorders (WMSDs) are among the most prevalent occupational health problems in the manufacturing sector, particularly in tasks involving prolonged standing, repetitive movements, and awkward postures. Poorly designed workstations restrict workers' natural movement and increase biomechanical

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loading on the musculoskeletal system, leading to discomfort, fatigue, and long-term injuries such as low back pain and upper limb disorders.

Observational ergonomics tools such as the Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) have been widely used to identify postural risks in industrial environments (McAtamney & Corlett, 1993; Hignett & McAtamney, 2000). While these methods are widely accepted for ergonomic screening, many previous studies relied on direct observation alone and provided limited evidence on how workstation redesign decisions were systematically translated into measurable postural improvements. Furthermore, the integration of Digital Human Modelling (DHM) with ergonomic risk assessment tools remains underutilized in small-to-medium manufacturing enterprises, despite its ability to simulate anthropometry-based posture variations prior to physical intervention.

This study addresses this gap by integrating DHM within CATIA software with RULA and REBA assessments to (i) quantitatively evaluate ergonomic risks associated with standing manual assembly work, and (ii) validate the effectiveness of a redesigned workstation through simulation-based postural analysis. By grounding workstation redesign in empirical discomfort data, anthropometry, and digital posture evaluation, this work advances beyond descriptive ergonomic assessments and provides a structured, evidence-based approach for ergonomic intervention in manufacturing settings.

The objectives of this study are to: Assess ergonomic risk levels of operators at a manual insert workstation using CMDQ, RULA, and REBA; Simulate existing working postures using DHM to identify critical biomechanical risk factors; Design an ergonomically improved workstation based on identified risks and user needs; and Evaluate postural improvements of the redesigned workstation using RULA analysis.

Digital Human Modelling

Digital human modeling (DHM) is an increasingly popular tool for simulating human movement and posture in various fields, including biomechanics, ergonomics, medicine, and human-computer interaction. DHM allows for the creation of virtual human models that can be used to analyze and predict the risk of musculoskeletal disorders, design products and environments that are more comfortable and safer for human use, and study human behavior in different scenarios. DHM has been widely applied to predict biomechanical loading and ergonomic risks during occupational tasks (Zubair et al., 2025; Benharkat et al., 2025). DHM can be used to predict the load on the low back during various movements and postures. The study used a digital human model to simulate different lifting tasks and found that the model could accurately predict the load on the low back in different lifting scenarios. This suggests that DHM may be useful for predicting the risk of low back injuries in the workplace.

Ergonomic Risk Factor

Ergonomic risk factors are physical factors arming the musculoskeletal system within the environment. Ergonomic risk factors include repetitive movement, manual handling, workplace design working procedure, workstation height un-ergonomically and poor body positioning. The main ergonomic risk factors in the workplace are a high repetition of tasks, vigorous effort and sustained awkward postures. In addition, awkward body posture and other ergonomics hazards contribute to a high number of musculoskeletal disorders (MSD). Injuries caused by the stress of ergonomic hazards on the body are not always immediately apparent, making it difficult to detect these hazards. Ergonomic risk factors often impact employers and workers and their families. Previous studies in manufacturing and small-scale industries have shown that repetitive tasks and awkward postures significantly contribute to the development of work-related musculoskeletal disorders (Okpala, C. C., & Chukwutoo, C., 2017). It is found that there is a physical factor in the workplace that affect the worker's health. The severity of ergonomic hazards often depends on the level of exposure over time. MSDs develop gradually over time as a result of intensive work.

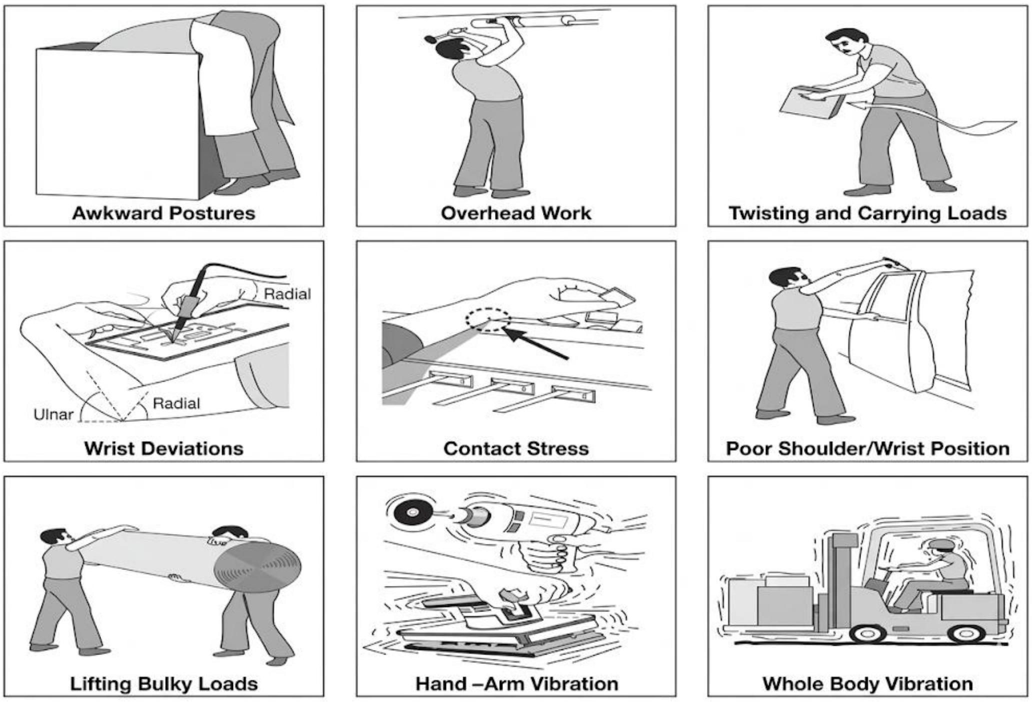

Figure 1: Illustration of Ergonomic Risk Factors (Okpala, C. C., & Chukwutoo, C., 2017)

Standing Workstation Design Principle by DOSH

A standing workstation is defined as a workstation where tasks are performed in a relatively stationary standing position with minimal lower-limb movement (International Labour Organization [ILO], 2021). In the standing position the body is held upright by the big muscles of the trunk and lower limbs. The employee stands throughout the length of the work shift and he or she does not move from one workstation to another.

The Malaysian Department of Occupational Safety and Health (DOSH) and international ergonomics guidelines emphasize height adjustability, postural variation, and lower-limb support in standing workstation design (ILO, 2021). Here are some important design principles for a standing workstation.

The workstation should have height-adjustable features to accommodate users of different heights. This allows individuals to set the workstation at a height that enables their elbows to be at a 90-degree angle when their hands are resting on the work surface. This promotes proper posture and reduces strain on the upper body. Next, re-design or rearrange tasks to allow employees to sit or stand whenever necessary for him or her to do so. Avoid tasks which require standing in a static posture and provide a chair or a stool for sitting on or standing against.

Moreover, provide workstation accessories such as a cushioned surface to stand on (anti-fatigue floor mat). Better soles for shoes. Adjustable working surface to accommodate differences in employees' height and small foot bench. Lastly, arrange for task variation so that an employee can perform different tasks that allow the legs to move and reduce static loading.

Rapid Entire Body Assessment (REBA)

The Rapid Entire Body Assessment (REBA) method was developed by Hignett and McAtamney (2000) to evaluate whole-body postural risks associated with work-related musculoskeletal disorders. REBA was proposed by Hignett and McAtamney (2000) in the UK as a requirement observed in the field of postural analysis. REBA provides a quick and easy way to assess different working attitudes for risks. It divides the body into individually coded sections according to the plane of motion. It can be stationary, dynamic, rapidly changing or unstable, called coupling scores, where manual manipulation can occur. It provides a scoring system for muscle activity across the body, which is highly sensitive. Handling loads is important, but you do not always use your hands. REBA also gives an action level with a sign of importance and requires minor equipment: Pen and paper method (Hignett and McAtamney, 2000) . Simple tasks were analyzed varying in the load, movement distance and height

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to define the initial body segments and establish body part ranges according to the diagrams of the body part.

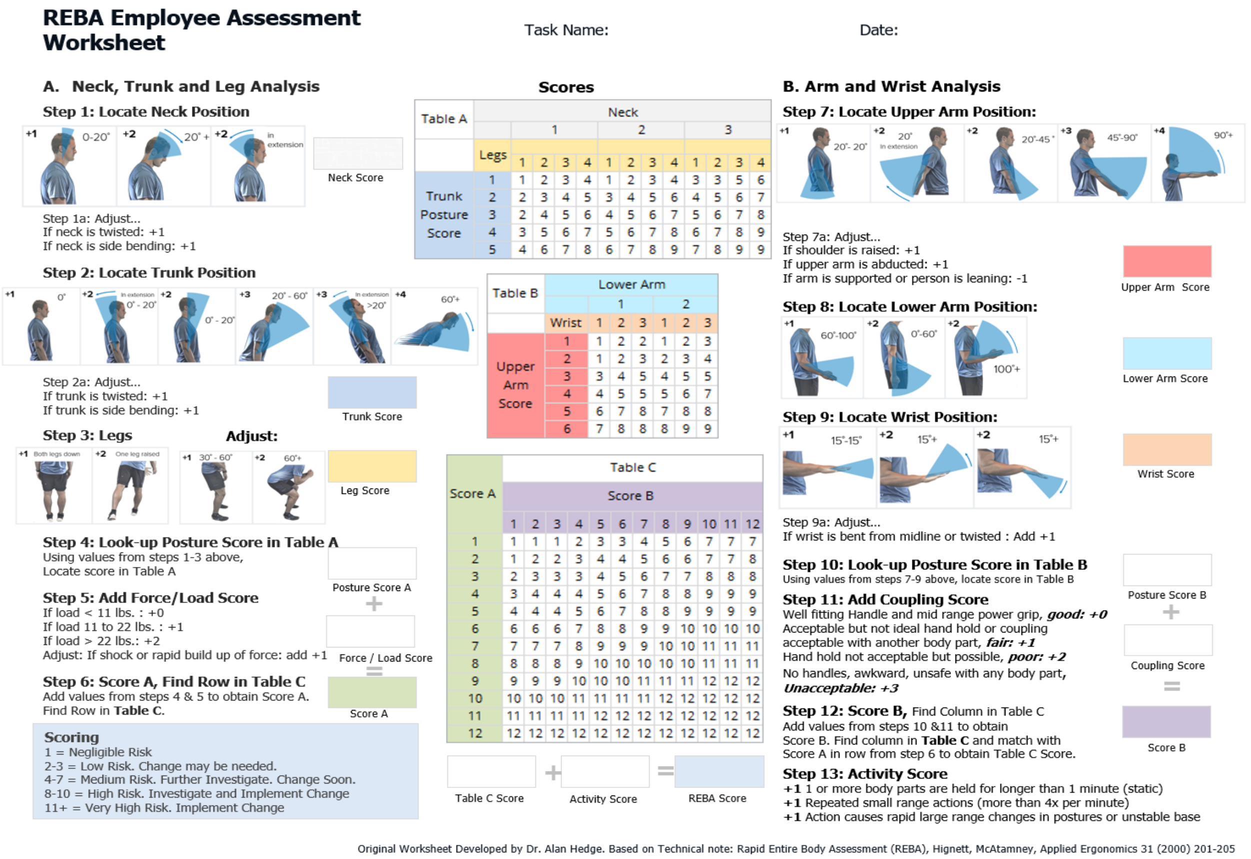


Figure 2: REBA assessment worksheet (Hignett and McAtamney, 2000)

Rapid Upper Limb Assessment (RULA)

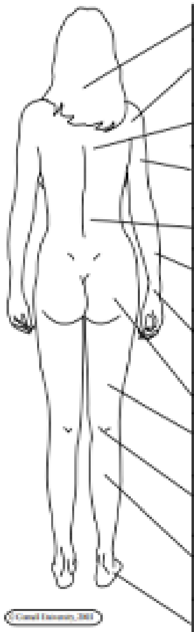
McAtamney and Corlett (1993) introduce RULA (Rapid Upper Limb Assessment). The Rapid Upper Limb Assessment (RULA) is a survey method developed for use in the ergonomic assessment of workplaces with reported work-related upper limb disorders. RULA is a screening tool that assesses whole-body biomechanical and postural loading, with particular attention to the neck, trunk, and upper limb. Designed to assess operators who may be exposed to musculoskeletal strains known to contribute to upper limb disorders. RULA helps provide a method for rapidly screening large numbers of operators. However, the developed scoring system also indicates the stress level experienced by each body part. RULA is device-free and, after training on how to use it, has proven to be a reliable tool for those whose job it is to perform workplace assessments. It can be used as a screening tool or integrated into broader ergonomic assessments of epidemiological, physical, psychological, environmental and organizational factors.

Cornell Musculoskeletal Discomfort Questionnaire (CMDQ)

The Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) is a validated instrument for assessing the prevalence and distribution of musculoskeletal discomfort across body regions (Hedge et al., 1999).The Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) is a widely used tool for assessing musculoskeletal discomfort and ergonomic risks in various occupational settings. The CMDQ consists of a series of questions that capture information about the presence, severity, and location of musculoskeletal discomfort. Participants are typically asked to rate the level of discomfort experienced in different body regions, such as the neck, shoulders, back, and upper extremities, using a scale ranging from "no discomfort" to "severe discomfort." The questionnaire also includes items related to the duration and frequency of discomfort, as well as any factors that may exacerbate or alleviate the discomfort, such as specific activities or ergonomic conditions. This comprehensive approach allows researchers and practitioners to gather detailed information about the nature and extent of musculoskeletal discomfort experienced by individuals.

Table 1: Discomfort survey of body parts

The diagram below shows the approximate position of the body parts referred to in the questionnaire. Please answer by marking the appropriate box.



		During the last work week how often did you experience ache, pain, discomfort in:					If you experienced ache, pain, discomfort, how uncomfortable was this?			If you experienced ache, pain, discomfort, did this interfere with your ability to work?		
		Never	1-2 times last week	3-4 times last week	Once every day	Several times every day	Slightly uncomfortable	Moderately uncomfortable	Very uncomfortable	Not at all	Slightly interfered	Substantially interfered
Neck		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Shoulder	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Upper Back		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Upper Arm	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lower Back		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Forearm	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Wrist	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hip/Buttocks		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Thigh	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Knee	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lower Leg	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Foot	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

CATIA Software

Computer Aided Three-Dimensional Interactive Application (CATIA) is a mechanical design software. CATIA is developed to expand product features with additional knowledge elements. CATIA is a feature-based parametric solid modelling design tool that gives the users the advantage of learning the Windows graphical interface. This software allows the users to model a 3D view of the product. CATIA has advantages where it may be accustomed to model 3D view of the merchandise. The software permits every kind of 3D assembly creation for a wide range of engineering uses. Two primary software tools can be used to solve ergonomic issues: Human Measurements Editor and Human Builder. The Human Measurements Editor act as a tool in making elaborate size of human model by a complex series of the manipulation of the model and analyzed the interaction between the model and the product that already been designed before. Using both Measurement Editor and Human Builder in CATIA, this tool will analyze the human posture that influences body posture wherever the task implementation and the assembly. CATIA has been widely used for ergonomic simulation and digital human modelling to assess operator posture and workstation interaction (Vahdani et al., 2014).

METHODOLOGY

The study was conducted through a structured sequence of methodological stages. Initially, a comprehensive literature review was undertaken to establish the theoretical foundation related to ergonomic risk assessment and digital human modelling. The target population was then identified, followed by the development of a questionnaire to capture operators' ergonomic experience and discomfort levels. Working postures at the manual insert workstation were subsequently observed and assessed during task execution. Finally, the collected data were analysed to evaluate ergonomic risks and to support the development and validation of an improved workstation design.

A cross-sectional ergonomic assessment was conducted at the manual insert workstation of an air-conditioner manufacturing company in Malaysia. Ten female operators (aged 23–32 years) with at least one year of work experience participated voluntarily.

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Data collection comprised:

- **Discomfort assessment** using the Cornell Musculoskeletal Discomfort Questionnaire (CMDQ);
- **Observational posture analysis** supported by photographic and video recordings; and
- **Anthropometric measurements** to develop representative digital human models.

Existing working postures were reconstructed using Digital Human Modelling in CATIA V5. RULA was employed to assess upper limb postural risks, while REBA was used to evaluate whole-body postures. Ergonomic risks were categorized according to standard action levels.

Based on the assessment outcomes, an improved workstation design was developed focusing on height adjustability, reach optimization, postural support, and reduced static loading. The redesigned workstation was subsequently re-evaluated using RULA within CATIA to quantify ergonomic improvement.

Survey

The survey is conducted by a face-to-face method. The assessor is directly involved in interviewing the employee in the assembly department. The questionnaires that have been constructed are also distributed to the employee. By doing a brief interview of discussion with individual about research field allows the assessor to identify the problem that are faced by the operators in the assembly department that urge to be solved. Assessment on working posture

The operators interviewed to gain some information on the working posture, complex task and the illness experienced by the operators.

OBSERVATION	POSTURE	HAZARD
The worker standing in an awkward posture, her back bone was bent		• Back pain • Shoulder pain • Neck pain
The worker's leg is placed at a tiny rod, standing in improper posture and leg position was improper.		• Back pain • Shoulder pain • Knee pain • Neck pain
The worker inserting component, her back bone was bent for a long time. Hand was placed at a wrong position and neck position was improper		• Back pain • Shoulder pain • Knee pain • Neck pain • Elbow pain

Figure 3: The observed postures of the worker at the workstation

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Simulation of Working Posture

CATIA (Computer Aided Three-Dimensional Interactive Application) is a computer-aided design software widely used to support ergonomic analysis in manufacturing environments. The software enables the development of three-dimensional models of workstations and products for evaluating and improving ergonomic design. In this study, CATIA was employed to simulate operators' working postures during manual insert tasks through a structured digital human modelling process. Ergonomic design and task analysis were first conducted to identify key postural requirements of the operation. A representative human model was then created using the Human Builder module in CATIA, incorporating relevant anthropometric parameters. The virtual mannequin was configured to replicate the task environment and operator–workstation interaction, allowing postural behavior to be analysed systematically for subsequent ergonomic risk assessment using RULA and REBA methods.

Usability Evaluation of the Redesigned Workstation

To complement the digital posture-based ergonomic evaluation, the redesigned workstation was physically fabricated and subjected to a usability assessment involving the same group of operators. The usability study focused on short-term evaluation of perceived comfort, reachability, posture support, and ease of task execution following workstation redesign. Participant feedback was collected using a structured questionnaire to capture immediate user experience rather than long-term musculoskeletal health outcomes. This usability evaluation was intended to validate practical acceptance and functional suitability of the redesigned workstation under real working conditions.

Longitudinal evaluation of musculoskeletal discomfort and injury incidence was beyond the scope of the present study.

RESULTS AND DISCUSSION

CMDQ results indicated high prevalence of discomfort in the neck (100%), lower back (100%), upper back (96%), thighs (>90%), and feet (>90%), confirming significant ergonomic strain associated with prolonged standing manual insert tasks. Observational analysis identified three critical postures characterized by trunk flexion, asymmetrical leg support, and excessive upper limb reach.

RULA and REBA analyses of the existing workstation revealed medium to very high ergonomic risks, with RULA scores reaching 7 and REBA scores reaching 11 for the most critical posture, indicating an urgent need for intervention. These findings are consistent with prior studies linking prolonged standing and awkward trunk postures to increased work-related musculoskeletal disorder risk (Kamat et al., 2022; Yusof & Shahida, 2021).

Following workstation redesign, RULA reassessment demonstrated a reduced score of 3 for both left and right upper limbs, indicating a substantial improvement in working posture. The integration of adjustable working height, optimized component reach, and supportive features effectively reduced biomechanical loading. This result confirms the value of DHM-supported ergonomic design in validating workstation improvements prior to physical implementation.

Based on the observed neutral postural configuration of the redesigned workstation, an indicative REBA risk level of approximately 3–4 (low risk) was inferred to support the RULA-based improvement findings; this estimate is provided for interpretive completeness rather than as a full worksheet-based REBA assessment.

A. Analysis of Demographic Background

A study was conducted on a group of individuals from the manual insert departments at TAKARA Manufacturing Sdn. Bhd (TKR), an electrical company. The study employed the Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) to conduct an ergonomic risk analysis. The study included ten female subjects who were in good health. The participants' ages ranged from 23 to 32. The mean values and standard deviations for the individuals' age, height, and weight were calculated. The mean values and standard deviations were found to be 27 ± 10.58 years, 156 ± 13.02 cm, and 58 ± 9.31 kg, respectively (Table 3). Each participant confirmed their willingness to participate after being informed about the study. Before completing the questionnaire, the participants received and read an information letter. From Cornell Musculoskeletal Discomfort Questionnaire (CMDQ), there were three participants that had musculoskeletal problems. Two of them had took medication for back body pain and one had a minor slip disc.

Table 2: Mean and Standard Deviation of Demographic Variables of the Participants

	Mean	SD	Minimum	Maximum
Age	27	10.58	23	32
Height (cm)	155.8	13.02	149	161
Weight (kg)	58	9.31	54	63
Working Hours	9.7	1.13	8	12

B. Analysis of Psychophysical Experience for Body Parts - Musculoskeletal Discomfort Overview (CMDQ)

The Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) was used to provide an overview of self-reported musculoskeletal discomfort among operators at the manual insert workstation. The results indicate a high prevalence of discomfort in key body regions associated with prolonged standing and repetitive manual assembly tasks. All participants (100%) reported discomfort in the neck and lower back regions, while 96% reported discomfort in the upper back. Discomfort in the lower limbs was also prominent, with more than 90% of operators indicating discomfort in the thighs and feet, reflecting sustained static loading during prolonged standing work.

Upper limb discomfort was reported at a moderate level compared to axial and lower-body regions. While some operators experienced discomfort in the shoulders, arms, wrists, and hands, the reported intensity and frequency were lower than those observed for the neck and lower back. This pattern suggests that overall postural demand and workstation height constraints contributed more substantially to musculoskeletal strain than fine motor hand activity alone.

These CMDQ findings corroborate the posture-based ergonomic risk assessment outcomes obtained through RULA and REBA analyses. High discomfort prevalence in the neck, trunk, and lower extremities corresponds directly with elevated RULA and REBA scores observed under existing workstation conditions. As such, CMDQ results were used to triangulate objective ergonomic assessment findings and to inform the prioritisation of workstation redesign interventions targeting postural alignment, working height, and load distribution rather than isolated hand function alone.

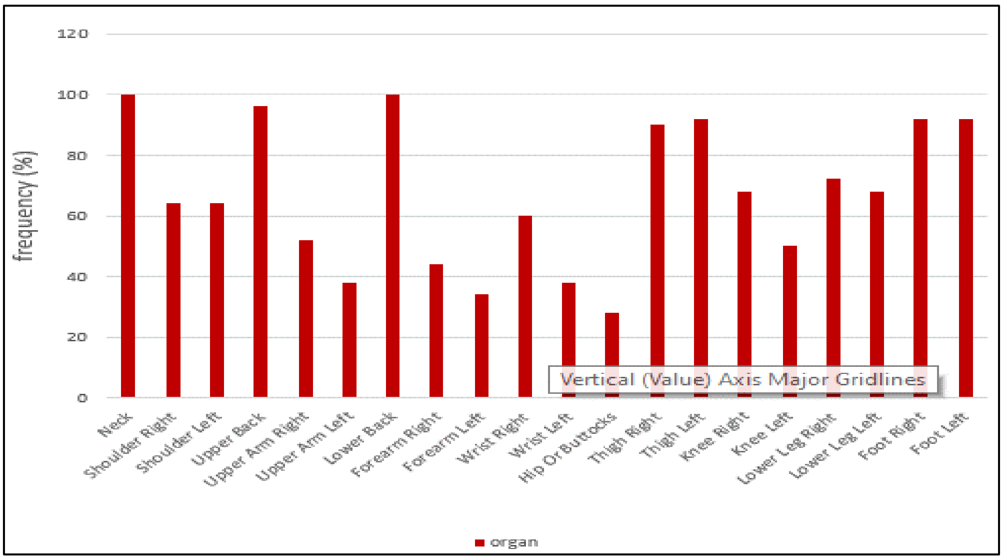

Figure 4: Graph of existing pain and discomfort in different areas of the body parts

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Table 3: Summary of Body Regions with High Discomfort Prevalence (CMDQ)

Body region	% reporting discomfort
Neck	**100%**
Lower back	**100%**
Upper back	**96%**
Thighs	**>90%**
Feet	**>90%**
Upper limbs (overall)	**Moderate**

C. Existing Posture modeling

Digital human modelling (DHM) was used to simulate representative working postures observed at the manual insert workstation. The simulated posture of the existing workstation demonstrates noticeable trunk flexion, elevated upper-limb reach, and uneven weight distribution on the lower limbs (Figure 5). These characteristics are indicative of awkward postures commonly associated with increased musculoskeletal disorder risk in prolonged standing tasks.

The constrained working envelope and fixed working height forced operators to adopt compensatory postures in order to maintain task performance. Over extended periods, such postures are likely to increase cumulative musculoskeletal loading, particularly in the neck, lower back, and lower extremities. These DHM simulations provided a quantitative and visual basis for subsequent ergonomic risk evaluation using RULA and REBA.

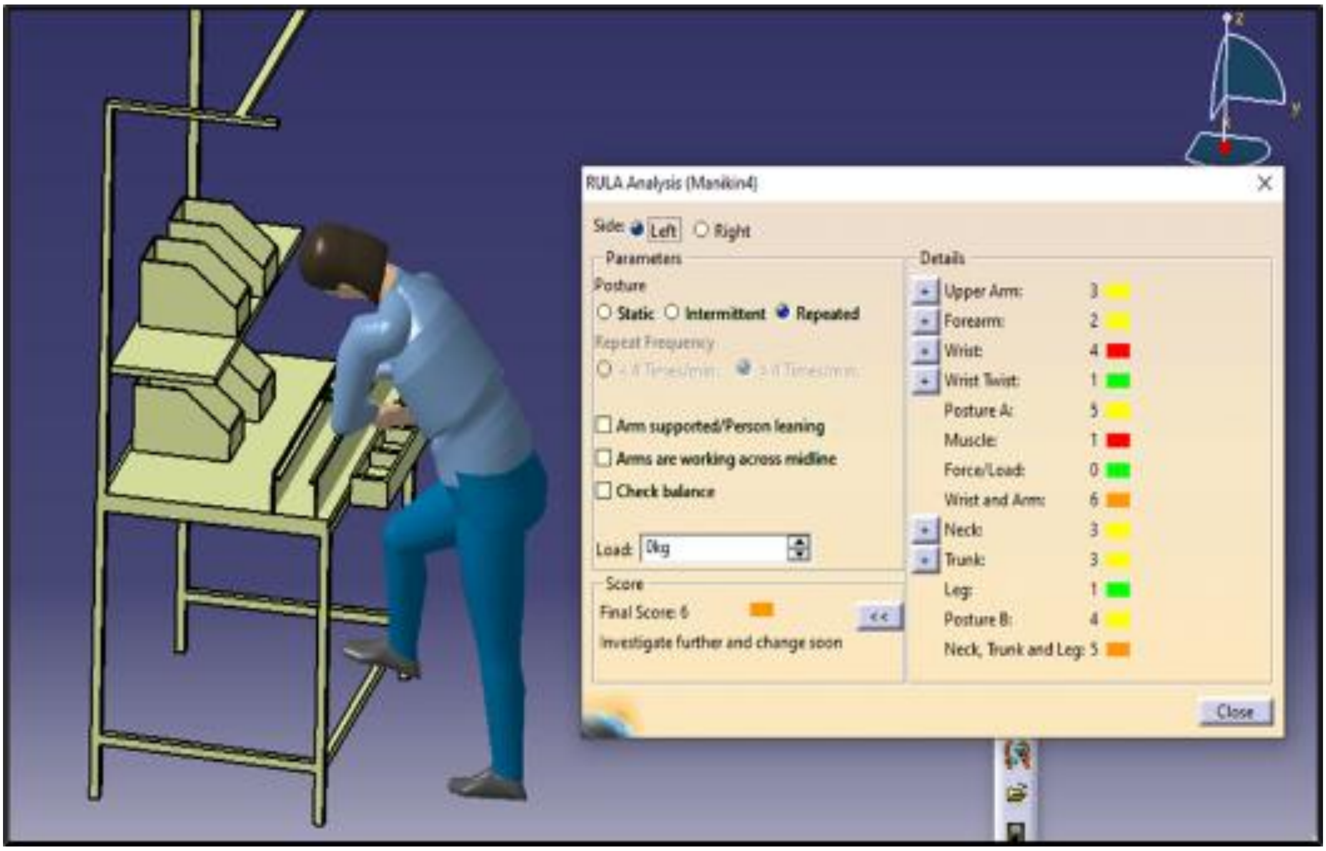

Figure 5: Existing Working Posture using CATIA

D. REBA and RULA result

Three methods of assessment were performed to determine the WMSDs encountered among employees for each process for posture 1, posture 2 and posture 3. The data obtained from the observation, discomfort survey and RULA and REBA analysis are then compared based on the most experienced pain by TKR employees. Thus, to obtain the optimum risk factor and the most significant of WMSDs

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Task	Observation	Discomfort survey			REBA	RULA
		Body parts	Right hand	Left hand	Score	
Posture 1	• Wrist • Upper arm • Shoulder • neck	• Shoulder (right and left) • Upper arm (right and left) • Forearm (right and left) • Wrist (right and left)	All shaded area • Area A • Area B • Area C • Area D • Area E • Area F		5	5
Posture 2	• back pain • shoulder • neck	• Shoulder (right and left) • Upper arm (right and left) • Forearm (right and left) • Wrist (right and left)	All shaded area • Area A • Area B • Area C • Area D • Area E • Area F		5	7
Posture 3	• upper arm • lower arm • back pain • neck • lower body	• Shoulder (right and left) • Upper arm (right and left) • Forearm (right and left) • Wrist (right and left) • Leg (right and left) • Wrist (right and left)	All shaded area • Area A • Area B • Area C • Area D • Area E • Area F		11	6

Figure 6: REBA and RULA result (existing workstation)

RULA Analysis

RULA assessment of the existing workstation revealed high ergonomic risk levels for upper-limb and trunk postures (Figure 6). Elevated RULA scores were primarily driven by excessive arm elevation, forward trunk inclination, and sustained static postures. In most assessed postures, RULA scores fell within the range requiring immediate or near-term ergonomic intervention, indicating that the workstation design was not adequately matched to operator anthropometry and task requirements.

The findings suggest that the existing workstation places substantial biomechanical demands on the upper body, particularly during repetitive manual insert activities. These results align with the CMDQ findings, where operators reported high levels of discomfort in the neck and upper back regions.

REBA Analysis

REBA analysis was conducted to evaluate whole-body ergonomic risk associated with critical working postures. The results indicated medium to very high musculoskeletal risk levels (Figure 6), with the highest scores corresponding to postures involving trunk flexion combined with prolonged static standing.

High REBA scores were predominantly influenced by trunk posture, leg position, and limited opportunities for postural variation. These findings highlight that lower-limb and whole-body postural demands represent a significant ergonomic concern in standing manual insert workstations, complementing the upper-limb-focused findings from RULA analysis.

Collectively, both RULA and REBA results confirm that the existing workstation poses a substantial ergonomic risk and warrants redesign intervention to mitigate musculoskeletal disorder risk.

Workstation Redesign and Ergonomic Intervention

Based on CMDQ findings and ergonomic risk assessment outcomes, an improved workstation design was developed using CATIA. The redesign incorporated adjustable working height, optimized reach zones, and improved task layout to address the identified risk factors (Figure 7). The primary design objective was to reduce trunk flexion, minimize excessive upper-limb elevation, and distribute postural load more evenly across the lower limbs.

Unlike the existing fixed-height configuration, the redesigned workstation allows operators to maintain a more neutral posture during manual insert tasks. The design process was guided by anthropometric data and validated through DHM simulation to ensure compatibility with a range of user body dimensions.

The final workstation configuration was selected based on its ability to address the ergonomic risk factors identified through CMDQ, RULA, and REBA analyses, with emphasis on posture neutrality, height adjustability, and reach optimisation.

E. New workstation table

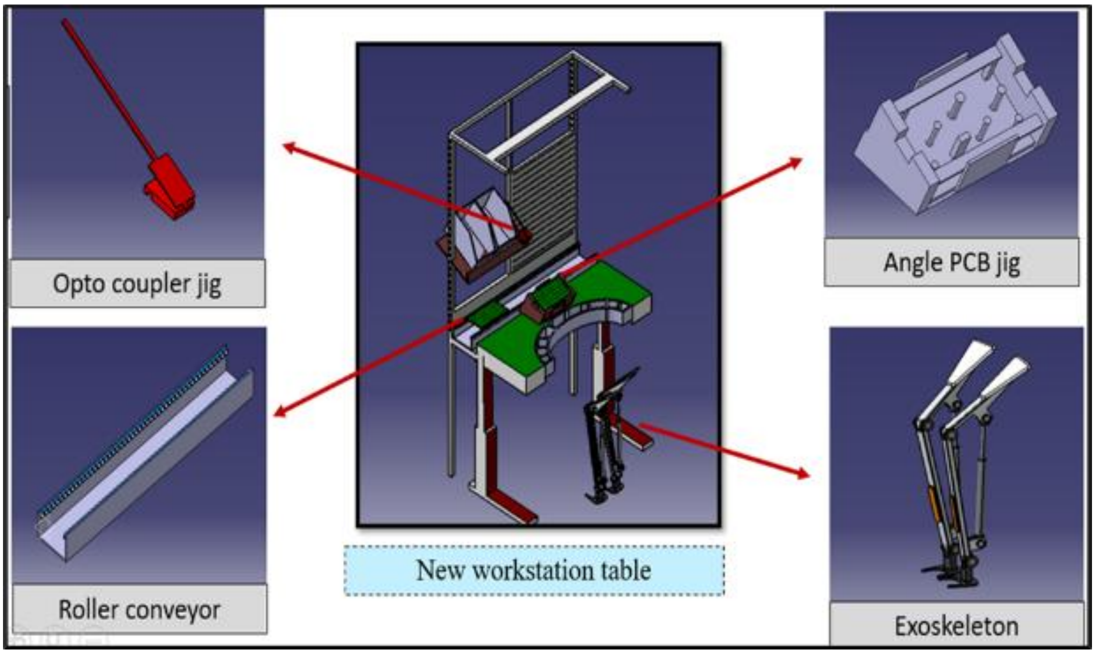

Figure 7: Redesign workstation table

The new workstation table has two parts: a fixed back section for the printed circuit board (PCB) conveyor and an adjustable front section for manual insert activities. The U-shape design of the front table promotes ergonomic posture and easy access to the upper compartment, enhancing productivity. An adjustable upper compartment shelf with a perforated panel allows for convenient storage of electrical parts.

The new design includes a lower exoskeleton to reduce fatigue and strain on employees' lower body during prolonged standing or manual tasks. The inclusion of a lower-body exoskeleton support in the redesigned workstation was guided by established findings on user experience factors such as comfort, perceived usefulness, and postural support, which are critical for acceptance of passive exoskeleton systems in industrial settings (Halim et al., 2022).

An optocoupler jig has been introduced to enhance productivity by aiding in the precise alignment of optocouplers during assembly. A roller conveyor system facilitates smooth PCB movement, reducing the risk of damage and improving workflow efficiency.

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Additionally, the new workstation table features a 45-degree PCB jig, enhancing visibility and comfort during manual insert tasks. Compared to the previous design, the updated version offers greater flexibility and adaptability. Overall, these ergonomic enhancements contribute to increased employee well-being, higher productivity, and improved manufacturing processes in the manual insert department.

F. RULA result for new workstation table

Table shows the result scoring of RULA for new workstation table used at manual insert station at TKR Manufacturing. The result of the analysis depicts there is an improvement of the operators' body posture when using the new workstation table

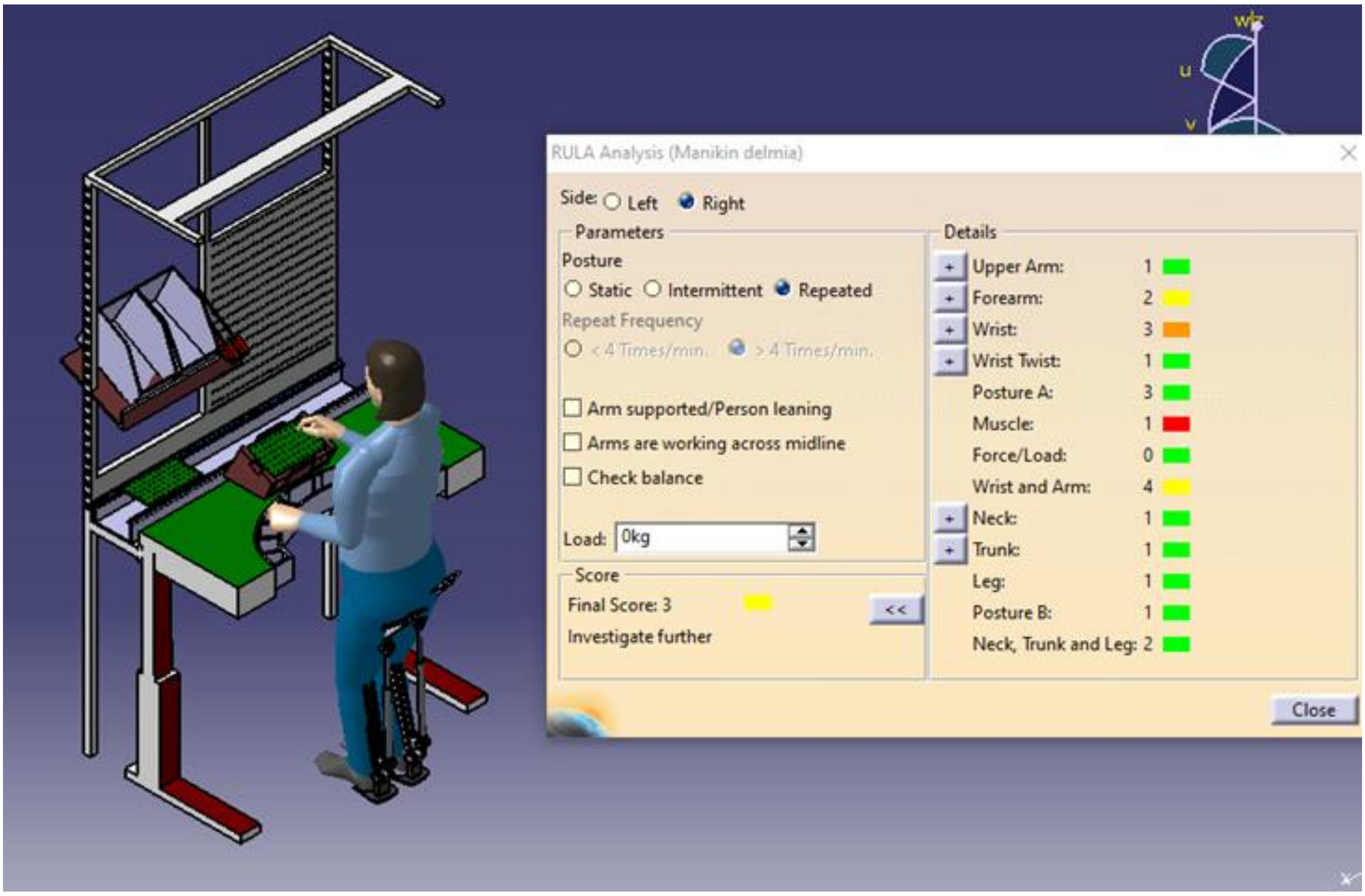

Figure 8: RULA result for new workstation design

Following workstation redesign, RULA reassessment demonstrated a reduced score of 3 for both left and right upper limbs, indicating a substantial improvement in working posture. The integration of adjustable working height, optimized component reach, and supportive features effectively reduced biomechanical loading.

The reduction in RULA risk level was further supported by user feedback obtained during the usability evaluation, in which operators reported improved posture comfort, reachability, and task execution when using the redesigned workstation.

This result confirms the value of DHM-supported ergonomic design in validating workstation improvements prior to physical implementation.

Evaluation of Ergonomic Improvement

The effectiveness of the redesigned workstation was evaluated using RULA analysis under simulated working conditions. The comparison of RULA scores before and after redesign demonstrates a clear reduction in ergonomic risk (Figure 8). The RULA score decreased from high-risk levels (≥6) for the existing workstation to a score of 3 for the redesigned workstation.

Post-redesign ergonomic validation focused on upper-body posture using RULA, as the primary whole-body risk factors identified through REBA, namely excessive trunk flexion and lower-limb instability, were directly addressed through workstation height adjustment and task layout redesign and were therefore not reassessed quantitatively.

The redesigned configuration promotes neutral trunk and lower-limb postures, which are consistent with a low whole-body ergonomic risk profile based on an indicative interpretation of REBA scoring criteria.

This reduction indicates a meaningful improvement in operator posture, particularly in terms of trunk alignment and upper-limb positioning. The improvement confirms that the redesign successfully addressed the primary ergonomic deficiencies identified in the initial assessment.

The findings demonstrate the value of integrating DHM with ergonomic assessment tools to validate workstation design improvements prior to physical implementation. This approach supports evidence-based ergonomic intervention and offers a practical framework for reducing musculoskeletal risk in manufacturing environments.

CONCLUSION

This study employed a digital human modelling-driven approach to assess ergonomic risks, redesign a manual insert workstation, and evaluate the usability of the redesigned solution within a manufacturing assembly environment. This study investigated ergonomic risks associated with prolonged standing manual insert tasks in a manufacturing environment by integrating Digital Human Modelling (DHM) with Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA). The findings demonstrate that the existing workstation configuration imposed substantial musculoskeletal loads on operators, particularly affecting the neck, trunk, and lower limbs. High prevalence of self-reported discomfort, as identified through the Cornell Musculoskeletal Discomfort Questionnaire (CMDQ), corroborated the elevated ergonomic risk levels quantified by posture-based assessments.

RULA and REBA analyses of digitally simulated working postures revealed medium to very high musculoskeletal risk levels, driven primarily by trunk flexion, elevated upper-limb reach, and prolonged static standing. These outcomes highlight the limitations of fixed-height standing workstations in accommodating operator anthropometric diversity and sustaining neutral postures during repetitive manual assembly activities.

An ergonomically improved workstation was subsequently developed using CATIA-based digital simulation, guided by empirical discomfort data and structured ergonomic assessment results. Evaluation of the redesigned workstation demonstrated a substantial reduction in ergonomic risk, with RULA scores decreasing from high-risk levels (≥6) to a moderate level (score = 3). This improvement indicates a meaningful enhancement in postural alignment and reduction in biomechanical loading, achieved without compromising task functionality.

The study confirms the effectiveness of integrating DHM with ergonomic risk assessment tools as a systematic and evidence-based approach for workstation design and evaluation. By enabling virtual validation of ergonomic interventions prior to implementation, this approach offers practical value for manufacturing organisations seeking to reduce work-related musculoskeletal disorder risk while supporting productivity and worker well-being.

Several limitations should be acknowledged. The study was conducted with a limited number of participants and focused on a specific manual insert workstation, which may restrict the generalisability of the outcomes. While the redesigned workstation was physically implemented and demonstrated positive usability outcomes, ergonomic improvements were evaluated over a short-term period using posture-based assessment methods. Future studies may strengthen these findings by incorporating extended field trials and longitudinal monitoring of musculoskeletal health indicators.

Overall, this study contributes to the growing body of ergonomic research by demonstrating how digital human modelling can be effectively integrated with established assessment tools to support user-centred, data-driven workstation design in manufacturing environments.

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