

SIMULATION OF WELDING WORKBENCH DESIGN FOR STUDENTS' PRACTICAL WORK LEARNING USING DIGITAL HUMAN MODELING

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Abstract The design of a welding workbench for the learning process must consider the risks of musculoskeletal disorders (WMSDs). This study aims to develop an ergonomic welding workbench design to reduce the risk of awkward working postures, such as excessive neck flexion and elevated arm positions during welding. Using a digital human modeling simulation approach with Catia V5 R21 software, the design was evaluated based on ergonomic parameters, including LBA, OWAS, CA, and RULA. This study fills a gap in ergonomic literature by providing a quantitative evaluation model tailored to the body postures of Indonesian students. The results reveal that Alternative Design I has superior specifications, including adjustable table height, permanent welding component clamps, and a table tilt angle of up to 30 degrees. The workbench reduces spinal stress and improves working comfort. OWAS analysis indicates reduced musculoskeletal system risks, while RULA evaluation demonstrates improved comfort levels with adjustable table heights. Practical applications of these findings include enhancing safety and efficiency in welding learning processes at educational institutions. The design improves students' productivity and health by providing a more ergonomic working environment. This research lays the groundwork for further development of adaptive ergonomic workbench designs tailored to local needs and recommends future studies to explore applying similar technologies in other fields.

Keywords: Workbench design concept, ergonomics, welding

1. Introduction

Work-related musculoskeletal disorders (WMSDs) are the most common musculoskeletal issues worldwide and a leading cause of work-related complications and disabilities [1]. This condition is particularly relevant in developing countries, including Indonesia, where the risk of WMSDs frequently arises in jobs such as welding. Welding work requires static, defensive, and often forced postures for extended periods, thereby increasing the risk of injury [2]. Similar challenges are observed in welding practice sessions, where students often encounter non-ergonomic postures such as forward neck flexion and elevated arm positions, leading to early muscle fatigue and the potential for long-term musculoskeletal injuries [3]. The need for evaluation and design of ergonomic welding workbenches is crucial to provide effective and comfortable solutions for students. Several studies have proposed various solutions to

mitigate the risk of WMSDs, such as ergonomic workplace adjustments and worker training [4]. However, these approaches are less relevant to the specific needs of Indonesian students, as most studies rely on anthropometric data from other countries, which do not accurately represent the body conditions of local students. Furthermore, there is limited research using digital simulations to quantitatively evaluate WMSD risks [5].

Several ergonomic solutions have been proposed to reduce the impact of the welding work environment. Ahmad et al. [6], designed a welding workbench with fixed legs and manual clamping components, but it had significant limitations in flexibility and adaptability to users' working postures, often resulting in non-ideal working positions. Francisco et al. [7], analyzed upper limb stress during automobile assembly welding work and proposed periodic adjustments to the welding workstation. Their findings demonstrated that changing body posture and welding torch position could reduce occupational hazards. Zhang et al. [8], designed and evaluated six digital human models and welding torches using Jack software to improve

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welders' standing ergonomics. Recently, many ergonomic studies on working postures have adopted a digital human model approach to assess risks in similar environments for workers [10, 11, 12].

This study proposes a design approach utilizing Catia V5 R21 software to simulate students' working postures based on the ergonomic requirements for welding workbench design. Digital simulations in this study are not only used to evaluate posture risks but also to provide design recommendations that enhance comfort and reduce the risk of musculoskeletal injuries. The study has several main objectives: (1) to design an ergonomic welding workbench concept based on students' actual needs, (2) to evaluate the concept using the Pugh method, and (3) to perform simulations to analyze the design's compatibility with Indonesian students' body postures. This approach aims to create a workbench that can be adjusted for optimal height and angle, providing improved comfort and reducing injury risks during welding practice sessions.

2. Methods

This research was conducted in several stages to produce an ergonomic welding table design suitable for students' learning needs. The updated methodology stages are as follows:

1. This study did not involve direct sampling. Instead, it utilized the Indonesian anthropometric database [12], focusing on data criteria for ages 21–25, parameters including height, seated elbow height, standing eye height, and arm span. This data was used to model the ergonomic requirements for the welding table design.
2. Designing the concept of the welding table based on identified needs evaluated from real-world issues. The concept evaluation for the welding table design was conducted using the Pugh method [13].
3. Simulating and modeling the welding table design concept combined with human body simulation to evaluate the posture of Indonesian students using Catia V5 R21 software [14]. [15].

The analysis was conducted using Catia V5 R21 to model digital humans and the welding table design concept. The criteria included simulating welding operations, dynamic welding operations adapting to various student working postures, and conducting example operation and

action analysis. The scheme is shown in Figure 1.

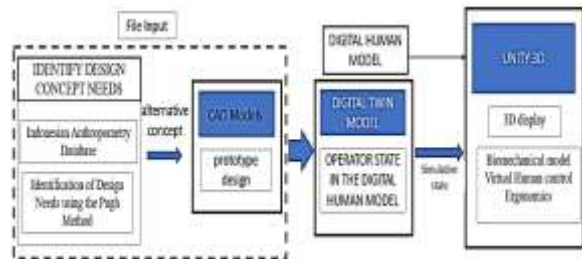


Fig. 1 Schematic diagram for digital human modeling models

The schematic diagram in Figure 1 illustrates the input parameters used, including the prototype of the welding workbench design based on the design criteria. The digital human model serves as a dynamic animation representation of the welding workbench design, including its position and design, tested with various table height parameters. This study utilizes four analysis modules from Catia V5 R21: Lower Back Analysis (LBA), Ovako Working Posture Analysis (OWAS), Rapid Upper Limb Assessment (RULA), and Comfort Assessment (CA). Catia V5 R21 analyzes body posture during welding, both qualitatively and quantitatively, to design a comfortable workbench and improve working conditions. Potential biases, such as unrecorded spontaneous postures and environmental factors like lighting and temperature, are also acknowledged.

Evaluation of working posture on the human model is carried out standing by simulating welding work by analyzing body forces through real-time observations when raising the forearm in the work environment. The evaluation of working posture in this study was carried out by assessing low back pressure, especially indicating the strength of the L5 and L4 lumbar vertebrae [16]. The assessment parameters were carried out in two stages. First, compare the welding simulation results with the National Institute for Occupational Safety and Health (NIOSH) database to determine whether each value is within a controllable range, namely that lower back disorders may occur when lower back pressure exceeds 3400 N. The higher the value obtained, the higher the value. the greater the likelihood and severity of lower back injury [18, 19]. Second, comfort level assessment is carried out by indicating the level of danger caused by certain behaviors and by providing optimal recommendations when simulating a

human model using a welding workbench. comfort assessment based on the Porter database [19], providing a comfort rating of the corresponding human posture. The parameters of the virtual welding work are identified using the comfort value parameters when using Formula (1). The best comfort value is 0, the comfort value is acceptable in the range 0–1, and more than 1 needs to be increased; the higher the value, the lower the comfort [20].

$$cv = \begin{cases} \frac{[MD-OV]}{HV-MD}, & OV > MD \\ \frac{[MD-OV]}{MD-LV}, & OV > MD \\ 0, & \text{other} \end{cases} \quad (1)$$

Description:

- CV: comfort value conversion;
- MD: mode value;
- OV: original value;
- HV: highest value; And,
- LV: lowest value

The evaluation of back and extremity stretching is performed using the Ovako Work Posture Analysis System, which quantitatively analyzes posture feasibility and the risk of WMSDs [21] [22]. Identifying worker posture helps assess the level of risk to reduce fatigue [14].

3. Results

3.1 Identify Welding Workbench Needs

The need for a welding workbench design arises due to several issues, namely its inability to accommodate the operator's posture requirements, leading to musculoskeletal disorders.

According to anthropometriindonesia.org [12], human body posture shows variations in body dimensions, with data based on percentiles of body posture for Indonesians aged between 21–25 years. This data is used as a representative body model for Indonesian students, as described in Table 1.

Table 1 describes various body dimensions relevant for designing a welding workbench that aligns with the welding operator's posture. For instance, the average height for males is 169.79 cm, and for females, it is 153.64 cm, while the seated elbow height for males is 30.99 cm, and for females, it is 22.96 cm. This data provides a clear overview of the

design requirements for a workbench that can be adjusted to the user's body posture.

Table 1. Body Size Parameters Of Indonesian Students Aged 21 – 25 Years

Dimension Name	Gender	Average value	Standard Deviation	5th	50th	95th
Body height (cm)	M	169.79	5.49	160.76	169.79	178.82
	F	153.64	6.22	143.41	153.64	163.87
Elbow height in sitting position (cm)	M	30,99	5.85	21.37	30.99	40.61
	F	22,96	3.5	17.21	22.97	28.72
Standing eye height (cm)	M	158,80	5.7	149.43	158.8	168.18
	F	143,78	4.57	136.27	143.78	151.29
Length of arm span forward	M	72,21	18.53	41.73	72.21	102.7
	F	66,18	10.83	48.36	66.18	84

Welding workbench designs are generally constructed with fixed legs, making the height non-adjustable to accommodate the worker's posture. This fixed design has been identified in several studies to result in a working posture where the operator forms an angle of 180 degrees, causing the head, neck, and shoulders to form an angle of 35 degrees, while the waist and shoulders form an angle of 25 degrees. This posture leads to rapid fatigue and stiffness in the upper extremity muscles [23]. Additionally, another issue arises as welding workbenches are not easily adjustable to accommodate the position of objects being welded, often causing shifts due to impacts during the welding setup. These issues in welding workbench design create discrepancies between the actual conditions in welding training processes and the ideal conditions, leading to gaps as illustrated in Figure 2.

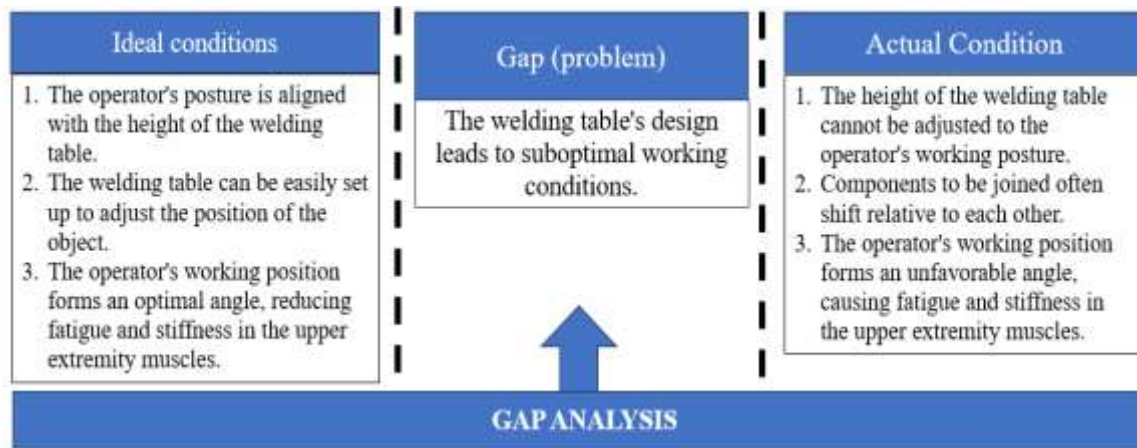


Fig. 2 Gap Representation Of Problems In Welding Workbench Design

The gap representation of the problem in Figure 2 explains that the actual situation that occurs in several problems results in operator productivity decreasing because the dimensions of the welding table cannot adjust to the operator's working posture, resulting in differences in height, and it becomes slanted, resulting in imprecise welding results. Apart from that, the use of a welding workbench in ideal conditions should be able to adjust the operator's working posture so as to reduce WMSDs for the operator while working.

3.2 Identify Needs for Welding Workbench Design Concept

Identify the needs for the welding workbench design concept and evaluate it based on the problems that occur in actual conditions. The welding workbench design concept is carried out using compositions that are described as technical design requirements so that the target requirement specifications can be identified for improving the welding workbench design. Technical Requirements The welding workbench design concept is explained in Table 2.

3.3 Preparation of the Welding Workbench Design Concept

The welding workbench design concept is developed using a morphological chart. Identification is performed to discover key elements in order to expand the search for solutions from various alternatives. Table 2 is a morphological chart of the welding workbench design concept.

The morphological chart from Table 3 shows the design concept obtained based on the division of internal and external search solutions.

The concepts obtained were three design concepts divided based on color, namely blue for design concept I, orange for design concept II, and black for design concept III.

3.4. Evaluation of Work Station Design Concepts

Screening three welding workbench design concepts that have been obtained were identified using product concept assessment using the Pugh method [13]. Product concept assessment is carried out by conducting discussions with users and experts to obtain four selection criteria based on the Pugh method, namely performance, features, durability, and serviceability. Table 4 is the result of a summary of the conceptual screening of welding workbench designs.

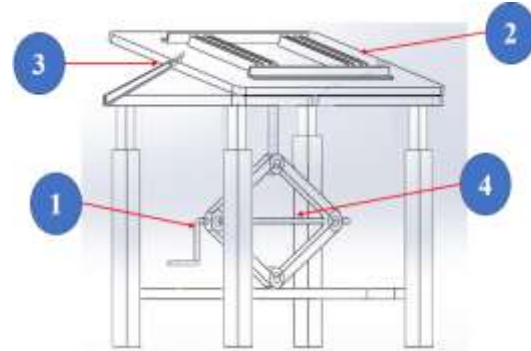
Table 2. Technical Requirements For Welding Workbench Design Concepts

No	Design Needs	Target Specifications
1	Speed up welding setup	The table is permanently installed to reduce preparation time.
2	Achieve precise and optimal welding results	Clamp components to prevent shifting during welding.
3	Simple operating mechanism	Can be operated manually.
4	Adjustable tilt for operator comfort	The table can be tilted up to 30°.
5	Adjustable table legs for operator posture	Legs can be adjusted in height from 50–100 cm.

Tabel 3. Morphological Chart Alternative Concept

No.	Function Solution	Alternative 1	Flow alternatives		Alternative 2
			1	2	
1.	Table frame	The workbench is permanently fixed			The workbench can be adjusted directly or with other tools.
2.	Component clamps	Clamps are permanently fixed			Clamps can be adjusted.
3.	Operation	Manual steps without adjustment tools			Does not require other tools for adjustments.
4.	Table inclination	Tilt is fixed at a 30° angle			The tilt angle can be adjusted.
5.	Table height	Height is adjusted using a hydraulic system			Height is adjusted using a screw system.

several opinions so that the highest alternative value is obtained, namely design concept I with specifications as parameters: The welding workbench can be adjusted directly, welding component clamps are made permanently, steps can be used manually without set-up tools, the tilt of the table can be adjusted to the angle of inclination, and the height of the table can be adjusted using a screw system. Figure 3 is the result of an alternative welding workbench design concept that has been validated.



Information:

1. Can be adjusted directly
2. Welding component clamps are permanently made
3. The table tilt angle can be adjusted
4. The table height is adjusted using a screw system

Fig. 3 Results Of Alternative Welding Workbench Design Concepts That Have Been Validated

Table 4. Recapitulation Of Welding Workbench Design Concept Screening

No.	Selection Criteria	Recapitulation of Design Concept Alternative Screening		
		Design Concept I	Design Concept II	Design Concept III
1	Performance	+	0	0
2	Features	+	+	+
3	Durability	+	+	+
4	Serviceability	+	+	-
Amount (+)		4	3	3
Amount (0)		0	1	0
Amount (-)		0	0	1
Final score		4	3	2

Recapitulation of concept filtering for welding workbench design in Table 3. Alternative concepts have been identified from

3.5. Modeling and Simulation of the Welding Work Environment

Two sets of simulation modules were used to test the welding workbench design using Catia V5 R21 software: first, the operator was positioned standing while using the welding workbench design concept; second, the operator was positioned performing a welding simulation. The body dimensions of Indonesian students aged 21–25 years were adjusted according to Table 1. The height parameters of the welding workbench design were determined by three values: 50 cm, 70 cm, and 100 cm, while the tilt of the welding workbench was maintained at a parameter of 30 degrees. Figure 4 represents the virtual environment for the human model simulation testing with the validated welding workbench design concept based on the specified parameters.



Fig. 4 Virtual Environment Of Human Model Simulation Testing With A Validated Welding Workbench Design Concept.

1. Lower Back Analysis

The LBA assessment in Figure 4 with a human model simulated with the welding workbench design concept was carried out using male and female human models with presentations of 5, 50, and 95. Each percentile was analyzed according to NIOSH provisions, where the worker's back load is assessed with a minimum requirement of 500 N and a maximum of 3480 N. Figure 5 explains the results of LBA

testing on a human model using the welding work table design concept, which was tested based on table heights of 50 cm, 70 cm, and 100 cm with a table tilt of 30 degrees.

The LBA test in Figure 5 demonstrates the welding worktable design concept with various height parameters. The working forces at different heights are able to affect the spine of the simulated human model during welding. As the height of the worktable increases, the resulting LBA values decrease. The worker's position is considered safer and more comfortable when using a welding worktable at a height of 100 cm. However, a welding worktable with adjustable height, tailored to the worker's posture needs, helps reduce the risk of accidents and enhances welding worker comfort.

2. Ovako Working Posture Analysis

The OWAS evaluation was identified on the working posture of the human model when using the welding worktable design based on table height, which showed a category of class 2. Adjusting the working posture height when using the welding workbench can reduce the risk of musculoskeletal damage.

3. Comfort Assessment (CA)

The Comfort Assessment (CA) of the human model's working posture was conducted to determine the simulation parameters in virtual welding tasks. The CA was identified based on the comfort values calculated using Formula (1). The assessment results are presented in Figure 6.

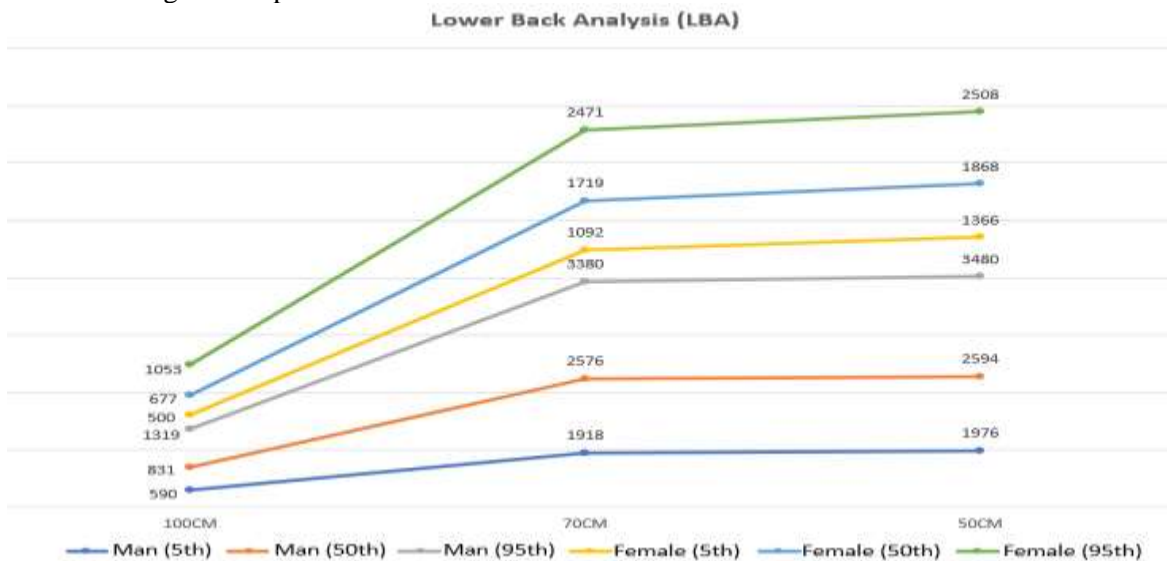


Fig 5. LBA Test Results On A Human Model Using The Welding Workbench Design Concept

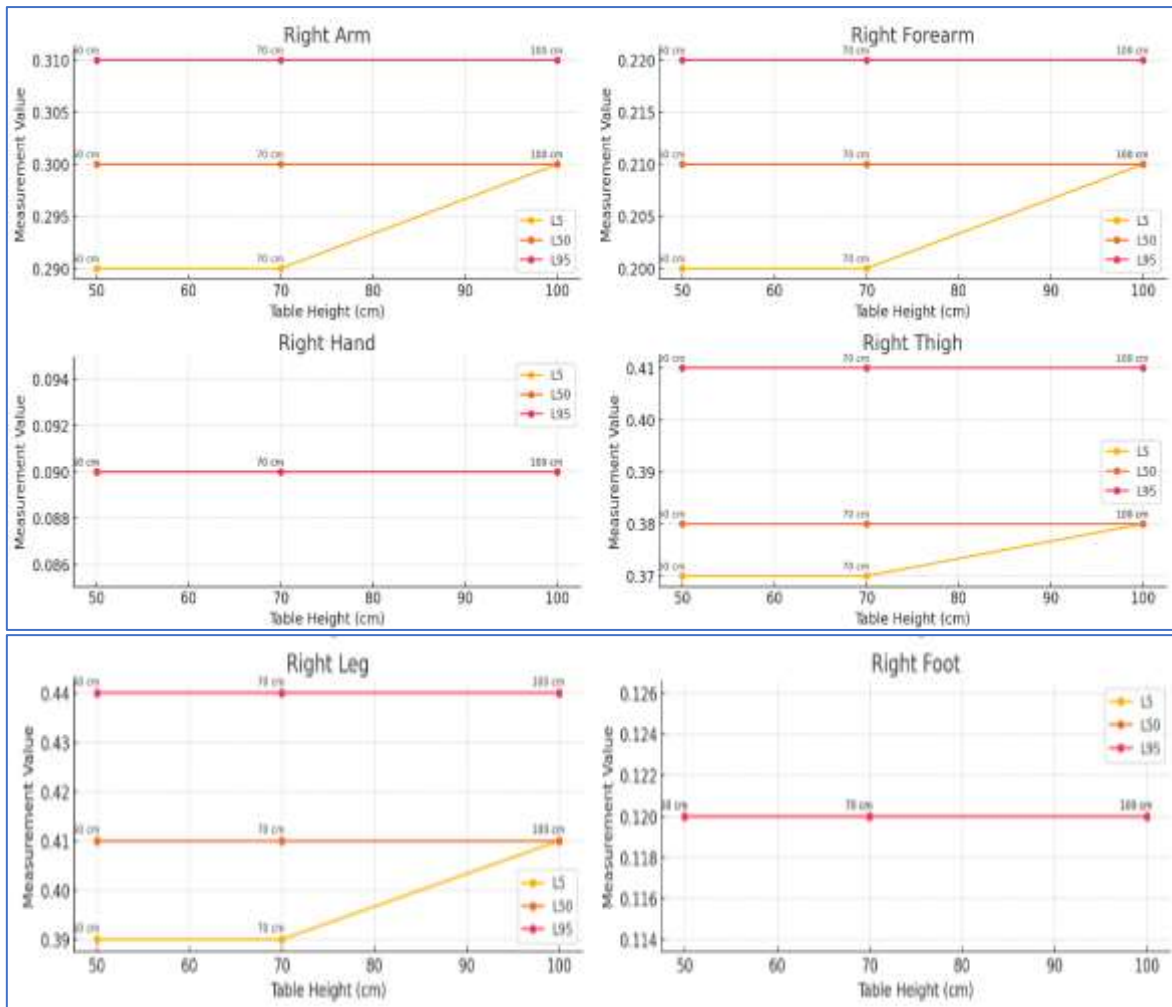


Fig. 6 Results Of Comfort Assessments Carried Out On Human Models For Various Table Heights (50 Cm, 70 Cm, And 100 Cm)

Based on the analysis, most body parts showed stability across different table heights (50 cm, 70 cm, and 100 cm), with only a few specific areas, such as the thigh, leg, and forearm, exhibiting minor changes. The right arm and right forearm remained stable, with a slight increase in the L95 value at a table height of 100 cm. The right hand and right foot showed no changes, maintaining constant values for all parameters (L5, L50, and L95) across all heights. However, the right thigh and right leg displayed a pattern of change in the L5 value, with a slight increase at a table height of 100 cm, while L50 and L95 remained steady. This discomfort response remained within the tolerance limits as the values stayed below the threshold of 1. Overall, the welding table height still supports operator comfort, despite some potential

discomfort in certain body parts that may require further attention for ergonomic improvement.

4. Rapid Upper Limb Assessment (RULA)

The RULA assessment system in the Catia V5 R21 software is evaluated based on the scores obtained, where a higher score indicates a greater impact of posture on the musculoskeletal system. If the RULA score exceeds 4, improvements need to be made to the welding workbench design as a recommendation for posture adjustments. The RULA assessment using a digital human model is conducted to evaluate the welding workbench design concept, with improvements that should be made to minimize discomfort and the risk of work-related injuries. Figure 7 shows the results of the RULA assessment evaluation using height parameters in the welding worktable concept.

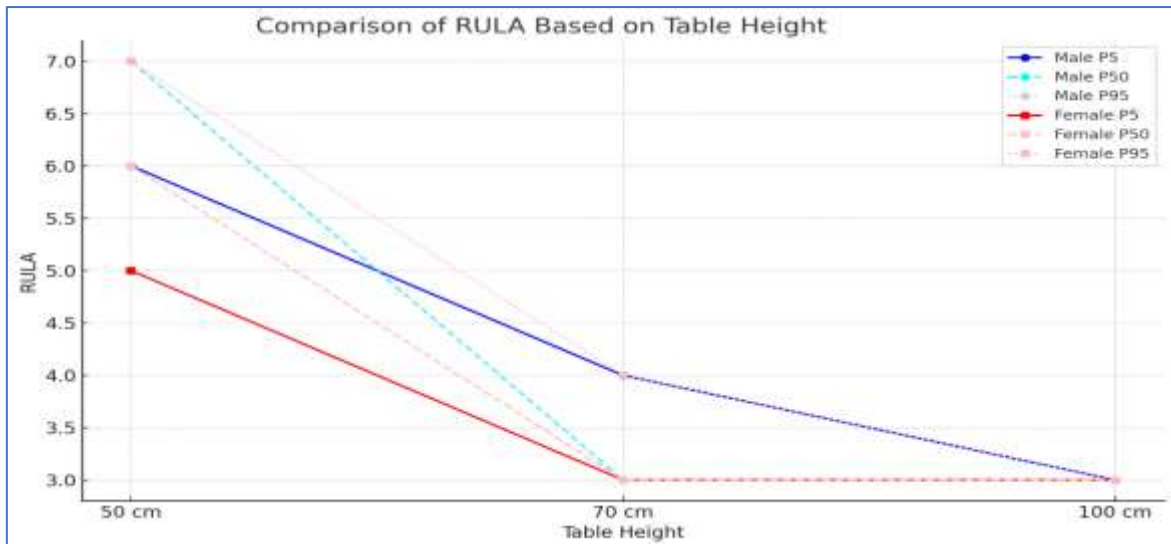


Fig. 7 RULA Assessment Using the Welding Worktable Design Concept

The RULA assessment using the welding worktable concept in Figure 7 shows that the use of a welding table with a height of 50 cm does not align with the welding work posture simulation. However, the adjustable height of the table can accommodate the worker's posture needs, as seen when the table height is increased. The RULA results were obtained with a comfort level that aligns with the recommendations.

4. Discussion

4.1 Ergonomic Considerations of Work Desk Design

The alternative design for the welding workbench is evaluated based on anthropometric data from anthropometriindonesia.org [12], for the age range of 21–25 years. According to the Higher Education Statistics [24], most active students are between 18 and 30, with a dominant participation rate in the 18–24 age group. The selection of anthropometric data for the 21–25 age range is considered representative, as it reflects the body dimensions of most undergraduate students. This approach ensures that the workbench design is not only ergonomic but also optimized to support the comfort and productivity of students during practical learning processes. However, issues with the welding workbench design arise from the fixed legs and tabletop, which cannot be adjusted and may lead to musculoskeletal disorders (WMSDs). According to Zhang et al. [20], improper work posture caused by an unsuitable table height is a major contributor to WMSDs in operators. The non-ergonomic body posture during welding causes a 180-degree angle at the head, neck, and

shoulders, and a 25-degree angle at the waist and shoulders, leading to fatigue and muscle stiffness. Design concept 1 is chosen because it can be adjusted to individual posture, helping to prevent WMSDs.

The adjustable design concept in Figure 3 was selected based on an evaluation using the Pugh method [13]. Ergonomic considerations were used as the basis for identifying opportunities for improvement in the proposed welding equipment by introducing a tilt mechanism and adjustable table height. According to Alam et al. [25], posture adjustment is crucial as it can reduce muscle fatigue and enhance long-term productivity. The height adjustment feature, ranging from 50 to 100 cm, along with the table tilt mechanism in this design, can prevent the formation of non-ergonomic body angles, which are often found in non-adjustable workbench designs. These adjustments enable more natural working positions during the welding process and provide greater comfort for the operator without the need to change positions to reach different work areas.

4.2 Implikasi Simulasi Operasional Ergonomi pada Meja Kerja Las

The simulation analysis using Catia V5 R21 software offers a more comprehensive ergonomic evaluation approach compared to traditional methods. This approach integrates virtual simulation with verification based on the actual posture of the human body during operation. The simulation is conducted by creating various welding environment scenarios that can adaptively align with human body

postures. The use of digital human models significantly reduces testing costs, as it eliminates the need for direct participation from welding operators. Moreover, digital human-based simulations are conducted without the complexities of real-world variables or potential behavioral disturbances of operators before and after operations. In this study, the digital human model was employed as a parameter to analyze and test alternative welding workbench designs, ensuring that safety and ergonomic aspects were met before the product was manufactured.

The ergonomic implications of the welding workbench design through simulation based on a digital human model are evaluated by considering factors such as pressure on the lower back, work posture, comfort, and the potential for musculoskeletal risks. This simulation reflects how the design of the welding workbench can be optimized to support the efficiency and safety of the operator. The simulation test was conducted by comparing workbench heights of 50 cm, 70 cm, and 100 cm with an angle setting of 30°. The LBA assessment in Figure 5 revealed that the height of the workbench affects the pressure on the spine. A higher workbench (100 cm) results in lower pressure compared to a lower workbench (50 cm or 70 cm). These findings support the ergonomic theory by NIOSH [26], which sets the safe load limits for the spine between 500 N and 3480 N.

The LBA results are consistent with previous studies, which show that adjustable body postures provide significant benefits in improving comfort and reducing the risk of injury. Ariyanti et al. [27], recommend that welding work should be supported by tools such as benches, supports, and pulleys used at welding stations, which can help improve poor working postures. This finding aligns with the work of Albolino, [28], which emphasizes the importance of adjusting body posture and using assistive tools to enhance operator comfort and safety. The simulation results provide recommendations that the use of a workbench with adjustable height and angle features can optimize work posture and reduce fatigue.

The adjustment of height and tilt in the welding workbench, based on the OWAS assessment categorized as Class 2, indicates the need for modifications in the workbench design to prevent injury risks. These adjustments can help optimize the operator's working posture,

reduce joint pressure, and improve work efficiency. A similar strategy was implemented by Zhang et al. [20], who emphasized that posture adjustments not only enhance the operational welding process but also help prevent operator fatigue and injuries. EL-Maturity [29], further explained that posture adjustments in the workplace play a crucial role in reducing muscle fatigue and the potential for operator injuries. These studies reinforce the findings that the use of an adjustable welding workbench design holds significant potential to reduce fatigue and injury risks for operators.

According to the CA assessment in Figure 6, most of the operator's body parts remain stable at different workbench heights (50 cm, 70 cm, and 100 cm), although there is slight discomfort in some body parts. However, the changes remain within the tolerance limits. Additionally, slight changes were observed in the thigh and right leg at the 100 cm workbench height. This study aligns with the findings of Markova et al. [30], which indicate that the correct workbench height can enhance operator comfort by considering body weight distribution and proper posture placement during operation. These findings also support ergonomic principles that emphasize the importance of workbench height adjustment to improve comfort and optimize the operator's working posture.

The less ergonomic working posture based on the RULA assessment in Figure 7 shows that a fixed-height workbench (50 cm) results in a higher score. In contrast, the adjustable height feature of the workbench allows the operator to modify their working posture, thereby reducing the RULA score and injury risk. This finding aligns with the research by Chandra et al. [31], which indicates that adjustable workstations can reduce the risk of injury and improve the physical comfort of workers. These findings provide recommendations supporting the importance of adjustable welding workbenches to enhance ergonomics and reduce health risks for workers. Kibria et al. [32], also emphasized that the use of adjustable workstations is crucial to reducing muscle and joint strain and improving operator comfort in the long term.

4.3 Design Implications and Recommendations

This research provides recommendations that indicate the adjustable design of the welding

workbench, including height and tilt adjustments, offers various ergonomic benefits. Simulations using human digital modeling in a welding environment with adjustable height and tilt features significantly reduce the risk of musculoskeletal injuries, improve operator comfort, and support work efficiency. These findings align with previous research emphasizing the importance of flexibility in workstation design to enhance worker safety and comfort.

The use of Catia V5 R21 software for simulation in human-machine design is highly recommended to save costs and improve research efficiency. This tool allows designers to evaluate the impact of the design on the operator's posture and potential musculoskeletal injury risks before physical prototypes are created. Additionally, the design process can be carried out iteratively, optimizing the design virtually to achieve more ergonomic, efficient, and safe solutions for the operator.

As a recommendation, when designing and manufacturing welding workbenches, it is suggested to integrate automated adjustment technology for table height and tilt. This feature not only increases flexibility and adaptability to various operator postures but also simplifies the adjustment of the workbench according to specific needs, ultimately improving operator comfort, safety, and productivity in the long term.

5. Conclusion

This study successfully simulated the concept of an ergonomically designed welding workbench using the PUGH method as the foundation for planning a workbench for students' practical learning. Evaluations conducted through digital human modeling, utilizing the LBA, OWAS, CA, and RULA methods, demonstrated that the workbench design with adjustable height and tilt features significantly reduces the risk of work-related musculoskeletal disorders (WMSDs) while enhancing comfort and productivity. Based on the body dimensions of Indonesian students, this design is not only contextually relevant but also makes a significant contribution to developing ergonomic standards for vocational education. The implementation of this innovative design is expected to improve the quality of welding practical learning while establishing new benchmarks for safety and efficiency in educational environments.

REFERENCES

- [1] F. Yang *et al.*, "The prevalence and risk factors of work related musculoskeletal disorders among electronics manufacturing workers: a cross-sectional analytical study in China," *BMC Public Health*, vol. 23, no. 1, Dec. 2023, doi: 10.1186/s12889-022-14952-6.
- [2] K. E. LeBlanc and L. L. LeBlanc, "Musculoskeletal disorders," Jun. 2010. doi: 10.1016/j.pop.2010.02.006.
- [3] K. Krüger, C. Petermann, C. Pilat, E. Schubert, J. Pons-Kühnemann, and F. C. Mooren, "Preventive strength training improves working ergonomics during welding," *International Journal of Occupational Safety and Ergonomics*, vol. 21, no. 2, pp. 150–157, 2015, doi: 10.1080/10803548.2015.1029290.
- [4] T. Phajan, K. Nilvarangkul, D. Settheetham, and W. Laohasirivong, "Work-related musculoskeletal disorders among sugarcane farmers in North-Eastern Thailand," *Asia Pac J Public Health*, vol. 26, no. 3, pp. 320–327, 2014, doi: 10.1177/1010539514528026.
- [5] L. Lourenço and S. Luís, "Musculoskeletal Disorders in Portuguese Welders: Effects on Bodily Pain and Health-Related Quality of Life," *Front Public Health*, vol. 9, May 2021, doi: 10.3389/fpubh.2021.660451.
- [6] N. S. Ahmad, A. Alhusna, A. Abdullah, O. Kee Thyng, and T. L. Xin, "Musculoskeletal Disorders Among Dental Students," 2020. [Online]. Available: www.jrmds.in
- [7] C. Francisco and T. Edwin, "Implementation of an ergonomics program for the welding department inside a car assembly company," in *Work*, 2012, pp. 1618–1621. doi: 10.3233/WOR-2012-0361-1618.

- [8] Y. Zhang, X. Wu, J. Gao, J. Chen, and X. Xv, "Simulation and ergonomic evaluation of welders' standing posture using Jack software," *Int J Environ Res Public Health*, vol. 16, no. 22, Nov. 2019, doi: 10.3390/ijerph16224354.
- [9] A. R. Mohammed, M. O. Mohamed, Y. A. Alhubaishy, K. A. Nasser, and I. S. Fahim, "Ergonomic analysis of a working posture in steel industry in Egypt using digital human modeling," *SN Appl Sci*, vol. 2, no. 12, Dec. 2020, doi: 10.1007/s42452-020-03872-y.
- [10] X. Ji, R. O. Hettiarachchige, A. L. E. Littman, and D. Piovesan, "Using Digital Human Modelling to Evaluate the Risk of Musculoskeletal Injury for Workers in the Healthcare Industry," *Sensors*, vol. 23, no. 5, Mar. 2023, doi: 10.3390/s23052781.
- [11] R. Raghunathan and S. R., "Review of Recent Developments in Ergonomic Design and Digital Human Models," *Industrial Engineering & Management*, vol. 5, no. 2, 2016, doi: 10.4172/2169-0316.1000186.
- [12] penghimpun ergonomi indonesia, "Rekap Data Antropometri Indonesia," http://www.antropometriindonesia.org/index.php/detail/artikel/4/10/data_antropometri.
- [13] D. D. Frey, P. M. Herder, Y. Wijnia, E. Subrahmanian, K. Katsikopoulos, and D. P. Clausen, "The Pugh Controlled Convergence method: Model-based evaluation and implications for design theory," *Res Eng Des*, vol. 20, no. 1, pp. 41–58, Mar. 2009, doi: 10.1007/s00163-008-0056-z.
- [14] M. Iqbal, L. Angriani, I. Hasanuddin, F. Erwan, H. Soewardi, and A. Hassan, "Working posture analysis of wall building activities in construction works using the OWAS method," *IOP Conf Ser Mater Sci Eng*, vol. 1082, no. 1, p. 012008, Feb. 2021, doi: 10.1088/1757-899x/1082/1/012008.
- [15] Y. Zhang, X. Wu, J. Gao, J. Chen, and X. Xv, "Simulation and ergonomic evaluation of welders' standing posture using Jack software," *Int J Environ Res Public Health*, vol. 16, no. 22, Nov. 2019, doi: 10.3390/ijerph16224354.
- [16] M. Malakoutian, C. A. Sanchez, S. H. M. Brown, J. Street, S. Fels, and T. R. Oxland, "Biomechanical Properties of Paraspinal Muscles Influence Spinal Loading—A Musculoskeletal Simulation Study," *Front Bioeng Biotechnol*, vol. 10, Jun. 2022, doi: 10.3389/fbioe.2022.852201.
- [17] T. R. Waters, V. Putz-Anderson, A. Garg, and L. J. Fine, "Revised NIOSH equation for the design and evaluation of manual lifting tasks," *Ergonomics*, vol. 36, no. 7, pp. 749–776, 1993, doi: 10.1080/00140139308967940.
- [18] J. Hlávková *et al.*, "Evaluation of lumbar spine load by computational method in order to acknowledge low-back disorders as occupational diseases," *Cent Eur J Public Health*, vol. 24, no. 1, pp. 58–67, Mar. 2016, doi: 10.21101/cejph.a4332.
- [19] M. Porter E, "Clusters and Competition: New Agendas for Companies, Governments, and Institutions," *Harvard Business School Press*, 1998.
- [20] Y. Zhang, X. Wu, J. Gao, J. Chen, and X. Xv, "Simulation and ergonomic evaluation of welders' standing posture using Jack software," *Int J Environ Res Public Health*, vol. 16, no. 22, Nov. 2019, doi: 10.3390/ijerph16224354.
- [21] Z. Li, R. Zhang, C. H. Lee, and Y. C. Lee, "An evaluation of posture recognition based on intelligent rapid entire body assessment system for determining musculoskeletal disorders," *Sensors*

- (Switzerland), vol. 20, no. 16, pp. 1–21, Aug. 2020, doi: 10.3390/s20164414.
- [22] M. Gómez-Galán, J. M. González-Parra, J. Pérez-Alonso, I. Golasi, and Á. J. Callejón-Ferre, “Forced postures in courgette greenhouse workers,” *Agronomy*, vol. 9, no. 5, 2019, doi: 10.3390/agronomy9050253.
- [23] K. Nedohe, K. Mpofu, and O. Makinde, “Assessment of Ergonomics Risk Experienced by Welding Workers in a Rail Component Manufacturing Organization,” in *Lecture Notes in Mechanical Engineering*, Springer Science and Business Media Deutschland GmbH, 2023, pp. 227–236. doi: 10.1007/978-3-031-18326-3_23.
- [24] K. Pendidikan and D. Kebudayaan, “Statistik Pendidikan Tinggi,” 2020.
- [25] D. Alam, M. D. Alam, S. Mohsin, A. Khan, T. S. Rajput, and A. Parvez, “Ergonomic Design of Arc Welding Workstation Using Younger Age Group Operators,” *Shahnawaz Mohsin Int. Journal of Engineering Research and Application* www.ijera.com, vol. 8, pp. 12–22, 2018, doi: 10.9790/9622-080503122212|P.
- [26] N. Arjmand, M. Amini, A. Shirazi-Adl, A. Plamondon, and M. Parnianpour, “Revised NIOSH Lifting Equation May generate spine loads exceeding recommended limits,” *Int J Ind Ergon*, vol. 47, pp. 1–8, May 2015, doi: 10.1016/j.ergon.2014.09.010.
- [27] S. Ariyanti, L. Widodo, M. Zulkarnain, and K. Timotius, “DESIGN WORK STATION OF PIPE WELDING WITH ERGONOMIC APPROACH,” *SINERGI*, vol. 23, no. 2, p. 107, Jul. 2019, doi: 10.22441/sinergi.2019.2.003.
- [28] S. Albolino, “Ergonomics in a Global World,” 2019, *IOS Press*. doi: 10.3233/WOR-182835.
- [29] H. J. EL-Matury, “Evaluation of Work Station and Working Posture on Welding Section Review of Ergonomic Factors in Metal SME Road Court Medan,” *Jurnal Aisyah: Jurnal Ilmu Kesehatan*, vol. 5, no. 2, pp. 235–247, Dec. 2020, doi: 10.30604/jika.v5i2.686.
- [30] V. Markova, M. Markov, Z. Petrova, and S. Filkova, “Assessing the Impact of Prolonged Sitting and Poor Posture on Lower Back Pain: A Photogrammetric and Machine Learning Approach,” *Computers*, vol. 13, no. 9, Sep. 2024, doi: 10.3390/computers13090231.
- [31] A. Chandra and P. K. Arora, “Study on Ergonomic Risk Assessment of Welding Workers using - RULA,” *Evergreen*, vol. 11, no. 2, pp. 1240–1247, Jun. 2024, doi: 10.5109/7183430.
- [32] M. G. Kibria, M. S. Parvez, P. Saha, and S. Talapatra, “Evaluating the ergonomic deficiencies in computer workstations and investigating their correlation with reported musculoskeletal disorders and visual symptoms among computer users in Bangladeshi university,” *Heliyon*, vol. 9, no. 11, Nov. 2023, doi: 10.1016/j.heliyon.2023.e22179.