ERGONOMIC RISK EVALUATION OF COLLABORATIVE ROBOT ASSEMBLY WORKSTATION USING MOTION CAPTURE SYSTEMS: A CASE STUDY

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Abstract:

Motion capture systems, which enable continuous traceability in assessment process, have been integrated into ergonomic workflows as technology has advanced. In this study, Xsens, which uses wearable sensors for digital motion capture and analysis, was integrated with Process Simulate v2502 software to facilitate ergonomic assessments, creating a digital and real-time work environment where employees assemble products and collaborate with robots. Ergonomic data of employees were collected using wearable sensors, and REBA, OWAS, and RULA analyses were performed. The analysis shows that the scores obtained from wearable sensors yield effective results and are important for ergonomic assessment and occupational safety.

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1 Introduction

Ergonomic assessments, which systematically examine the interaction between humans and the work environment, have shifted direction with the advancement of technology. While older methods such as OWAS, RULA, and REBA, which are still valid today, have provided a standardization for ergonomic analyses, they still have limitations in focusing on momentary postures and therefore representing continuous movements. To overcome these limitations, sensor-based motion capture systems, which provide continuous traceability in the assessment process, have been incorporated into ergonomic processes.

Motion capture systems are currently used in many different fields of ergonomic risk assessment such as work posture analysis for musculoskeletal disorders [1], [2], [3], [4], and load analysis [5], [6] etc. Therefore, this study aimed to determine the effectiveness of motion capture systems by applying measurements of two workstations in human-robot collaboration. In this context, data was collected using the Xsens MVN Analyze Pro 2024.2 motion capture system and digital human modelling and analysed in the Process Simulate software environment. The first section of the study discusses the background, which includes OWAS, RULA and REBA. The second part presents the study's framework and environment, followed by the results.

2 Background and Objectives

Ergonomics has become a fundamental element of safety and productivity with increasing working hours and the resulting musculoskeletal strain. Consequently, the importance of systematic risk assessment is also growing. Methods used for systematic risk assessments, such as OWAS, RULA, and REBA, provide a structured analysis of postures and loads but require many manual processes. However, increasingly advanced technology is enabling a shift from traditional methods to digital approaches, providing automation and greater objectivity in assessment.

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2.1 OWAS

The Working Analysis System (OWAS) is an ergonomic observation method used to assess the risk of physical strain due to work posture. It was created in 1977 by a group of ergonomists, engineers, and workers from the Finnish steel industry. The OWAS method divides the human body into four categories, which include three positions for the arms, four for the back, seven for the lower extremities, and three for the weight of the load. All positions are evaluated for the risk of developing musculoskeletal disorders. The urgency of workplace safety measures is determined based on the scores shown in the Table 1 [7].

Table 1. Interpretation of OWAS Risk Categories

Score	The Urgency of Action
1	No special attention is needed, except in special cases.
2	It is necessary to take into account the positions during the next inspection.
3	Positions need to be changed in the near future.
4	Positions need to be changed immediately.

2.2 RULA

Rapid Upper Limb Assessment (RULA) is an ergonomic method for assessing the risk of work posture of the upper limbs, which includes the load on the neck, upper limbs, and torso. The method was developed in 1993 by Corlett and Mc Atamney based on research on the loads on the upper limbs and back. REBA evaluates the positions of the upper arm, lower arm and wrists (Group A), neck, trunk and legs (Group B). The method evaluates the posture of various body parts, loads, and muscle activity. Evaluation is performed by assessing the deviation of individual body parts from the neutral position of a human and then calculating the risk (scale 1-7) based on the assessment. The REBA method defines four action levels (1-4) into which the final ratings (1-7) are divided. For each level, the urgency of changes is determined (Table 2). Action level 1 means acceptable posture over a non-repeating longer period of time, action level 2 means additional analysis and possible changes, action level 3 means re-analysis and introduction of changes in the short term, and level 4, immediate analysis and change [8].

Table 2. Action Level for RULA [8]

Action Level	Necessary Changes
Action Level 1	A score of 1 or 2 indicates that posture is acceptable if it is not maintained or repeated for long periods
Action Level 2	A score of 3 or 4 indicates that further investigation is needed and changes may be required.
Action Level 3	A score of 5 or 6 indicates that investigation and changes are required soon.
Action Level 4	A score of 7 indicates that investigation and changes are required immediately.

2.3 REBA

Rapid Entire Body Assessment (REBA) is a method for assessing the risk of the entire body, which identifies critical work postures. It was developed by McAtamney and Hignett as a tool to assess the risk of musculoskeletal disorders (WRMSD) based on the posture of the entire body. Initially, it was used by doctors in the field to determine critical health care situations. It is necessary to determine the positions of the individual body parts that are most stressed. Ratings are assigned by measuring the deviation angles of each human limb, and these ratings are then adjusted based on the type of muscle activity, the quality and type of object grip, and then we calculate the total rating. The REBA method offers an assessment on a scale of 1-15 (Table 3), where the scores are categorized into five action levels (0-4). For each level, a risk level for the development of musculoskeletal disorders and actions are determined. Level 1 has negligible risk and no actions are needed, level 2 has low risk with possible actions, level 3 has medium risk with necessary actions, level 4 has high risk, actions will be needed soon, and level 5 has high risk with immediate actions [8].

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Table 3. Action Level for REBA [8]

Action Level	Score	Risk Level	Action
0	1	Negligible	None Necessary
1	2-3	Low	May Be Necessary
2	4-7	Medium	Necessary
3	8-10	High	Necessary Soon
4	11-15	Very High	Necessary Now

2.4 Digital Ergonomic Assessment

Digital ergonomics refers to the use of digital models and methodologies for designing, implementing, and improving products and work systems. The focus of the study is on the human being and the related anthropometry and biomechanical characteristics, which are complemented by posture and movement analyses performed with the help of sensor-supported technologies and simulation tools. Traditional ergonomic assessments (OWAS, RULA, REBA) are based on observation and manual analysis. Compared to digital ergonomics, this approach is less expensive, but it is subjective and requires more time. The advantages of digital ergonomics are automated data analysis, greater accuracy, and objectivity. Ergonomic methods can be performed with simulation software that automatically provides assessments based on captured movement data. In industry, digital ergonomic assessment is increasingly used to monitor and analyse workloads during task execution, allowing for an objective evaluation.

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3 Material and Methods

In this study, the Xsens Motion Capture system was used to collect real-time data for digital ergonomic analyses. The data obtained from the sensors was processed with MVN Analyze Pro 2024.2 software to generate a human biomechanical model. The generated motion data and digital human model were transferred to the Process Simulate environment, which enables the creation of a digital replica as well as ergonomic analysis.

3.1 Research Framework

The purpose of this study is to perform digital ergonomic analysis on real-time data from wearable motion capture systems using the Xsens, MVN Analyze Pro 2024.2 and Process Simulate v2502 software packages. Xsens MVN Analyze Pro 2024.2 is a portable inertial motion capture system designed to record full-body movements. The system, which consists of 17 wireless motion trackers and a suitable suit, generates real-time graphical output, including joint angles [9]. The sensors measure angular velocity, linear acceleration, and magnetic orientation, which are then combined with sensor fusion algorithms to calculate segment orientation, joint angles, and 3D position [10]. Process Simulate is simulation software included in the Tecnomatix platform that can create a digital equivalent of the physical production line by modelling production processes and simulating operation sequences in a digital environment. The software's Human module includes planning, simulation, and optimization of tasks, optimization and simulation of assembly/process, and ergonomic analysis for human-centred operations, contributing to in safer and more efficient workplaces [11]. For the case study, two physical workstations were initially created in a designated laboratory setting. In these work environments, ergonomic data from the worker was collected using wearable technologies through repetitive tasks performed for 10 minutes following a defined workflow. The two workstations were then digitally simulated using the Process Simulate software package. Data collected from real-world workspaces using Xsens sensors and the MVN Analyze Pro 2024.2 were transferred to digital workspaces after calibration, and OWAS, REBA, and RULA analyses were performed. The workflow of the study is illustrated in Figure 1.

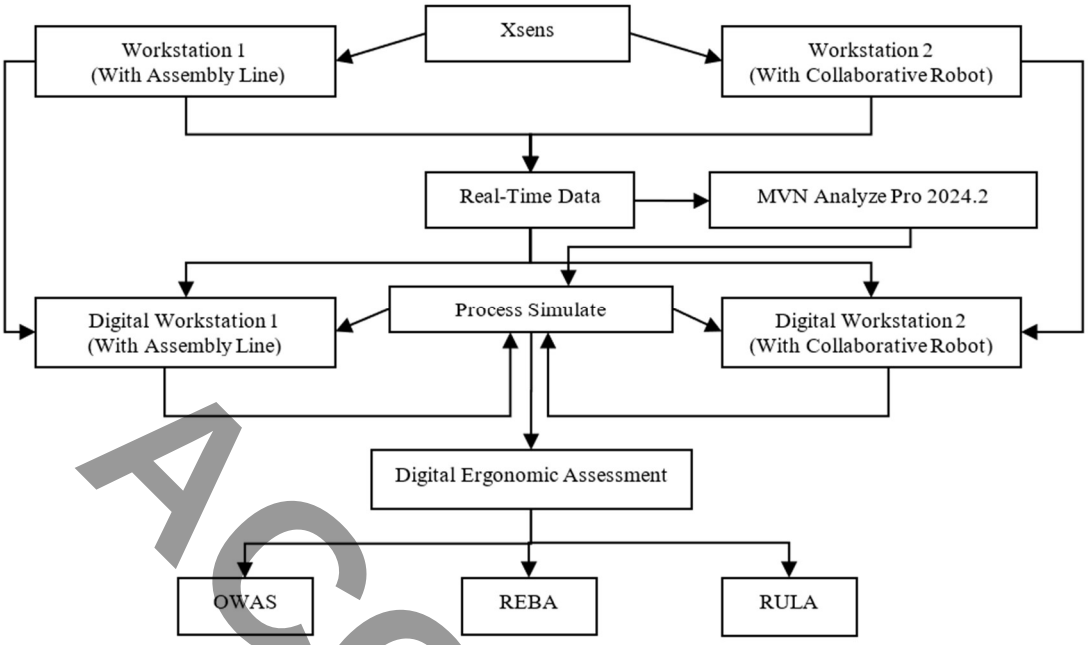


Figure 1. Workflow of the Study

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3.2 Research Environment

Within the scope of the study, two separate work setups were created in a controlled environment. In the first setup, the worker takes materials (0.1 gr) from the right and left sides of the workbench and performs the first assembly. After the assembled part is placed on the table, the second assembly is performed. After both assemblies are completed, these sub-parts are mounted onto the main part that arrives via the assembly line. If there is a black mark on the main part, the product is placed in the right container; if there is no black mark, it is placed in the left container, thus completing the process. The first work setup created is shown in Figure 2.

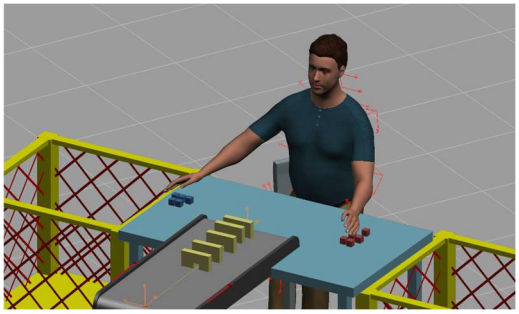


Figure 2. Workstation-1's Environment

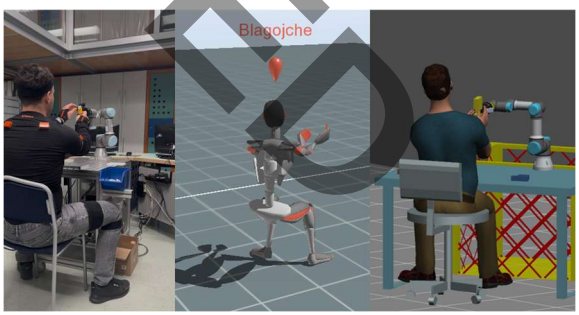


Figure 3. Workstation-2's Environment

In the second work setup, the worker activates the collaborative robot via a button to orient it towards the assembly position. While the robot changes position, the worker takes a part from each of the containers located on the right and left edges of the workbench and performs the first assembly. After the assembled part is placed on the workbench, parts are again taken from the containers for the second assembly. Once the second assembly is complete, the lower part on the table is taken and mounted onto the main part held by the robot, and the process is finished. The second work setup created is shown in Figure 3. The study was conducted with a single subject whose demographic characteristics were defined as 25 years of age, 1.824 m height, and 92 kg weight. The Process Simulate Human module provides a digital human model based on the ANSUR II anthropometric database for male users. Therefore, the generated digital male model was calibrated according to the subject's anthropometric characteristics.

4 Results

4.1 Workstation-1 Results

4.1.1 Workstation-1 Ergonomic Metrics Result

Ergonomic metric analysis shows the flexion, extension, rotation, and lateral bend angles for the neck and back; the flexion, extension, and supination/pronation angles for the left and right wrists; the flexion, extension, abduction, and humeral rotation angles for the left and right shoulders; and the flexion angles for the left and right elbows, as well as the duration for each joint to remain in these angles throughout the worker's work cycle. Workstation 1 had only four significant risky angles: neck extension (>20°), back axial twist (>20°), left wrist radial/ulnar (>20°), and left elbow flexion (>100°). In the neck region, the extension angle was observed to be 5-20° for 73% of the work cycle and 20° or more for 1%; the rotation angle was observed to be 5-20° for 76% of the work cycle and 20° or more for 2%. In the back region, the extension angle is observed to be 5-20° for 40% of the work cycle; the axial twist angle is 5-20° for 54% of the work cycle and 20° for 1%. For the left wrist, the radial/ulnar deviation angle is 5-20° for 30% of the work cycle and 20° and above for 36%; for the right wrist, the supination/pronation angle is 30-65° for 19% of the work cycle and 65° and above for 4%; the radial/ulnar deviation angle is 10-20° for 27% of the work cycle and 20° and above for 9%. In addition, the flexion angle for the left and right elbows is 60-100° for more than 50% of the work cycle, and for the left elbow it is 100° and above 8% of the work cycle. All ergonomic metrics are shown in Figure 4 for all body parts.

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Figure 4. Ergonomic Metrics for Workstation-1

4.1.2 Workstation-1 OWAS Results

The OWAS analysis for Workstation-1 was calculated automatically using data obtained from Xsens for the entire process and performed according to posture angles. Results revealed that the highest score observed during the 10-minute workflow process was four. Most scores were classified as Category 1, indicating insignificant risk. As a result, the evaluation was limited to scores ranging from 2 to 4, with 115 observations obtained for scores in these categories. According to the analysis, 72.2% (83 observations) of the observed postures were classified as Category 2, 21.7% (25 observations) as Category 3, and 6.1% (7 observations) as Category 4. The findings show that the defined workflow involved mostly moderate ergonomic risk, with occasional high-risk postures necessitating corrective action. Based on the duration of the session and the recording frame, the posture combination scores and the action category score, are shown in Table 4.

Table 4. Workstation-1 OWAS Analysis Results

				Code Posture Combination					
Time (Sec)	**Operation**	**Object Weight (kg)**	**Action Category**	**Back**	**Arms**	**Legs**	**Load**	**-**	**Head**
80.8	Frame 859	0	3	3	1	4	1	-	1
103.79	Frame 1105	0	3	3	1	4	1	-	1
119.13	Frame 1268	0	3	3	1	4	1	-	1
154.47	Frame 1645	0	3	3	1	4	1	-	1
170.2	Frame 1813	0	3	3	1	4	1	-	1
170.87	Frame 1820	0	3	2	1	4	1	-	1
174.23	Frame 1856	0	3	3	1	4	1	-	1
174.83	Frame 1862	0	3	2	1	4	1	-	1
241.44	Frame 2573	0	3	3	1	4	1	-	1
241.87	Frame 2577	0	4	4	1	4	1	-	1
245.1	Frame 2612	0	3	2	1	4	1	-	1
246.43	Frame 2626	0	3	2	1	4	1	-	1
249.83	Frame 2662	0	3	3	1	4	1	-	1
250.67	Frame 2671	0	3	2	1	4	1	-	1
258.67	Frame 2756	0	3	2	1	4	1	-	1
258.69	Frame 2757	0	4	4	1	4	1	-	1
258.77		0	3	3	1	4	1	-	1
259.5	Frame 2765	0	3	2	1	4	1	-	1
260.76	Frame 2779	0	3	2	1	4	1	-	1
263.63	Frame 2809	0	3	2	1	4	1	-	1
264.97		0	3	2	1	4	1	-	1
277.64	Frame 2959	0	4	4	1	4	1	-	1
277.7		0	3	3	1	4	1	-	1
298.2	Frame 3177	0	3	4	2	1	1	-	5
299.13	Frame 3187	0	3	4	2	1	1	-	5
323.57	Frame 3447	0	4	4	1	4	1	-	1
323.6	Frame 3448	0	3	3	1	4	1	-	1
325.43	Frame 3467	0	4	4	1	4	1	-	1
326	Frame 3473	0	3	3	1	4	1	-	1
326.07	Frame 3474	0	4	4	1	4	1	-	1
328.97	Frame 3505	0	3	3	1	4	1	-	1
329.43	Frame 3510	0	4	4	1	4	1	-	1

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4.1.3 Workstation-1 REBA Analysis Results

REBA analysis was performed on a single posture (149.22 sec). For the analysis, addforce/load and coupling scores were manually selected and evaluated. As a result of the analysis, the left REBA score was determined as 8 and the right REBA score as 5. The risk level for the left extremity was determined as high, requiring immediate intervention; for the right extremity, it was determined as 5, requiring intervention.

Left REBA Score:			8
Action Level	REBA Score	Risk Level	Action (including further assessment)
0	1	Negligible	None necessary
1	2 or 3	Low	May be necessary
2	4 to 7	Medium	Necessary
3	8 to 10	High	Necessary soon
4	11+	Very High	Necessary NOW

Right REBA Score:			5
Action Level	REBA Score	Risk Level	Action (including further assessment)
0	1	Negligible	None necessary
1	2 or 3	Low	May be necessary
2	4 to 7	Medium	Necessary
3	8 to 10	High	Necessary soon
4	11+	Very High	Necessary NOW

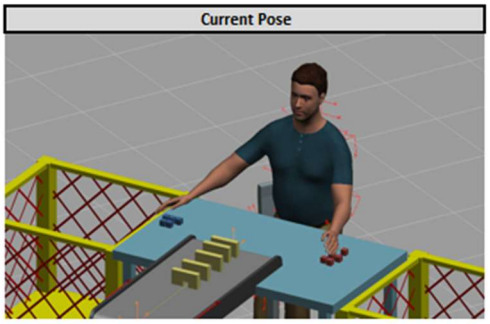


Figure 5. Workstation-1 Worker's Posture for REBA Analysis (149.22)

4.1.4 Workstation-1 RULA Analysis Results

The RULA analysis, like REBA analysis, for Workstation-1 was conducted on a risky posture (149.22 seconds) with an OWAS score of 4, as it could not be performed for the entire process. Figure 5 also shows the worker's posture for 149.22 seconds for RULA analysis. During the analysis, posture angles collected with Xsens were automatically determined, while muscle use and forced use scores were manually selected and evaluated. Figure 6 depicts separate scores for the right and left upper extremities. According to the analysis results, the score determined as a risky category in OWAS was also calculated as 6 for the right extremity and 7 for the left extremity in the RULA analysis. In accordance with the score results, the right side indicates high risk and requires immediate correction, while the left side indicates extremely high risk and requires immediate intervention.

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TABLE C Right							
Final A Score	Final B Score						
	1	2	3	4	5	6	7+
1	1	2	3	3	4	5	5
2	2	2	3	4	4	5	5
3	3	3	3	4	4	5	6
4	3	3	3	4	5	6	6
5	4	4	4	5	6	7	7
6	4	4	5	6	6	7	7
7	5	5	6	6	7	7	7
8+	5	5	6	7	7	7	7

TABLE C Left							
Final A Score	Final B Score						
	1	2	3	4	5	6	7+
1	1	2	3	3	4	5	5
2	2	2	3	4	4	5	5
3	3	3	3	4	4	5	6
4	3	3	3	4	5	6	6
5	4	4	4	5	6	7	7
6	4	4	5	6	6	7	7
7	5	5	6	6	7	7	7
8+	5	5	6	7	7	7	7

Figure 6. Workstation-1 RULA's Final Left and Right Scores

4.2 Workstation-2 Results

For Workstation-2, a single cycle duration was used instead of a 10-minute recording. The cycle process was divided into sub-operations based on the task, as shown in Figure 7. The start time and operation duration of each task for a total cycle of 14.64 seconds.

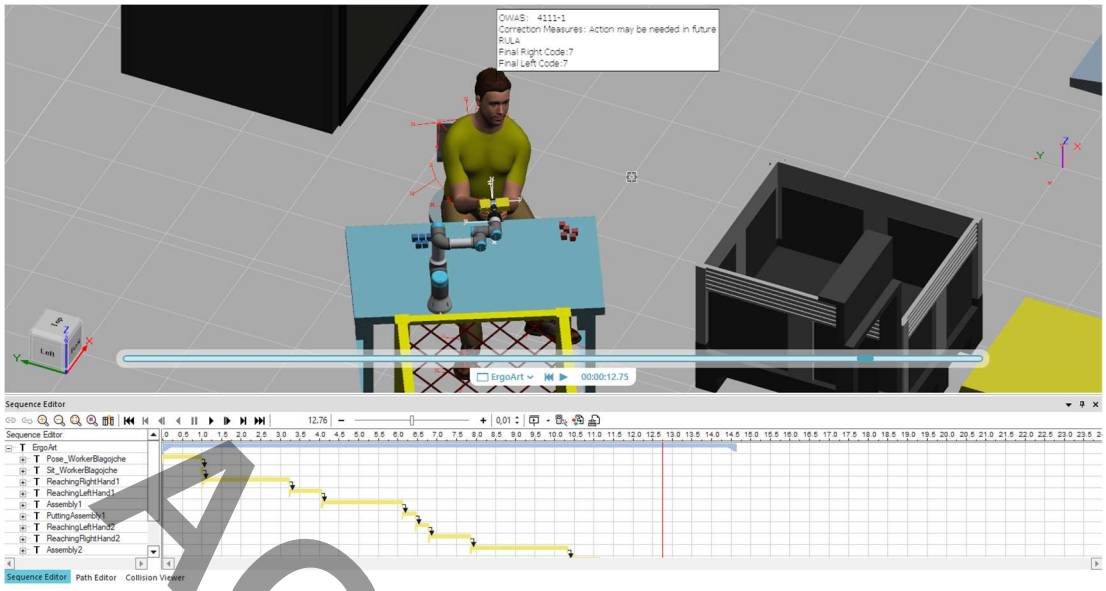


Figure 7. Sub-operations for Workstation-2 on Process Simulate

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4.2.1 Workstation-2 OWAS Results

The same procedures were followed for this process as well, and the entire analysis was performed by the program using Xsens data without requiring manual intervention. Since the process could be broken down into sub-tasks, material weight was also included in the analysis. Since the movement covers a specific range, the material weights grasped at the beginning and end of the task vary, but because materials are very small, they do not affect the score. As a result of the analysis, all sub-task scores were classified as Category 2 and identified as requiring future improvement.

Table 5. Workstation-2 OWAS Analysis Results

Time	Operation	Object	Action	Code Posture Combination					
(Sec)		Weight (kg)	Category	Back	Arms	Legs	Load	-	Head
0-1	Pose_WorkerBlagojche_Pose	0	2	2	1	1	1	-	1
1.03	Sit_WorkerBlagojche_Sit	0	2	2	1	1	1	-	1
1.07-3.23	ReachingRightHand1_Pose	0 - 0.1	2	2	1	1	1	-	1
3.27-4.03	ReachingLeftHand1_Pose	0 - 0.1	2	2	1	1	1	-	1
4.07-6.1	Assembly1_Pose	0.2	2	2	1	1	1	-	1
6.13-6.43	PuttingAssembly1_Pose	0.2	2	2	1	1	1	-	1
6.47-6.8	ReachingLeftHand2_Pose	0 - 0.1	2	2	1	1	1	-	1
6.83-7.83	ReachingRightHand2_Pose	0 - 0.1	2	2	1	1	1	-	1
7.87-10.33	Assembly2_Pose	0.1 - 0.2	2	2	1	1	1	-	1
10.37-11.17	GettingAssembly_Pose	0.2 - 0.4	2	2	1	1	1	-	1
11.2-13.67	CollaboratingRobotHuman_Pose	0.4 - 0	2	2	1	1	1	-	1
13.7-14.63	ButonInteraction_Pose	0	2	2	1	1	1	-	1

4.2.2Low Back Demands

For the defined workstations, Low Back Analysis was performed as a supporting analysis, even though the back flexion remained within the 0-20° limits and the material was very small, resulting in a value well below the limits. As shown in Figure 8, the analysis results show Compression 1236 N (Limit: 3400 N), Anterior/Posterior Shear 200 N (Limit: 700 N), and Lateral Shear -5 N (Limit: 700 N), which are below the recommended limits for low back compressive and shear forces.

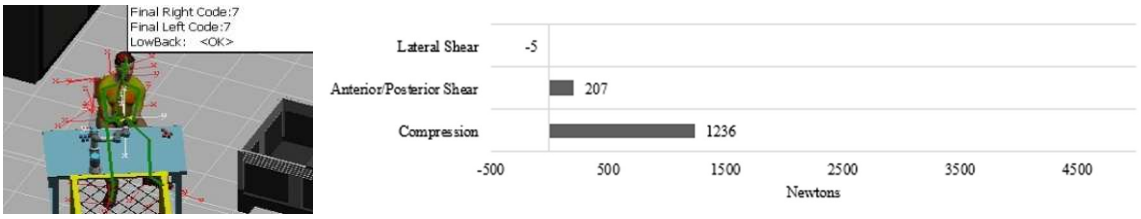


Figure 8. Low Back Analysis for Workstation-2 and L4/L5 Forces

5 Conclusion

Within the scope of the study, two different work environments were designed, and ergonomic posture data was collected using Xsens motion capture systems. Then, digital copies of the work areas were created using the Process Simulation program. Based on the workflows created, Ergonomic Metric Analysis, OWAS, RULA, REBA, and supporting low back demand analyses were performed on the worker. According to the ergonomic metric results for the first work area, the riskiest angles were found for the right and left wrists. The worker performs work in a seated position, using their hands and arms in cooperation with robots, and exceeding an angle of >20 degrees for the left wrist in 30% of the work and for the right wrist in 9% of the work indicates the need for adjustments to the work environment. According to the ergonomic analysis, there are risk factors in the left wrist due to radial/ulnar deviation, in the right wrist due to pronation/supination and radial/ulnar deviation, and in the left elbow due to flexion. To reduce these risks, the part position, working height, and fixture design should be adjusted to support more natural joint positions, and tasks such as turning, aligning, and holding parts by hand should be reduced as much as possible with the help of the robot or simple supporting tools. In the OWAS analysis, most posture scores obtained in a 10-minute work environment were category 1, with 83 observations in category 2, 25 observations in category 3, and 7 observations in category 4. This indicates that while the overall body is mostly in an ergonomic position, there are also some risky positions. For RULA and REBA analyses, a static evaluation was performed on a posture with a high OWAS score, indicating a left REBA score of 8, a right RULA score of 6, and a left RULA score of 7, requiring immediate intervention. The OWAS results show that some postures in the work cycle still need improvement, especially those in Categories 3 and 4. To reduce these positions, the workstation layout, working height, and material location should be rearranged. The REBA and RULA results also show that changes are needed, particularly for the upper body. For this reason, the fixture design, part position, and the way tasks are shared between the worker and the robot should be improved to help the worker keep the wrists, elbows, and arms in a more natural position and reduce repetitive manual work. For work area 2, a more customized work cycle was used, and OWAS and low back demand analyses were performed. Unlike work area 1, work area 2 contains no risky positions. The low back demand analysis was conducted as a supporting analysis, and since the work was performed while sitting, it remained below the defined limits. The study showed that motion capture systems can be used effectively in ergonomic analyses by reducing manual workload and limiting subjective evaluation. Another advantage is that, during repetitive tasks, these systems continuously record posture data and make it possible to determine which postures workers spend more time in, providing more useful results than static measurements. For this reason, motion capture systems may offer a more consistent and detailed approach to ergonomic assessment than manual measurement methods. However, the use of such systems in industrial settings may still be influenced by practical factors such as equipment cost, training needs, calibration procedures, data processing steps, and the need for technical knowledge. In addition, worker acceptance and the compatibility of the system with existing production processes are also important for successful implementation. Since the study was conducted with only one participant, this should be considered a limitation in terms of the generalizability of the findings. Future studies including a larger number of participants would provide more reliable and broadly applicable results.

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