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Comparative Study of Ergonomic Assessment Outputs in Mechanical Workshop Practices with Rapid Upper Limb and Entire Body Methods

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ABSTRACT

Mechanical workshop practices often expose individuals to awkward postures, repetitive motions and ergonomic risk factors that contribute to musculoskeletal disorders (MSDs). This study assessed ergonomic risks in workshop tasks using the Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) validated the outcomes through human model simulations and evaluated agreement and disagreement between assessment methods. Fifteen male students with prior workshop experience participated. RULA results indicated that 78% of tasks posed low risk and 12% posed medium risk, whereas REBA classified all tasks as medium risk. Validation using CATIA v5 simulations demonstrated full agreement with the RULA outcomes where the high-risk factors were identified in the lower arm and muscle use dimensions of RULA and in the lower arm and activity score of REBA, while both methods consistently reported medium risk for the neck and trunk. The legs and upper arm displayed no risk across both tools. Survey responses further confirmed agreement on the lower arm, trunk and neck risks but revealed disagreement for upper arm and leg evaluations which suggest that incorporating simulations into ergonomic evaluation can enhance the efficiency and credibility of risk identification, support earlier interventions and reduce time and resource requirements. Overall, the study highlighted the presence of MSD related risks in mechanical workshop practices and demonstrates that integrating observational tools with simulation-based validation which provides a comprehensive understanding of ergonomic challenges, contributing to improved workshop safety, student well-being and the broader advancement of ergonomic risk assessment in manual machining contexts.

Keywords: RULA; REBA; CATIA V5; ergonomics; mechanical workshop; MSDs

INTRODUCTION

Poor workshop design can markedly reduce user comfort and increase the risk of MSDs. Early adoption of correct posture is important for students to improve performance and reduce stress and fatigue (P.Saraswat et al. 2021). Reported prevalence rates for shoulder pain range from 18 to 26% of adults (Linaker & Walker-Bone, 2015) and lifetime prevalence of upper limb pain among working adults ranges from 7 to 26% (Walker Bone et al. 2004). In workshop environments, 20 to 70% of adults report upper limb pain, with the higher estimates associated with highly repetitive tasks of up to 25000 cycles per workday (Armstrong et al. 1993). RULA and REBA are widely used to assess ergonomic risk and support the design of healthier, more productive work environments (Mahesh S. Gorde 2019).

MSDs arise from ergonomic risk factors such as awkward postures and repetitive motion (Sebbag et al. 2019). Upper limb tasks in workshops place sustained demand on muscles, tendons, ligaments and nerves and increase the likelihood of injury (Aziz et al. 2020). A random sample of 116 production workshop workers found that 87.1% reported some MSD symptoms (Choobineh et al. 2009). Industrial workers commonly sustain work related injuries associated with awkward postures such as bending, twisting, overreaching and repetitive tasks (Zeina et al. 2015). Prolonged standing can produce MSDs including lower back pain, leg pain and foot pain (Jo et al. 2021).

In ergonomic analysis of the human body, RULA and REBA are widely used to evaluate the upper limb and whole-body risk through postures and movements. These tools are often used together or separately based on the study case and comparing with simulation study to improve accuracy and better results (Gómez-Galán et al. 2020; Manuel Hita Gutiérrez 2020). Based on other researchers, the use of RULA and REBA potentially to identify the effective methods apply under limited work environment to reduce the risk at work area (Yadi et al. 2018; Amit & Song, 2021).

Despite widespread use, there is limited validation of RULA and REBA specifically for mechanical workshop course practice and limited evaluation of agreement between observational assessments and biomechanical simulations. Palikh et.al, 2020 and Shraddha Palikhe, 2022 has done the simulation studies to predict the MSD risk and muscle stress while working in the construction and manufacturing industries. The results have successfully predicted the risks by combining anthropometry and hand force data and have highlighted common unsafe practices that can be mitigated through preventive ergonomics. The observation assessment can be validated through simulation results to strengthen the ergonomic evaluation in workspace (Palikh et al. 2020; Shraddha Palikhe 2022).

This study addresses those gaps by assessing mechanical workshop course practice using RULA and REBA and validating results with simulations of human models performing the observed postures. The study sample comprised 15 UOWM students, male, aged from 21 to 25 years with BMI from 18.5 to 24.9 and experienced in Mechanical Workshop Practices. The objectives are to conduct ergonomic assessment of mechanical workshop practice using RULA and REBA, validate the assessment results using simulation and evaluate agreement and disagreement between assessment results and simulation outputs. APECS has demonstrated high agreement with radiographic HKA measurements and is considered a valid method for angle estimation, supporting its application in this study (Welling 2023). Building upon these gaps, the present study seeks to advance ergonomic evaluation in workshop environments. Recent reviews highlight the growing role of motion capture and digital human modeling in ergonomic assessment, showing strong potential to enhance reliability and precision in MSD risk evaluation (Salisu et al. 2023; Vieira et al. 2024). This study contributes by bridging observational ergonomic assessment methods with digital human simulation, ensuring a more reliable framework for evaluating mechanical workshop practices

METHODOLOGY

PARTICIPANTS

Fifteen male students from UOWM participated in the study (mean age 23 years, mean height 175 cm, and mean weight 75 kg). All participants reported prior workshop experience. Eligibility criteria were applied to reduce between-subject variability associated with age, body mass index (BMI) and prior workshop exposure.

All participants received verbal and written information about the study objectives, procedures, potential risks and benefits and provided written informed consent prior to participation. Ethical procedures were observed throughout the study. An honorarium of RM30 was provided to each participant upon completion as a token of appreciation.

TESTED ACTIVITY

A workshop activity was designed in which participants performed four milling operations, chamfer, drill, facing and pocket, on a rectangular workpiece. Each operation required different combinations of tool control, such as tool path, depth of cut and feed rate and participants machined the workpiece to specified dimensions. The protocol collected objective and subjective data on how each machining method affected ergonomic comfort and the risk of MSDs.

Prior to testing, each participant completed a machine familiarization session and received instruction on required safety procedures. Standard safety protocols were enforced throughout the activity, including the use of PPE and verification of machine familiarity. Figure 1 shows the workpiece measurements. This workpiece details were set as the outcome of the machining operation. All participants were given same raw material and briefed about the operations sequence to constant the overall flow.

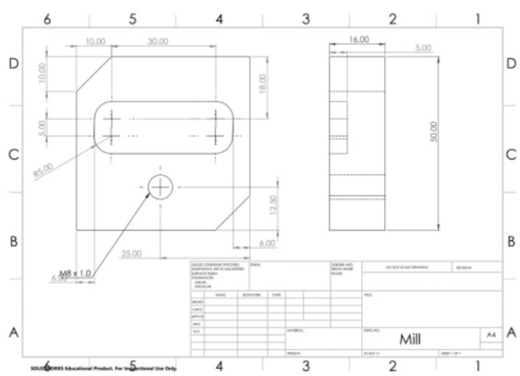

FIGURE 1. Workshop milling activity workpiece output measurements

activity, four video recordings were obtained and APECS generated analysis reports for major body segments such as the neck, shoulder, elbow, trunk (bend) and knee. The application provided time-based plots of the body angles, which were then processed using a web plot digitizer to extract numerical data points. From these plots, dominant angles were identified as they represent the critical postures and to be most relevant for ergonomic risk scoring.

In addition, mode angles were calculated for each body segment to establish representative values for further simulation. This combined approach ensured that both frequently assumed postures and peak postures were captured. The extracted angles were subsequently used as input parameters for digital human modelling to replicate actual workshop movements more accurately. By integrating motion data with ergonomic assessment, the study enabled a systematic quantification of posture loads associated with mechanical workshop practices as shown in Figure 2.

SURVEY DESIGN

Two questionnaires were administered, one before and one after the workshop activity. The pre-workshop questionnaire collected participant information including age, height, weight, level of workshop experience and the presence of current MSD symptoms in the arm (elbow), shoulder, neck, trunk (bending) and leg (knee). The post-workshop questionnaire gathered feedback on perceived discomfort and musculoskeletal strain experienced during the activity. Responses from both questionnaires were compared with the results of RULA and REBA to evaluate the effectiveness and consistency of the ergonomic assessments.

APECS MOTION ANALYSIS

The APECS application was used to analyse the motion of participants performing different machining tasks including chamfering, drilling, facing and pocketing. For each

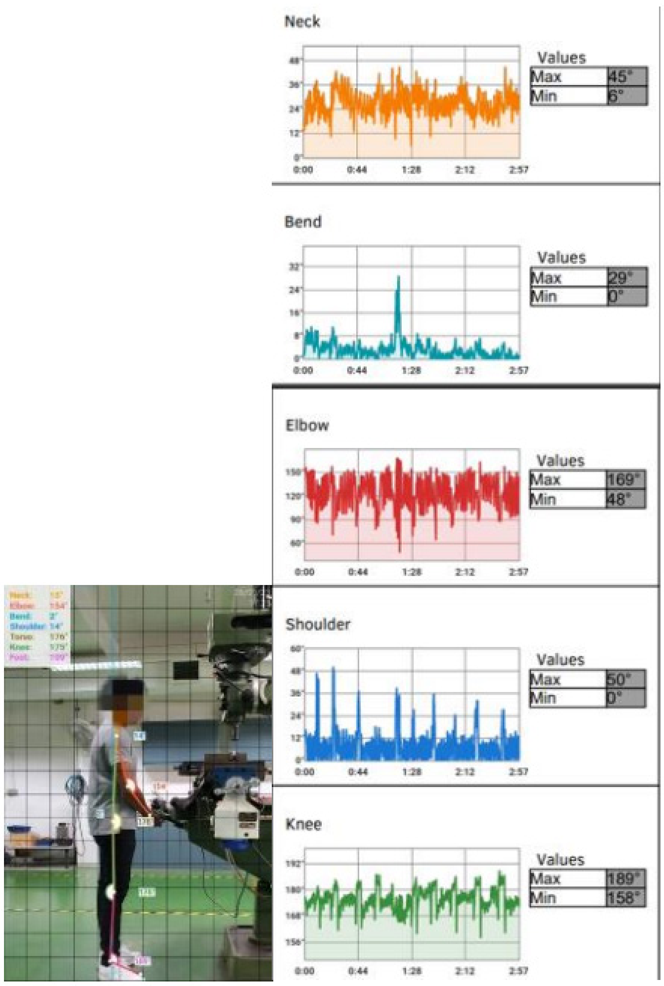

FIGURE 2. Motion analysis of neck, trunk, elbow, shoulder and knee during workshop activities using APECS

SIMULATION AND VALIDATION USING CATIA V5

The extracted dominant and mode angles from APECS were applied in CATIA V5 to simulate and validate the ergonomic risks associated with the observed working postures. A digital human model was generated using the CATIA manikin editor, with anthropometric parameters precisely adjusted to match the participant's height, weight, and limb dimensions. The identified joint and body angles were then entered into the manikin posture editor to accurately replicate the recorded movements and static positions. Subsequently, ergonomic analyses were conducted using the RULA and REBA modules within CATIA V5, which automatically calculated risk scores for each body segment. These analyses provided both numerical results and visual representations through color coded manikin models green indicating acceptable posture, yellow suggesting moderate risk, and red highlighting high-risk zones. This visual feedback enabled a more intuitive understanding of biomechanical strain distribution across the body during machining activities. By comparing the CATIA based risk scores with the raw APECS motion capture outputs and participant survey responses, the study has performed a cross validation of ergonomics data to ensure consistency and reliability between observational and computational subjective assessment methods. The simulation results are illustrated in Figure 3.

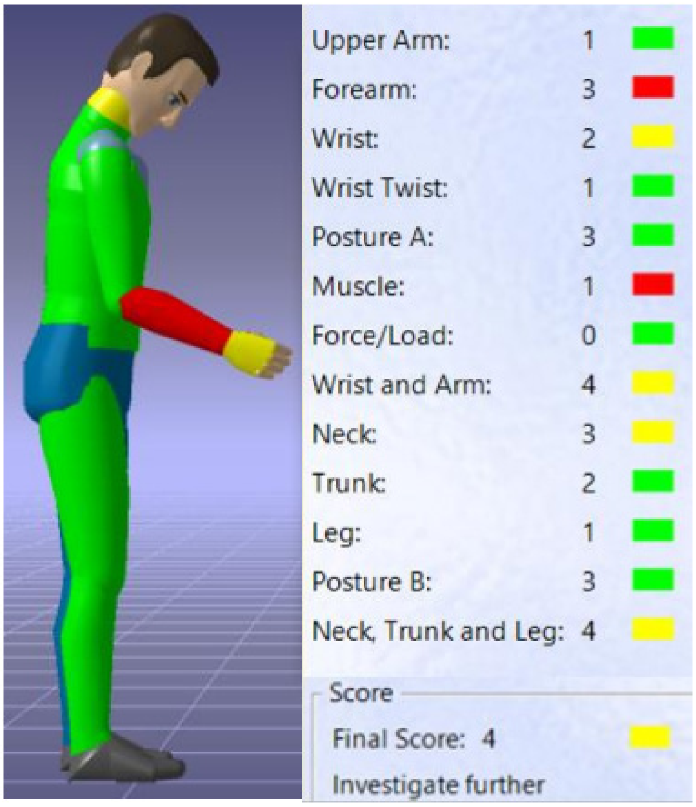

FIGURE 3. Ergonomic risk simulation of body postures using CATIA V5 with RULA output (green = acceptable, yellow = moderate risk, red = high risk).

The dominant joint angles identified during the experimental trials were applied in the RULA and REBA assessment frameworks to determine the corresponding ergonomic risk scores. The calculated mode angles obtained from motion data were then entered into the manikin posture editor allowing for accurate simulation of the observed working postures during machining activities. Following this, a detailed RULA analysis was performed on the virtual model to quantify the ergonomic risks associated with each body segment. The analysis generated both numerical risk indices and color-coded visual outputs, highlighting areas under significant postural strain such as the neck, shoulders, and lower back. This visualization facilitated a comprehensive understanding of how posture deviations contribute to musculoskeletal load and discomfort. The findings served as a critical input for evaluating design improvements in the adjustable ergonomic step bench to minimize physical stress and enhance operator comfort.

DATA ANALYSIS AND RESULTS

RULA AND REBA ASSESSMENT OUTCOMES

The displacement angles of the upper arm, lower arm, wrist, neck, trunk and legs during each machining task were measured using the APECS motion analysis application. These angles were then applied to the RULA assessment framework to calculate the corresponding risk indices, as illustrated in Figure 4. The results indicate that most participants exhibited low-to-medium ergonomic risks across the four tasks (chamfering, drilling, facing and pocketing). Lower arm posture and muscle use were consistently highlighted as higher-risk factors, while upper arm and leg postures were generally classified as low risk. The visualization of RULA scores in Figure 4 shows that chamfering, facing and pocketing produced similar risk distributions, whereas drilling demonstrated slightly higher variation, particularly in the lower arm and trunk regions. By integrating APECS measurements with RULA scoring, a more objective and quantifiable assessment of posture related MSDs risks was achieved, ensuring greater reliability of the ergonomic evaluation.

RULA CHAMFER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Upper Arm:	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
Lower Arm:	3	3	3	3	3	2	3	3	3	3	3	3	3	3	3
Wrist:	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Wrist Twist:	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Posture Score A:	3	3	3	3	4	2	3	3	3	3	3	3	3	3	3
Muscle Use:	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Force/Load:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wrist & Arm Score:	4	4	4	4	5	3	4	4	4	4	4	4	4	4	4
Neck:	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Trunk:	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Legs:	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Posture Score B:	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Neck, Trunk, Leg Score:	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
RULA Score:	4	4	4	4	5	4	4	4	4	4	4	4	4	4	4

RULA DRILL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Upper Arm:	1	1	1	1	1	2	2	3	1	1	2	1	1	2	1
Lower Arm:	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Wrist:	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Wrist Twist:	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Posture Score A:	3	3	3	3	3	4	4	4	3	3	4	3	3	3	3
Muscle Use:	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Force/Load:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wrist & Arm Score:	4	4	4	4	4	5	5	5	4	4	5	4	4	5	4
Neck:	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Trunk:	2	2	2	2	3	3	3	2	2	2	2	2	2	2	2
Legs:	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Posture Score B:	3	3	3	3	4	4	4	3	3	3	3	3	3	3	3
Neck, Trunk, Leg Score:	4	4	4	4	5	5	5	4	4	4	4	4	4	4	4
RULA Score:	4	4	4	4	5	6	6	5	4	4	5	4	4	5	4

RULA FACING	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Upper Arm:	1	1	1	1	1	1	2	1	1	1	1	1	1	2	1
Lower Arm:	2	3	3	3	3	3	3	3	3	2	2	3	3	3	3
Wrist:	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Wrist Twist:	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Posture Score A:	2	3	3	3	3	3	4	3	3	2	2	3	3	4	3
Muscle Use:	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Force/Load:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wrist & Arm Score:	3	4	4	4	4	4	5	4	4	3	3	4	4	5	4
Neck:	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Trunk:	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Legs:	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Posture Score B:	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Neck, Trunk, Leg Score:	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
RULA Score:	4	4	4	4	4	4	5	4	4	4	4	4	4	5	4

RULA POCKET	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Upper Arm:	1	1	1	1	1	1	2	1	2	1	1	1	1	1	1
Lower Arm:	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3
Wrist:	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Wrist Twist:	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Posture Score A:	3	3	3	3	3	3	4	3	4	2	3	3	3	3	3
Muscle Use:	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Force/Load:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wrist & Arm Score:	4	4	4	4	4	4	5	4	5	3	4	4	4	4	4
Neck:	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Trunk:	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Legs:	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Posture Score B:	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Neck, Trunk, Leg Score:	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
RULA Score:	4	4	4	4	4	4	5	4	5	4	4	4	4	4	4

No Risk — High Risk

FIGURE 4. RULA risk indices calculated from displacement angles measured using APECS (green = low risk, yellow = moderate risk, red = high risk)

Figure 4 highlights the ergonomic risk scores generated from RULA and REBA analysis risk by four machining tasks used in this study which are chamfering, drilling, facing and pocketing. The radar plots demonstrate that REBA consistently produces higher risk scores than RULA, with an average increase of 1–2 points throughout the whole-body area. For chamfering and pocketing, the two methods follow similar patterns, but REBA uniformly elevates the scores, classifying all postures within the medium-risk range. In contrast, RULA identifies 78% of postures as low risk and only 12% as medium risk. The largest discrepancy appears in the drilling and facing tasks, where REBA highlights widespread medium risks, while RULA indicates mostly low risks with localized concerns in the lower arm and trunk.

These differences suggest that RULA is more sensitive to specific upper limb postures, whereas REBA captures whole-body involvement, leading to more conservative risk classifications. Overall, the higher REBA values imply that relying solely on RULA may underestimate MSDs risks, while using both tools together provides a more balanced and comprehensive assessment of ergonomic conditions in mechanical workshop practices. Figure 5 shows same operations assessed using REBA.

REBA CHAMFER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Neck:	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Trunk:	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Legs:	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Posture Score A:	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Force/Load:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Score A:	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Upper Arm:	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
Lower Arm:	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2
Wrist Score	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Posture Score B:	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
Coubling Score	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Score B:	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
Table C Score	2	2	2	2	3	2	2	2	2	2	2	2	2	2	2
Activity Score:	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
REBA Score:	5	5	5	5	6	5	5	5	5	5	5	5	5	5	5

REBA DRILL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Neck:	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Trunk:	2	2	2	2	3	3	3	2	2	2	2	2	2	2	2
Legs:	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Posture Score A:	3	3	3	3	4	4	4	3	3	3	3	3	3	3	3
Force/Load:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Score A:	3	3	3	3	4	4	4	3	3	3	3	3	3	3	3
Upper Arm:	1	1	1	1	1	2	2	3	1	1	2	1	1	2	1
Lower Arm:	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Wrist Score	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Posture Score B:	1	1	1	1	1	2	2	4	1	1	2	1	1	2	1
Coubling Score	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Score B:	1	1	1	1	1	2	2	4	1	1	2	1	1	2	1
Table C Score	2	2	2	2	3	4	4	3	2	2	3	2	2	3	2
Activity Score:	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
REBA Score:	5	5	5	5	6	7	7	6	5	5	6	5	5	6	5

REBA FACING	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Neck:	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Trunk:	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Legs:	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Posture Score A:	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Force/Load:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Score A:	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Upper Arm:	1	1	1	1	1	1	2	1	1	1	1	1	1	2	1
Lower Arm:	1	2	2	2	2	2	2	2	2	1	1	2	2	2	2
Wrist Score	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Posture Score B:	1	1	1	1	1	1	2	1	1	1	1	1	1	2	1
Coubling Score	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Score B:	1	1	1	1	1	1	2	1	1	1	1	1	1	2	1
Table C Score	2	2	2	2	2	2	3	2	2	2	2	2	2	3	2
Activity Score:	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
REBA Score:	5	5	5	5	5	5	6	5	5	5	5	5	5	6	5

REBA POCKET	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Neck:	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Trunk:	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Legs:	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Posture Score A:	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Force/Load:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Score A:	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Upper Arm:	1	1	1	1	1	1	2	1	2	1	1	1	1	1	1
Lower Arm:	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2
Wrist Score	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Posture Score B:	1	1	1	1	1	1	2	1	2	1	1	1	1	1	1
Coubling Score	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Score B:	1	1	1	1	1	1	2	1	2	1	1	1	1	1	1
Table C Score	2	2	2	2	2	2	3	2	3	2	2	2	2	2	2
Activity Score:	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
REBA Score:	5	5	5	5	5	5	6	5	6	5	5	5	5	5	5

No Risk — High Risk

FIGURE 5. REBA risk indices calculated from displacement angles measured using APECS (green = low risk, yellow = moderate risk, red = high risk)

The REBA risk score analysis indicates that the neck and trunk showed medium risk, but the legs showed no risk across all tasks. If the workload used during workshop is less than 2 kg, the upper arm part of body showed no risk for most participants even though some drill tasks exhibited medium risk for few participants. It's different for the lower arm which showed high risk for all tasks while for the wrist scored no risk for the participants due to the zero scored when handling, well-fitted and great gripping the tools. However, the activity that scored high comes from the static posture that more than one minutes, repetitive small actions and rapidly large changes in postures when conducting the workshop activities. Overall, all the tasks yielded at medium REBA risk scores with the drill tasks scored the highest point compared to other tasks. Figure 6 shows the comparison of the risk scores of RULA and REBA

These observations further highlight the complementary nature of RULA and REBA in evaluating ergonomic risks across varying work postures. While RULA tends to emphasize localized upper-body assessment, particularly for the shoulder, neck, and wrist regions, REBA integrates whole-body dynamics, including leg and trunk positioning, which are essential for tasks requiring frequent bending or forward leaning. This distinction becomes crucial in machining environments where workers often alternate between static and dynamic positions while handling tools or materials.

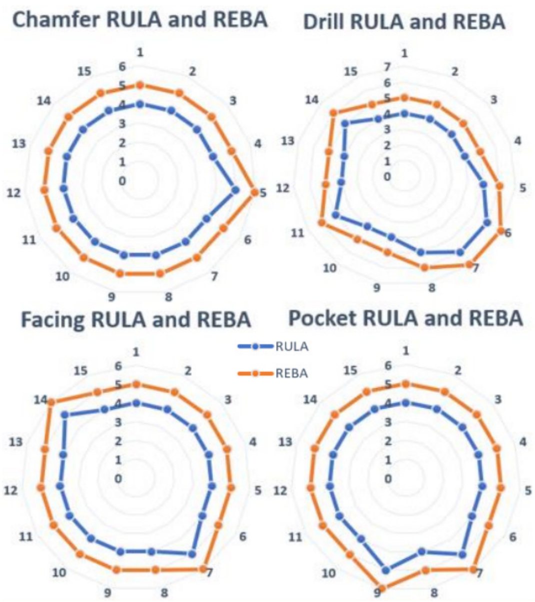

FIGURE 6. RULA and REBA score comparison

The ergonomic assessment results from RULA and REBA in Figure 6 were analyzed for those four machining tasks including chamfering, drilling, facing and pocketing. RULA indicated that 78% of the postures were classified as low risk and 12% as medium risk, suggesting that some modifications may be necessary to further reduce risk. In contrast, REBA assigned a 100% medium risk score across all tasks, highlighting the need for more detailed investigation and timely interventions to mitigate potential ergonomic issues to the users.

SURVEY RESULTS

Before the workshop, participants reported low pain levels in their lower and upper arms, trunks, necks and legs, with ratings mainly at 1 or 2, indicating minimal concerns. However, after the workshop, there was a notable increase in pain levels in the lower and upper arms, trunks, necks and legs. Lower arm pain exhibited the highest increase, reaching levels of 3, 4, or 5.

The workshop's impact on the neck was more pronounced than on the trunk or legs. These changes suggest the workshop may have contributed to elevated pain levels, especially in the neck, lower arm and upper arm, emphasizing the need for further investigation into workshop activities and ergonomics. Figure 7 and Figure 8 shows survey results collected from the participants tested before and after conducting the testing operations.

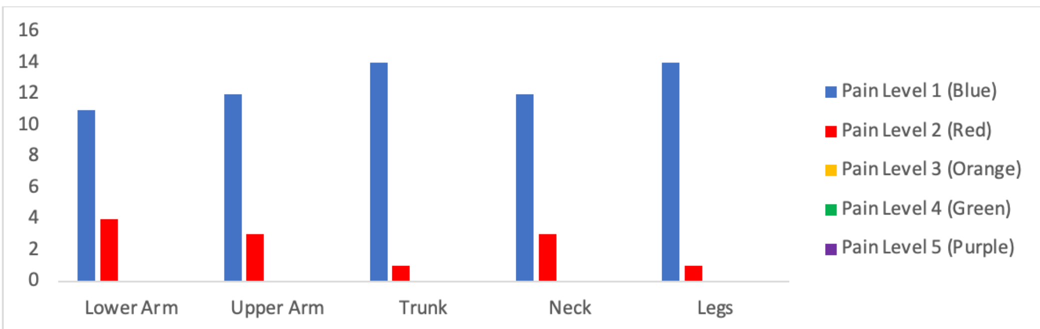

FIGURE 7. Self-reported participants pain level before operations

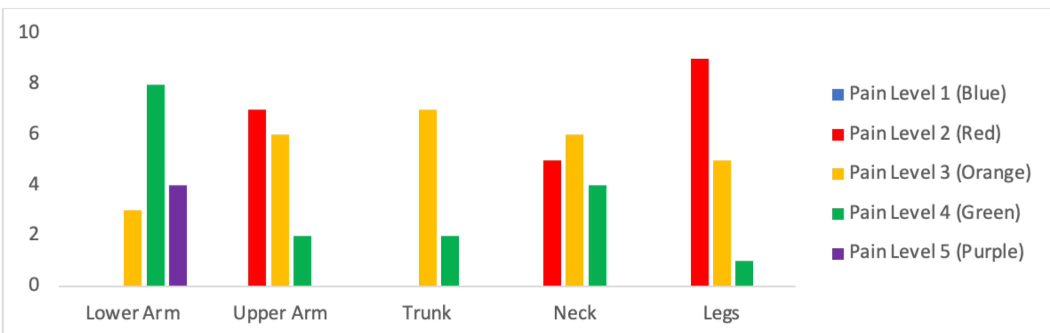

FIGURE 8. Self-reported participants pain level before operations

ANALYSIS OF RESULT CONCORDANCE AND DIVERGENCE

The near-identical results between RULA assessment and simulation verification validates the reliability of workshop environment ergonomic-based assessments. This consistency of results is due to the ability of the observation results to predict the ergonomic challenges that might happen in the simulation setting. The assurance of the effective method to address the issue in the workplace ergonomics also influences the consistency and accuracy between RULA assessment and the simulation results. Moreover, the consistency also proves the applicability of this method in the simulation setting as an approach towards improving the work environment.

The RULA analysis shows that the ergonomic environment is primarily good, with 78% of tasks categorized as low risk and 12% being medium risk, indicating effective existing practices. This emphasizes the potential for targeted interventions to further improve ergonomic conditions in specific areas. In contrast, 100% of tasks are classified as medium risk through REBA analysis which leads to the importance of evaluating the different risk assessment methods. The discrepancy highlights how important it is to have an extensive knowledge of evaluation tools and how crucial it is to choose the best approach for work environments. These insights help to guide the ergonomic plan by prioritizing the well-being and health measurement of the workers to reduce the risk of MSDs.

Not only that, but results also found from the RULA, REBA and surveys show the lower arm part as a high-risk area underscores a vital concern in musculoskeletal health. These systematic assessment tools objectively quantify musculoskeletal risks and are justified by subjective survey responses to express the consistent pain in the lower arm part. This result also emphasizes the need for targeted interventions to enhance comfortability and prevent long-term health issues associated with lower arm strain which improve overall well-being of the workers.

For the ergonomic assessment in both the neck and trunk are also identified as medium-risk areas according to the consensus among RULA, REBA and survey responses. The objective measurements from RULA and REBA, coupled with subjective survey insights, emphasize the need for targeted interventions in workplace ergonomics. Discomfort and musculoskeletal issues in the neck and truck able to be solved through ergonomic solutions for better health work environment, improve productivity and user well-being.

The discrepancy between RULA and REBA assessments, indicating no leg risk occured and from the survey reports only the slight leg pain occurred which highlight the complexity of ergonomic risk factors. This exposes the limitations of solely observational or quantitative assessments in capturing the full spectrum of user well-being, especially in prolonged standing. While RULA and REBA focus on upper body postures and entire body postures, it is overlooking lower limb discomfort, however, through surveys, it happens that require further investigation. Thus, addressing this condition is important through various methods, incorporating subjective feedback and implementing multifaceted interventions, such as anti-fatigue mats or ergonomic footwear. Similarly, the disagreement in upper arm results underscores the need for ergonomic assessments to consider specific muscle engagement for a more comprehensive approach.

CONCLUSION

This study demonstrated the significance of integrating ergonomic assessment tools with digital human simulation to evaluate and enhance working postures within mechanical workshop environments. The results consistently showed that the lower arm remains the most vulnerable body segment presenting the highest risk for MSDs. Other than that, the neck and trunk were subjected to moderate but persistent strain during prolonged standing, leaning and repetitive machining tasks. Although slight variations were observed between the two assessment approaches, the strong alignment between real-world observations and simulated outputs confirms that digital human modeling is a dependable and repeatable method for ergonomic evaluation across diverse workshop scenarios.

Beyond identifying high-risk postures, this research underscores the growing value of incorporating EMG and EEG data into simulation-based ergonomic assessments. The integration of physiological signals would provide deeper insights into muscle activation patterns, neuromuscular fatigue and cognitive workload, enabling an advanced multimodal approach to characterize operator performance. Such a framework offers the potential to bridge the gap between physical strain and mental stress, especially in complex machining activities where precision, attention and sustained force control are required.

Furthermore, the study highlights the importance of considering anthropometric variability, gender differences and user-specific movement patterns when developing ergonomic interventions. Integrating such diversity into simulation models would enhance accuracy and promote inclusive design, especially within educational institutions where individuals exhibit a wide range of body sizes, strengths and skill levels. This is crucial for ensuring that training environments do not inadvertently favor certain users while imposing unnecessary risks on others.

Eventually, the findings reinforce the need for proactive ergonomic education, structured training and preventive design strategies within mechanical workshops. By embedding ergonomic awareness into routine practice, institutions can transition from reactive corrective measures to a prevention-focused culture that prioritizes safety, comfort and long-term occupational well-being. Implementing these strategies will enable workshops to evolve into more supportive, human-centered learning spaces that protect students, enhance skill development, and reduce the long-term incidence of work-related MSDs.

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DECLARATION OF COMPETING INTEREST

None.

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