Proceedings of the 33rd European Safety and Reliability Conference (ESREL 2023)
Edited by Mário P. Brito, Terje Aven, Piero Baraldi, Marko Čepin and Enrico Zio

doi: 10.3850/978-981-18-8071-1_P567-cd

Approaches to assessing hand and wrist ergonomics in the workplace - a comparative case study

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Physical stress occurs in every activity of the work process. If this load is excessive, it poses a serious problem for the body. As a consequence of the strain, painful problems occur which initially reduce the worker's comfort. Over a long period of time, it already causes a decrease in productivity and thus financial consequences for the employer. Therefore, it is important to take preventive measures and avoid damage to health.
The methods chosen are a key component in the successful implementation of ergonomic assessment and design of work systems. In the case of upper limb ergonomics assessment, the most commonly used methods are index methods evaluated by researchers based on camera footage, simulation of work activities in specialized software, automatic assessment with spatial data capture by optical means, strain gauge method, and automatically integrated electromyography. In recent years, methods for assessing activities in virtual reality (such a method was developed at our workplace) have also started to be used.
This article aims to compare the most commonly used methods for hand ergonomics assessment.

Keywords: Human Factors, Occupational Hazards, Work-related Musculoskeletal Disorders, Ergonomics, Methods.

1. Research area

The main research question is to compare methods for assessing hand and wrist ergonomics in terms of outcome validity, usability and cost?

Some of the reasons for asking this question are:

- identify the strengths and weaknesses of the different methods and select the most appropriate one for the purpose of a quick on-site ergonomics assessment.
- evaluate the validity and reliability of different methods and ensure that they consistently and accurately measure what they are intended to measure.
- compare the usability and user satisfaction of different methods and ensure that they are easy to use, understand and interpret for ergonomists, workers or other stakeholders
- assess the cost-effectiveness of different methods and ensure that they provide a good return on investment in terms of improving hand ergonomics and reducing musculoskeletal disorders.
- to contribute to the development of knowledge and practice in hand ergonomics assessment and work system design.

2. Overview of the methods used to estimate the ergonomics of the workplace in terms of the hand and wrist

Based on a research of the issue from sources (Bisht (2013), Lowe (2019) and Garg (2011) some of the common methods used by ergonomists can be listed:

- Index methods: these are methods that use a scoring system to assess the level of risk or exposure to ergonomic hazards based on various factors such as position, force, repetition, duration, etc. Examples include RULA (Rapid Upper Limb Assessment), REBA (Rapid Entire Body Assessment), Strain Index and ACGIH TLV for hand activity level.
- Electromyography: this is a method that uses electrodes attached to the skin or inserted into muscles to measure the electrical activity of muscle fibres during contraction or relaxation. It can be used to measure muscle fatigue or workload in workers performing manual tasks.
- Simulation software: These are methods that use computer programs to model and analyse the biomechanics and physiology of human movements and interactions with work tools or the environment. Examples are Jack, AnyBody and LifeMOD.
- Optical data capture and automated recognition: these are methods that use cameras or sensors to record and measure the spatial coordinates of body segments or markers attached to them. Examples include Vicon, OptiTrack and Qualisys.
- Strain gauge method: this is a method that uses a device that measures the deformation or strain of materials when forces are applied. It can be used to measure the grip force that workers apply to hand tools or objects.

Some of the gaps and limitations in current knowledge are as follows:

- there is no consensus on which method is most appropriate for different types of manual tasks or work scenarios.
- lack of validation studies comparing different methods in terms of their accuracy, reliability, validity and applicability
- lack of standardised protocols for the use of different methods in practice
- there is a lack of cost-effectiveness analysis of different methods with regard to their advantages and disadvantages.
- there is a lack of integration of different methods to allow a comprehensive assessment of hand ergonomics.

3. Selection of methods for analysis and process selection

For the comparative study, a small batch machine assembly line was selected. Part of the study was measured in cooperation between students of Brno University of Technology and Bosch Diesel, part was evaluated from video images taken at the workplace. Slámová (2022)

4. Description of the experiment

Based on the selected methods, an experiment was designed to evaluate the loads that are applied to the workers at the machine assembly workplace on a daily basis.

The experiment involved three workers who were experienced in work performance (restriction of unnecessary movements), these workers carried out a study with integrated electromyography, they were also filmed by three cameras and after the experiment they were interviewed ergonomically.

4.1 Methods used

In the analysis, we focused on determining the local load, which depends on the attitude of the workers, the line layout and the technical equipment. Although environmental influences are also important in the assessment, they were not included in this work.

The main method used was the RULA method, which was evaluated by a group of three experts from Brno University of Technology. All other results were compared with the results from this method.

Integrated electromyography was the second method used to evaluate the load.

As a third method, the process was simulated in computer software (Jack).

Finally, the last solution was the evaluation of automatic methods for the recognition of ergonomic parameters from videos taken at the workplace.

The strain gauge method was not used because the work required minor manipulations and the available strain gauge gloves made this work substantially more difficult.

4.1.1 The RULA method

RULA (Rapid Upper Limb Assessment) is an ergonomic method designed to analyse biomechanical and postural loads on the upper limbs of the worker and to identify the muscular effort associated with the work posture. This method is used to screen for the risk of musculoskeletal disorders (MSDs). The RULA mainly assesses the upper limbs (shoulders, elbows, wrists) but also the neck and trunk. It is applied to tasks in which the operator mainly uses their upper limbs, with or without movement. The RULA score takes into account different joint angles, muscle loading and strength. Stanton (2004)

4.1.2 Integrated electromyography

A two-channel EMG Holter with data recording was used for the measurements. The electrodes were fixed on the hand with adhesive and secured with sleeves. At the beginning of the experiment, the maximum force was set using a dynamometer. Calibration of the force measurement was always performed using a strain gauge.

4.1.3 Simulation methods

Siemens JACK software, which is a very frequently used tool for ergonomic analysis, was used for modelling. Sun (2020).

4.1.4 Automatic evaluation

The movements were recorded by a video camera, and the recording was evaluated in custom software created in UNITY software. Tuma (2022).

4.2 Description of the experimental workplace and the course of the experiment

Experimental workstation for the custom assembly of the injection steering pump that is needed to perform the work. Tool holders, tools and boxes of components are placed around the table.

Lighting is located on the ceiling of the room, but also directly above the workstation. Work on this line is performed standing up. The first station, located at the conveyor, is 100 cm high and the second 112 cm high. When assessing the workstation, not only the height but also the reach distance that the worker has to cover is examined. The farthest point on this workstation is the piston grid, 95 cm away from the worker's body.

The assembly process itself consists of:

- workstation 1 - picking up the pump body, cleaning and pressing the 3 pistons into the body and turning the pump body,
- workstation 2 - insertion of spring and spacer ring.

After thorough preparation, we informed the worker to work as in a normal working day. We marked the beginning of the measurement, or anything important that happened during the measurement, with a marker so that we could evaluate potential problems. The continuous work time was 2 hours. To determine time characteristics, we made video recordings in parallel with the measurements.

5. Experimental results and discussion

This product was dynamic in nature, with right-handed work predominating. The difference in the number of movements detected between the operators was due to the different working stereotype. The average number of movements per piece was determined to be 107 for the right upper limb and 49 for the left. For the whole shift, the worker performs 7490 movements with the right hand and 3430 with the left.

5.1 Results by RULA method

Six core activities emerged as the most significant in the evaluation:

5.1.1 Lifting the pump body

This operation does not involve both limbs because the worker uses only the left hand. The right hand is used to hold or lean on the station structure. Here, not only the neck, back and neck are bent, but also the torso is rotated. Bending also results in uneven weight distribution on the lower limbs. This position of the body occurs for faster work. Since this action occurs once every ten minutes, there is no need to add additional points for muscle strain. The body weighs up to five pounds and it is an intermittent load over a short distance, so I add a point to the strength score.

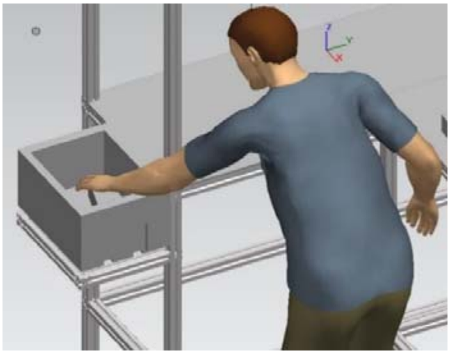

Fig. 1. Lifting the pump body

5.1.2 Cleaning the pump body holes

In this position, the worker is slightly bent over, holding the drill in the right hand with the wrist slightly turned. The other hand holds the drill and stands with both feet on the ground. In total, each hole is cleaned three times. This is a movement with an object up to five kilos, therefore one point is added for strength.

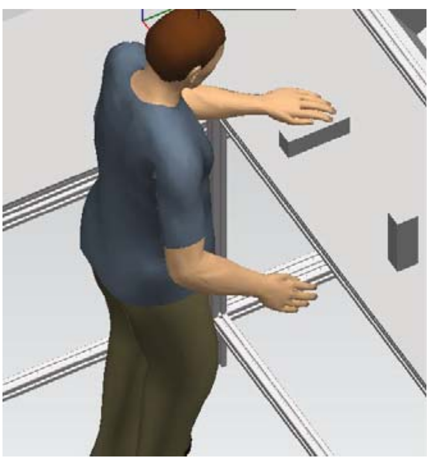

Fig. 2. Cleaning the pump body holes

5.1.3 Piston grip

In this position, the worker raises the arm to the right and must bend the wrist. Due to the positioning of the pins, the neck also turns to the right side. There is a one-sidedness to this station where the right upper extremity is predominantly used. This hand often reaches to its limit and smaller workers must transfer weight to their toes. For this reason, the workstation is suitable for taller workers who do not mind a greater reach. However, this position is also unsuitable for them, because even so the pistons are in an area suitable for less frequent handling. The upper and lower limbs and neck may therefore be overloaded. This position must be addressed as it is performed more than 4 times per minute.

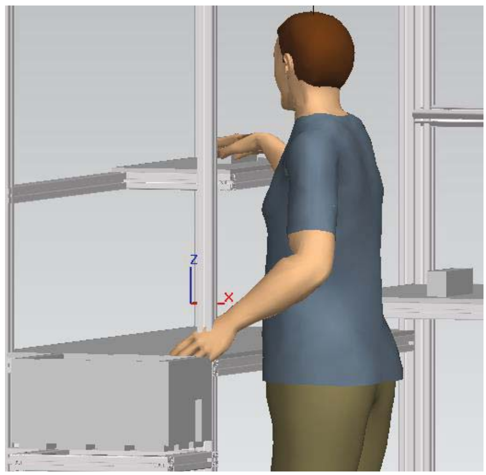

Fig. 3. Piston grip

5.1.4 Gripping a component from the crate

In this position, the worker removes the assembly material from the box, which is positioned at a height of 145 cm above the ground. This involves raising the arm above heart level and bending the wrist. The angle of rotation of the neck and torso is negligible. This activity does not occur frequently, so I do not add any additional points to the observed scores.

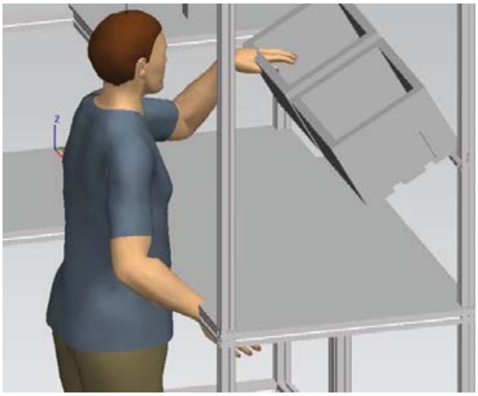

Fig. 3. Gripping the component from the crate

5.1.5 Piston and spring insertion

At this stage, all necessary components are inserted into the pump body. Here, the worker bends his wrists, holds his hands in the air and moves his fingers gently to ensure that the assembly goes correctly. In this position, most of the work is done with the fingers, so there could be more local stress. The neck and trumpets are in the same position as in the previous case and also do not add any additional points.

Fig. 4. Piston and spring insertion

5.1.6 Securing the body with clamps

After assembly, the components are secured with clamps. The photo shows us the beginning of the clamping process, when the worker needs to overcome the force required to secure the product. In this position, both wrists are bent. However, the position occurs twice per minute, so there is no need to add additional points.

Fig. 6. Securing the body with clamps

5.1.7 RULA evaluation

In this assessment, two positions were in category 3. The most highly rated position was lifting, where the worker bends his torso and puts a load on his body. The second inappropriate position is grasping a pin, which involves stretching the torso and lifting the foot off the ground.

Table 1. Results of the RULA method

No.	Activities	Rating	Category
1	Lifting the pump body	6	3
2	Cleaning the holes	3	2
3	Piston grip	5	3
4	Gripping the component	3	2
5	Inserting the piston and spring into the body	3	2
6	Securing the body with a clamp	3	2

5.2 *Results of the integrated electromyography method*

Evaluation of forces at work - the average force per working shift is given in the following table.

Table 2. Results of integrated electromyography

No.	Right hand (% F)MAX extensor	Right hand (% F)MAX flexor	Left hand (% F)MAX extensor	Lext hand (% F)MAX flexor
1	7,2	4,2	7	2,8
2	5	3,5	3,5	3,3
3	5,1	5	4,6	4,1
average	5,8	4,2	5	3,4

The limit value for dynamic work is the use of 30% Fmax, therefore both hands do not exceed this limit. It can be seen from the results that the right hand was used more.

5.3 Results obtained by the simulation software

The Siemens Jack simulation software evaluates all activities in the second hazard category.

Table 3. Simulation software results

No.	Activities	Rating	Category
1	Lifting the pump body	4	2
2	Cleaning holes	3	2
3	Piston grip	3	2
4	Gripping the component	4	2
5	Inserting the piston and spring into the body	3	2
6	Securing the body with a clamp	4	2

5.4 Results obtained by automatic evaluation

The captured video sequences were analysed in a proprietary environment created in UNITY, resulting in the calculation of changes in the angles of individual joints during the work activity. The detection results were recorded in a csv. file and further evaluated.

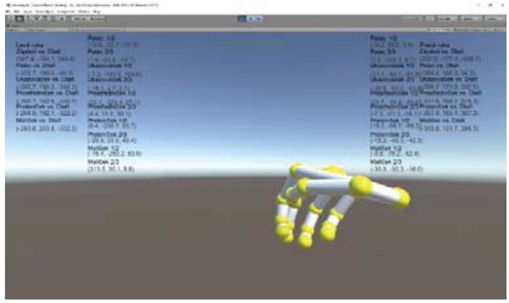

Fig. 7. Automatic evaluation

The RULA method was again used for the evaluation, but in this case it was automated.

Table 4. Results of the automated evaluation

No.	Activities	Rating	Category
1	Lifting the pump body	5	3
2	Cleaning the holes	3	2
3	Piston grip	4	2
4	Gripping the component	4	2
5	Inserting the piston and spring into the body	3	2
6	Securing the body with a clamp	3	2

6. Discussion of results

The experiment compared three methods used to evaluate hand strain, using integrated electromyography, the RULA method evaluated by a group of experts, simulation of the process in computer software (Jack - the RULA method was used) with our proposed automatic evaluation by optical methods to recognize ergonomic parameters from videos taken at the workplace (again using the RULA method).

Measurements at the machine assembly workplace were used. The results show that in this line the worker loads twice as much on the left hand, although he makes more movements with his right hand. This may be due to the greater strain or lack of training of this limb.

On the other hand, the RULA method points to an inappropriate position when removing pistons from the grids. The worker has to lean back and lift his legs. Considering that the worker performs this position several times a minute, it is an unsuitable position for the whole body. It is therefore appropriate to introduce measures for this activity. Other results were compared with the results of this method. The evaluation itself was time consuming for the analysts.

The integrated electromyography measurement is a convenient solution for analysts, where the entire movement is recorded on the holter and automatically evaluated by the supplied software. Less convenient is the measurement for workers who complained of discomfort when moving with the device in place. The results using this method differed from the RULA method, all movements came out as acceptable.

The evaluation using the Siemens Jack simulation software is convenient for the analyst, but again the inaccuracy in the evaluation for activity 3 was shown.

Evaluation by automated optical methods is challenging in terms of image data acquisition. In a few cases, shadowing or incorrect positioning occurred where the software could not correctly analyse the position. Measurements incorrectly evaluated action three, piston grip.

7. Conclusion

There are different methods of assessing hand and wrist ergonomics, according to review studies - for example, Govaerts (2021) - There are many methods of hand/wrist/arm ergonomics analysis, including the Rodgers Muscle Fatigue Model, the Ergonomic Job Measurement System (EJMS), the Washington State Occupational Safety and Health Act (WISHA) checklist, the RULA: Rapid Upper Limb Assessment, the Threshold Limit Value (TLV) for Hand Activity Level (HAL), and the Strain Index.

The presented experiment compares the most commonly used methods and contrasts them with the proposed automatic optical method for hand and wrist ergonomics assessment.

The results obtained by all the methods were comparable, but the proposed method faced measurement failures. This could be reduced by the use of machine learning and artificial intelligence methods, where the software would automatically calculate the movements when, for example, the contrast is reduced or a part of the hand is shaded. We will continue to work on this issue in the workplace.

Acknowledgement

The authors would like to acknowledge funding support from the Czech Ministry of Education, Youth and Sports under the project CZ.02.1.01/0.0/0.0/16026/0008404\Manufacturing engineering and Precision Engineering" Financed by the OP RDE (ERDF). The project is also co-financed by the European Union.

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