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An Ergonomic Evaluation of Working Posture among Palletizing Workers Based on the Digital Human Modeling Using CATIA

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Abstract

Palletizing is an important job in logistic operations. It is considered an extremely labor-intensive process when performed manually, as it includes awkward and repetitive working postures, which result in serious back injuries. This paper introduces a new assistive device that helps reduce the exposure to physical loads among palletizing workers. The risk factors associated with manual palletizing in the food industry were analyzed using the Rapid Upper Limb Assessment (RULA) method. Different postures were observed during manual palletizing in a food factory that had a RULA score of 7. An assistive device was proposed to improve the palletizing operation. As a result, after implementing the proposed assistive device, the RULA final score was dropped to 4 based on lifting at the elbow height of the pallet, 3 when lifting at low and medium heights of the loaded pallet during wrapping, and 4 when lifting at the highest point of the full pallet. In conclusion, the proposed assistive device helped improve the palletizing job and reduce its negative consequences for workers.

Keywords
Digital human modeling, RULA, Palletizing, Musculoskeletal disorders (MSDs), Jordan

1. Introduction
Palletizing is one of the major logistic processes that plays an important role in the transportation and storage of different types of products, as it simplifies handling and space utilization (Vargas-Osorio & Zúñiga, 2016). Pallets are the most fundamental unit of loading and transportation across the entire logistic activities around the world (Chen, et al., 2018). Manual palletizing is considered an extremely labor-intensive process, where stacking boxes on a pallet and wrapping each pallet are repetitive jobs and would cause serious injuries to the back and waist (Chen, et al., 2014).

Musculoskeletal disorders (MSDs) are defined as any injury in the head, arms, legs, back, or neck that affect muscles, tendons, joints, ligaments, cartilages, blood vessels, peripheral nerves, and bones (Yao, et al., 2019). The MSDs are one of the main occupational health threats in the industrial sector (Putz-Anderson, et al., 1997). They are the result of work-related tasks such as carrying, pulling, pushing, lifting, etc. Many of the workplace's musculoskeletal injuries are the result of slip-related falls, large proportion of these falls occurred while load carrying (Yang, et al., 2022).

Those musculoskeletal injuries that result from manual handling are usually associated with workers' physical damage, along with financial costs (Proud, et al., 2020).

The most popular biomechanical risk factors that might cause MSDs are excessive repetitive movements, extreme forces, heavy weights, awkward postures, prolonged static workloads, and manual material handling (Costa & Vieira, 2010). The MSDs affect occupational health, productivity, and workers' mental and physical performance, which lead to economic losses to both the worker and the community (Shikdar & Das, 1995). Workers in the palletizing sector are exposed to MSDs, especially low back pain due to lifting, lowering, pushing, pulling, carrying, etc. (Burdorf & Sorock, 1997). Based on the United States Bureau of Labor Statistics, in only the warehousing and storage sector, the total number of days spent away from work that resulted from overexertion and physical reaction was increased from 2016 by 1,350 cases, to 8,310 in 2017 (BLS, 2018). In addition, transportation and material handling workers incurred 12,750 cases in 2017, with an increase of 3,120 cases from 2016 (BLS, 2018).

To date, no research has considered the combination of mechanical design and the development of a palletizing assistive device, with the physical exposure of workers, for stacking and wrapping purposes, in terms of ergonomics consideration, best and worst case scenarios of using the device, device simplicity, availability, and low cost. Even though automation has been adopted to assist workers and reduce the physical workload, there is still a need to develop simple and inexpensive assistive devices for improving jobs. This study analyzed the risk factors associated with manual palletizing using the Nordic Musculoskeletal Questionnaire (NMQ), and the Rapid Upper Limb Assessment (RULA). In addition, a proposed palletizing assistive device was designed and tested to help improve the palletizing and wrapping operations.

2. Methods and Materials

An international food manufacturing company in Jordan was considered in this study. The NMQ was used to collect data from workers in the company, to assess the pain felt in different parts of the body. Many of the collected observations regarding the most awkward working postures were collected from palletizing workers, who perform manual pallet stacking and wrapping. A total of 12 workers, who were performing pallet stacking, wrapping, or both were asked to complete the questionnaire. Six different awkward postures were considered such as bending, twisting, adduction, and rotation, which were captured regarding 2 kg weight boxes stacking on a pallet. Five awkward postures regarding pallet wrapping were observed by each of those workers. Subsequently, the selected postures were simulated using the CATIA V5 software. Furthermore, the RULA was considered to assess the risk factors. In addition, a new ergonomically based design of an assistive device was sketched and inserted into the CATIA simulation. Then RULA was also reconsidered, while the simulated manikin was lifting boxes on a pallet, and wrapping the entire full pallet considering the best and worst-case scenarios.

2.1 The Digital Human Modeling (DHM)

Digital Human Modeling (DHM) is a digital representation of humans that is added to the simulation or computer-generated environment, to assist safely the performance prediction (Demirel & Duffy, 2007). It relies on the assumption that the majority of work settings regarding products and manufacturing can be designed using advanced computer-aided design (CAD) systems, integrated with computer graphics and three-dimensional (3D) rendering avatars, to represent workspaces and the humans who carry out multiple tasks while assessing many things such as a physical posture, an ergonomic risk, etc. (Chaffin, 2008). The DHM aims to reduce or eliminate the necessity of creating physical prototypes for new products and process design, and allow engineers of different fields to consider ergonomics principles in the early design stages (Duffy, 2008).

2.2 The Simulated Manikin

A manikin has been inserted into CATIA V5 software to simulate the postures that have been captured from the considered factory. The chosen manikin was selected from an American population, male gender and 50th percentile anthropometrics. The American population dimensions were selected rather than those for Jordan since the CATIA V5 software does not have a set of Jordan population dimensions. The 50th percentile was considered to make the American population similar to that of Jordanians. As shown in Figure 1, a number and a measurement indicator are assigned to each body segment, to illustrate the anthropometry that is extracted from the CATIA V5 software library. Table 1 defines the names of the anthropometric measurements shown in Figure 1.

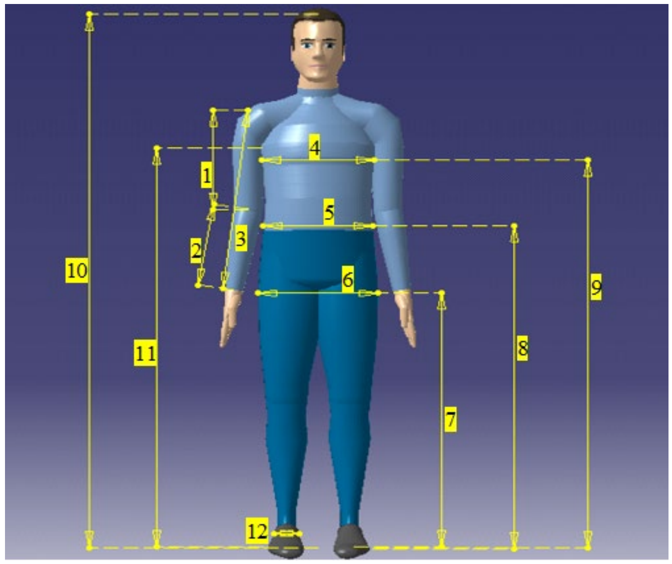


Figure 1. The simulated manikin – 50th percentile.

Table 1. The manikin anthropometrics - 50th percentile, based on the numbers shown in Figure 1.

Number	Variable	Mean (mm)	Stdandard deviation (mm)	Infimum range (mm)	Supremum range (mm)
1	Acromion- radiale length	340.8	17.2	272.0	409.6
2	Radiale-stylion length	269.9	15.7	207.1	332.7
3	Sleeve outseam	601.5	30.7	478.7	724.3
4	Chest breadth	321.5	25.5	219.5	423.5
5	Waist breadth	309.3	28.7	194.5	424.1
6	Hip breadth, standing	341.8	20.3	260.6	423.0
7	Crotch height, standing	837.2	46.2	652.4	1022.0
8	Waist height, omphalion	1058.8	50.9	855.2	1262.4
9	Chest height, standing	1275.9	56.1	1051.5	1500.3
10	Stature	1755.8	66.8	1488.6	2023.0
11	Axilla height	1320.9	58.0	1088.9	1552.9
12	Bimalleolar breadth	72.8	3.9	57.2	88.4

2.3 The Nordic Musculoskeletal Questionnaire (NMQ)

The NMQ was distributed to 12 workers who perform pallet stacking, wrapping or both in the selected factory. The questionnaire was divided into four sections: 1) Demographic questions, 2) questions related to pain faced in different parts of the human body, 3) questions related to the high prevalence of MSDs among manual palletizing within the last 12 months, and 4) questions related to MSDs in any time in the last 7 days. Two males and 10 females answered the questions. This male-female ratio was due to that the factory workers were mainly females. The average age of participants was 27.5 years, the average stature was 162.8 cm, and the average weight was 66.8 kg. The participants were working in the selected factory for an average of 51 hours per week (this includes the part-time duties). Four of the participants were performing pallet stacking, three of them were performing pallet wrapping and the rest were practicing both jobs, pallet stacking and wrapping jobs.

2.4 Rapid Upper Limb Assessment (RULA)

The RULA was introduced to be used for ergonomic examinations of workplaces wherever work-related upper limb disorders exist. It is a simple survey approach that does not require special equipment; to perform a rapid assessment of the neck, trunk, and upper limbs' postures accompanied with muscle performance and external workload accomplished by the body (McAtamney & Corlett, 1993). Furthermore, a coding framework is followed to create an action list that demonstrates the intervention level required, to minimize the risks of having injuries due to excessive physical workload on the worker (McAtamney & Corlett, 1993). In RULA, the assessment of workers is performed to understand the job duties and tasks, demands, workers' posture and movements during the work (Chaudhary & Singh, 2012). Therefore, the process of selecting a posture must be done by considering the most awkward postures and occupational duties, the posture that is maintained for the longest period, and the posture that requires the highest force.

The following steps are the working posture assessment of each processed task, as stated in the RULA method (Djiono & Noya, 2013). Furthermore, Table 2 shows the action levels based on (Stanton, et al., 2005).

Group A posture assessment (upper arm, forearm, wrist, and wrist twist).
Assigning the scores of muscle use and forces to group A.
Group B posture assessment (neck, trunk, and legs).
Assigning the scores of muscle usage and forces to group B.
Identifying RULA grand score and action level.

Table 2. The RULA scores and action levels.

Action level	Score value
1	Scores 1 or 2 indicate that the posture is acceptable if it is not maintained or repeated for long periods
2	Scores of 3 or 4 indicate that further investigation is needed, and changes may be required
3	Scores of 5 or 6 indicate that investigation and changes are required soon
4	Score of 7 indicates that investigation and changes are required immediately

The RULA scores in CATIA V5 software are divided into two sections: Posture A, which represents the upper arm, forearm, wrist and wrist twist, and Posture B, which represents the neck, trunk and legs. Each body segment has its risk factor according to a defined score range and color code as shown in Table 3. In addition, the CATIA V5 software provides the final score values in the range 1-7. These score values are 1-2 (green) indicating an acceptable posture, 3-4 (yellow) indicating that a further investigation is required and changes might be required (low risk), 5-6 (orange) indicating an investigation and some changes could be required soon (medium risk), 7 (red) indicating an investigation and changes are required immediately (very high risk).

Table 3. The RULA scores and the color code in CATIA V5 software.

Segment	Score range	Color associated to the score					
		1	2	3	4	5	6
Upper arm	1-6						
Forearm	1-3						
Wrist	1-4						
Wrist twist	1-2						
Neck	1-6						
Trunk	1-6						

2.5 Design Description

The CATIA V5 software was used to sketch a proposed assistive palletizing device. The device is a set of two apparatuses as shown in Figure 2. The first one helps with the process of pallet stacking (the one to the left side in Figure 2), while the second one helps in pallet wrapping (the one to the right side in Figure 2). The pallet-stacking device was assembled from a flat circular steel top plate. Thus the pallet could be placed on a bearing for the top plate, which could be rotated separately from a screw, flange to be inserted into the screw from the bottom side, to connect the top plate and the pallet with the screw, and from the upper side that is attached to bearing, which rotates the screw jack, which consists of screw, worm gears, shaft and pedal or motor. The screw moves vertically, up and down, driven by the shaft that is connected from one side to the gears, and the pedal or motor from the other side. The pallet-wrapping device consisted of a rod from the floor to the top of the fully loaded pallet, with a wrapping dispenser attached. The wrapping dispenser moves the plastic sheet roll vertically, up and down, based on the required height of the pallet to be wrapped. After sketching the proposed device shown in Figure 2, it was inserted into the ergonomic design and analysis in CATIA V5, to analyze the posture of the worker while using the device and perform the comparison, (before and after inserting the proposed assistive device).

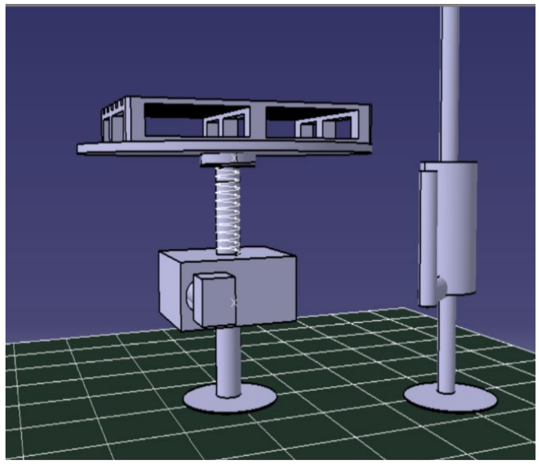


Figure 2. The proposed design illustration of the pallet stacking and wrapping assistive device.

3. Results and Discussion

3.1 The Nordic Musculoskeletal Questionnaire

The NMQ results for the 12 months part showed that workers have reported that they have been prevented from doing their normal work due to MSDs, with high prevalence to their lower back and shoulders, neck and upper back, ankles/feet, wrist/hands, hips/thighs, and knees in sequence, while the lowest was in the elbow. Regarding the NMQ results for the 7 days part, a high prevalence of MSDs was found in the worker's lower back, neck, shoulders, elbows, hips/thighs, and ankles/feet in sequence, while the lowest parts were in the wrists/ hands, upper back and knees. Overall, the most affected body parts were the worker's lower back, shoulders, and neck in both the 12 months and the 7 days parts of NMQ.

3.2 The RULA Scores

The RULA analysis was conducted on each of the observed and simulated postures, during pallet stacking and wrapping, with and before and after the use of the proposed assistive device in different important scenarios. The RULA results are illustrated in the following subsections.

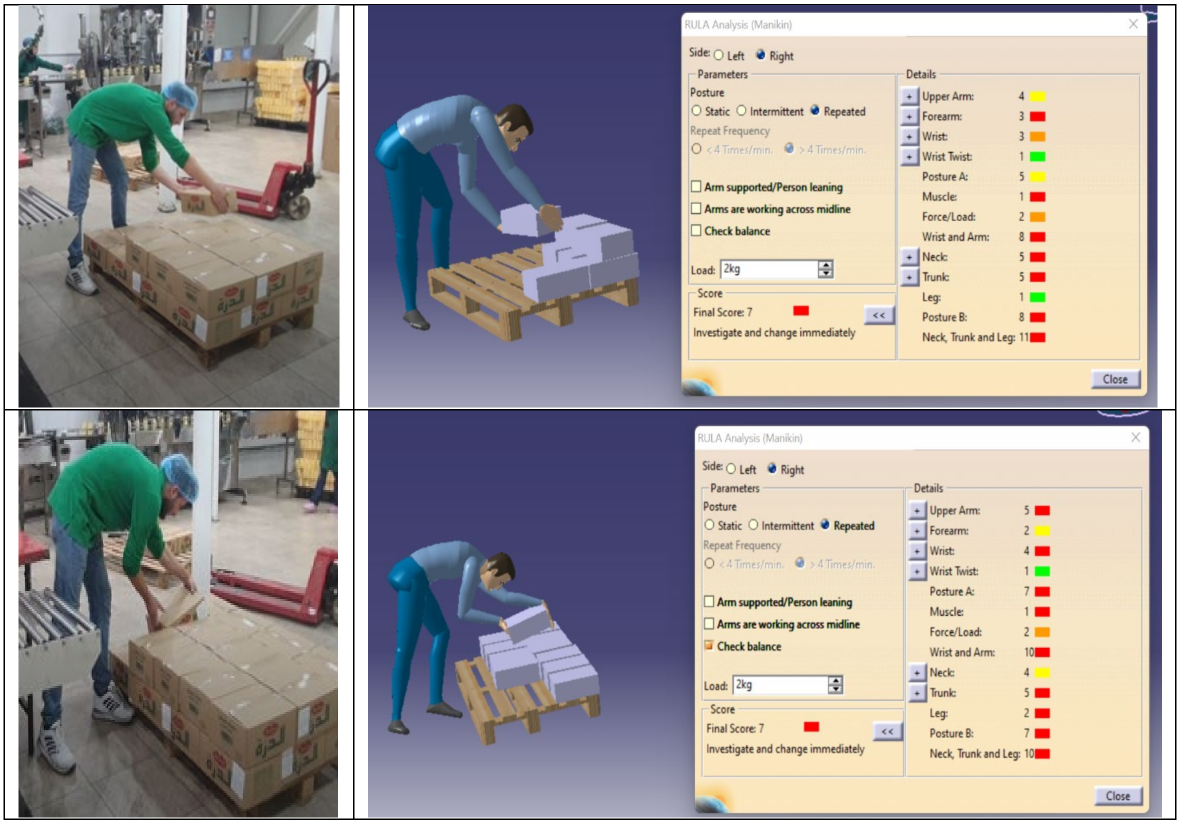
3.2.1 The RULA Scores of the Observed Postures during Pallet Stacking

After simulating the six observed body postures in the factory that are shown in Table 4, the right side of the manikin, and the repeated posture of lifting a 2-kg load (more than 4 times/ minute) were considered. As shown in Table 4, all of the simulated postures in the pallet stacking process had a final RULA score of 7 (very high risk), indicating that additional investigations and immediate change are required.

Table 4. The RULA scores of the observed postures - pallet stacking.

Observed posture	Simulated posture


RULA Analysis (Manikin)
Side: Left Right
Parameters
Posture
Static Intermittent Repeated
Repeat Frequency
< 4 Times/min. > 4 Times/min.
Arm supported/Person leaning
Arms are working across midline
Check balance
Load: 2kg
Score
Final Score: 7
Investigate and change immediately
Details
Upper Arm: 5
Forearm: 3
Wrist: 3
Wrist Twist: 1
Posture A: 7
Muscle: 1
Force/Load: 2
Wrist and Arm: 10
Neck: 5
Trunk: 5
Leg: 2
Posture B: 8
Neck, Trunk and Leg: 11
Close
RULA Analysis (Manikin)
Side: Left Right
Parameters
Posture
Static Intermittent Repeated
Repeat Frequency
< 4 Times/min. > 4 Times/min.
Arm supported/Person leaning
Arms are working across midline
Check balance
Load: 2kg
Score
Final Score: 7
Investigate and change immediately
Details
Upper Arm: 5
Forearm: 3
Wrist: 2
Wrist Twist: 1
Posture A: 6
Muscle: 1
Force/Load: 2
Wrist and Arm: 9
Neck: 5
Trunk: 5
Leg: 2
Posture B: 8
Neck, Trunk and Leg: 11
Close
RULA Analysis (Manikin)
Side: Left Right
Parameters
Posture
Static Intermittent Repeated
Repeat Frequency
< 4 Times/min. > 4 Times/min.
Arm supported/Person leaning
Arms are working across midline
Check balance
Load: 2kg
Score
Final Score: 7
Investigate and change immediately
Details
Upper Arm: 4
Forearm: 2
Wrist: 3
Wrist Twist: 1
Posture A: 4
Muscle: 1
Force/Load: 2
Wrist and Arm: 7
Neck: 5
Trunk: 5
Leg: 2
Posture B: 8
Neck, Trunk and Leg: 11
Close
RULA Analysis (Manikin)
Side: Left Right
Parameters
Posture
Static Intermittent Repeated
Repeat Frequency
< 4 Times/min. > 4 Times/min.
Arm supported/Person leaning
Arms are working across midline
Check balance
Load: 2kg
Score
Final Score: 7
Investigate and change immediately
Details
Upper Arm: 4
Forearm: 3
Wrist: 4
Wrist Twist: 1
Posture A: 6
Muscle: 1
Force/Load: 2
Wrist and Arm: 9
Neck: 5
Trunk: 5
Leg: 1
Posture B: 8
Neck, Trunk and Leg: 11
Close



The RULA analysis has been conducted after inserting the proposed assistive device into the ergonomic simulation in CATIA V5. The height of the device was designed based on the elbow height of the 95th percentile (1,250 mm). This was done to provide the device the freedom to move up and down, thus shorter workers might adjust the height based on their anthropometric measurements to be more comfortable. Figure 3 shows the use of the proposed device during pallet stacking in the best-case scenario. The results showed that the final RULA score was 4 of the worker, who was lifting 2 kg boxes, when the boxes were at the elbow height of the worker, indicating low risk and changes may be required. However, the final score for 4 could be related to the fact that the worker was lifting a load in a repeated posture, if the load's value was reduced to 1.5 kg or the type was intermittent rather than repeated, then the RULA final score would be decreased into 2, indicating that the posture is acceptable.

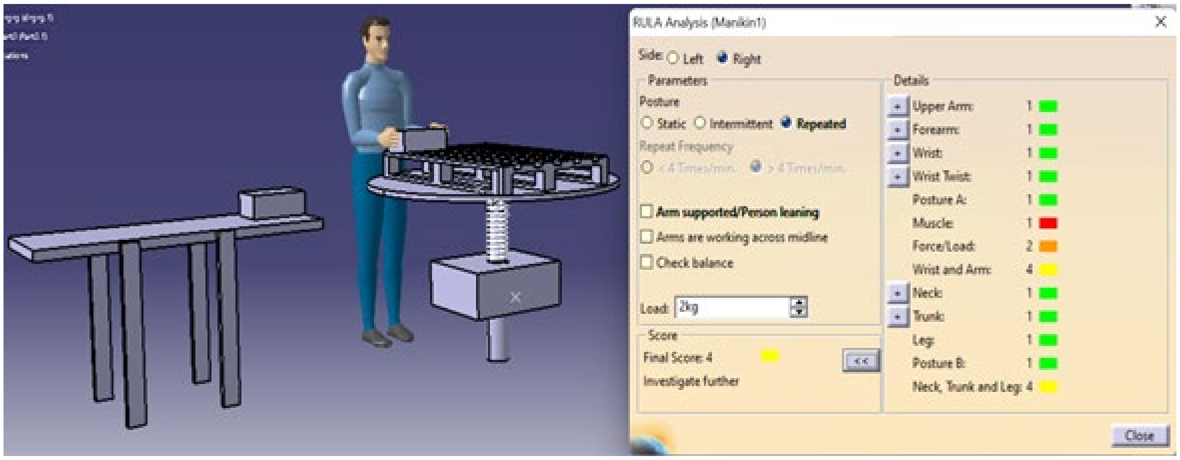


Figure 3. The RULA final score using the assistive device during pallet stacking (best-case scenario).

3.2.2 The RULA Final Scores with and without the Use of the Assistive Device during Pallet Stacking (Worst-case Scenario)

The worst-case scenario of the pallet stacking is at the maximum pallet height (1,400 mm). Figure 4 shows the result of the CATIA V5 simulated manikin of an observed posture in the factory during pallet stacking, where the pallet is placed on the floor. The final RULA score was 5 (medium risk), indicating that investigation and changes are required soon.

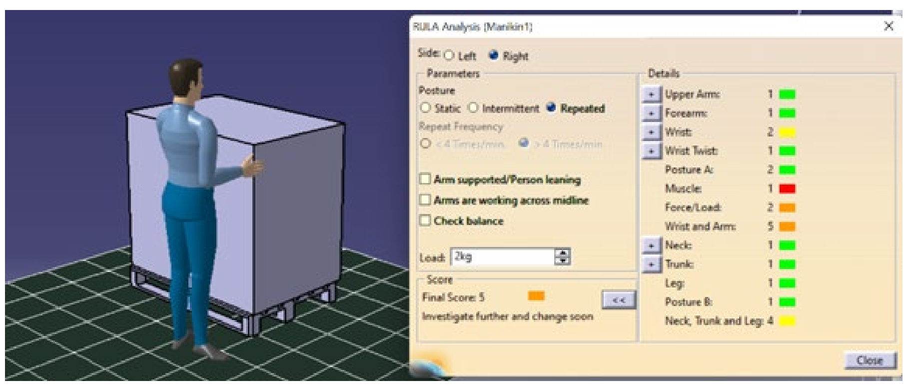


Figure 4. The RULA score without using the assistive device during pallet stacking (worst-case scenario).

According to the previously mentioned worst-case scenario, the RULA was applied to the worker's posture, while stacking boxes on the highest point on the top of the fully loaded pallet, after using the assistive device as shown in Figure 5. The results showed that for the 50th percentile of workers, the RULA final score on the right side of a repeated posture was 6 (medium risk), indicating additional investigations and changes are required. However, for the 95th percentile of workers, as shown in Figure 6, the final RULA score was 5 (medium risk), given that the worker was taller and reached higher areas that were less dangerous. Under those circumstances, the scores fell into the same category before and after the device insertion, which means that the device did help in the areas located below the elbow, and no changes for the higher ones.

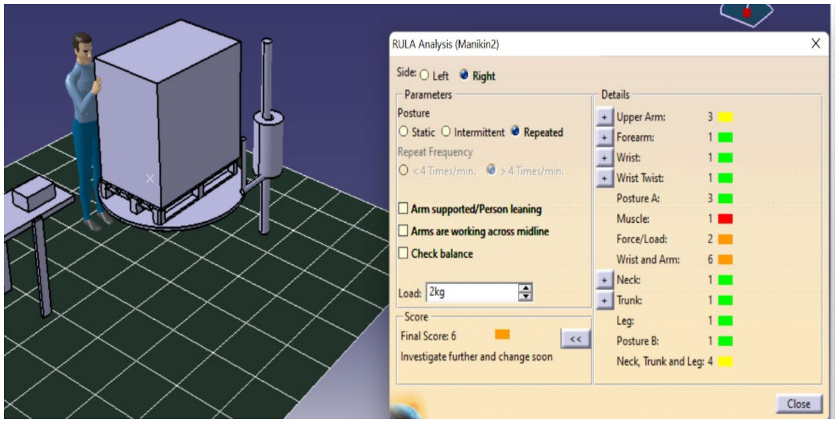


Figure 5. The RULA score with using the assistive device during pallet stacking (worst-case scenario) – 50th percentile of workers.

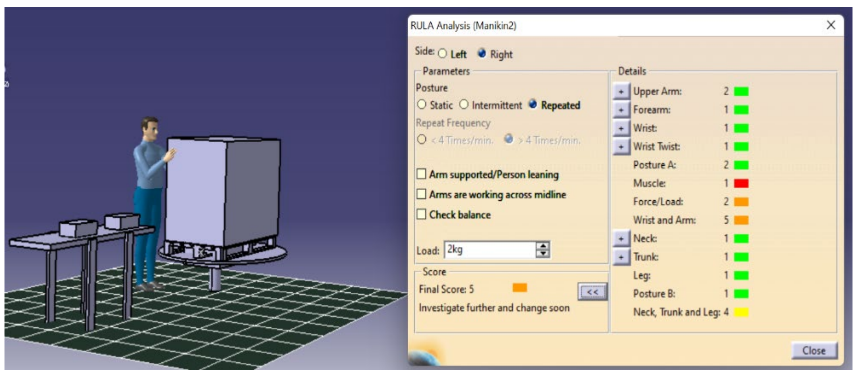


Figure 6. The RULA score when using the assistive device during pallet stacking (worst-case scenario) – 95th percentile of workers.

4. Conclusions

The DHM and simulation using CATIA V5 software were considered in this study, to simulate the postures of a palletizing worker, who works at a food factory in Jordan. An assistive device was proposed to help provide more convenient and comfortable postures for workers, to reduce the physical workload during palletizing. The postures were then simulated. The RULA was applied to study the ergonomic risks. The proposed assistive device was designed and inserted into the CATIA V5 simulation to apply an ergonomic analysis, at the best and the worst case scenarios. The results obtained from this study were as follows:

- Many awkward postures were observed in the factory and simulated while palletizing. The RULA showed that all of the observed postures had a final score of 7 (very high risk). This indicated that an additional investigation and changes are required, immediately.
- A proposed design of an assistive device based on the idea of rotating a screw jack that moves vertically up and down, using either pedal or motor, based on the industry was designed to reduce the workload, considering the elbow height of the 95th percentile male. The design was integrated with a wrapping dispenser that moves up and down on a rod to avoid bending, twisting and many other awkward postures.
- The RULA final score after using the proposed assistive device was reduced to 4 (low risk), based on the best-case scenario (lifting at the elbow height of the worker). However, in the worst-case scenario (lifting boxes to the highest point of a full-height pallet), the final score of an observed posture was 5 (medium risk), which was similar to that of the 95th percentile of the simulated manikin, while using the device, whereas the simulated RULA score of the manikin at the 50th percentile was 6 (medium risk), due to the differences in the anthropometric measurement.

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