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A New Methodology for Validation of the Ergonomics Risk Assessment in Industry

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Abstract: In order to carry out an ergonomic assessment of the entire working situation in the industrial field, we have created and implemented an ergonomic risk assessment methodology—Ergonomics Risk Assessment Methodology in Industry (ERAI)—which takes into account a number of aspects that have a major impact on the physical condition and health of workers as well as on their efficiency. This study was conducted on 18 assembly line workers. ERAI identifies the level of exposure of the neck, trunk, shoulders/arms, wrists/hands and feet and can be used using printed forms, but it is preferred to use software that implements this method, thus avoiding errors. For this purpose, we have developed the ERAI software application that allows the management of the entire evaluation project. The main activities, the sub-activities carried out by the worker, together with the anthropometric characteristics are entered into the application, evaluating the posture of each part of the body, the effort exerted, the physical condition, etc. ERAI highlights the possible problems related to the physical condition of workers, e.g., there are three workers with a weaker physical condition, and the score for them is between 258 and 282, which is very high compared to the score of the other workers, which varies between 43 and 141. The results obtained with ERAI provide a correct diagnosis, facilitating effective ergonomic interventions to reduce the level of exposure.

Keywords: ergonomics; musculoskeletal disorders; ergonomics risk assessment; ERAI

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1. Introduction

In many industrial fields, despite the obvious technical progress, we meet workers who complain of musculoskeletal disorders. More worrying is the fact that these disorders appear, in large numbers, in young workers, up to 30 years old. In this sense, one of the purposes of this research is to identify more precisely the causes that produce these disorders in so many workers in industry.

In industrial activities, workers must adopt various postures and handle various weights, most of the time with a certain repetitiveness and under certain working environment conditions, such as temperature, lighting, air currents, etc. If, during their activity, the workers make a wrong body movement, in addition to the effort made and an incorrect posture, musculoskeletal disorders (MSDs) may occur, which are among the most widespread disorders worldwide [1–9].

Many musculoskeletal disorders arise due to a lack of knowledge among workers regarding proper techniques and postures for handling masses or how to appropriately utilize narrow spaces in terms of posture. However, perhaps the most significant factor contributing to musculoskeletal disorders is that workers initiate activities, including predominantly static ones like sitting on a chair, without adequately preparing their bodies for these efforts. In other words, they do not "warm up" their bodies before commencing the activity.

Being related to work, musculoskeletal disorders account for the majority of occupational pathologies and mainly consist of a wide variety of disorders which can differ in terms of intensity and symptoms, leading to work restrictions, loss of working time, and, as a result, early retirement, such as pain in the neck and upper extremity [10–14] and low back pain [15–20]. All of these are responsible for a substantial increase in expenses related to various salary compensations, decreased productivity, and a lower quality of life for employees [21]. Moreover, workers can be significantly affected by air quality during the performance of the activity [22], but this aspect will be a parameter that will be taken into account in the future development of the ERAI method.

The ergonomics risk assessments using internationally established assessment methodologies, such as Rapid Entire Body Assessment (REBA) [23,24], Rapid Upper Limb Assessment (RULA) [25,26], Quick Exposure Check (QEC) [27–29], etc., revealed that a number of aspects, such as the physical condition and the health of the workers and the support they may have in carrying out their activities, are not highlighted, although they actually have a great impact on the health of the workers and the efficiency of their activities.

These established methodologies mainly analyze the parts of the body from a postural point of view, which also takes into account the duration of the exercise. However, the ergonomic conditions include many more important elements and are much more complex. For example, the working conditions in which the activity is carried out, such as the working space, the height of the work plane relative to the height of the worker, the physical support that the worker has or does not have when carrying out the activity, and the physical condition of the worker when carrying out the activity, are crucial elements that need careful consideration and can provide a more precise indication of the factors that may lead to musculoskeletal disorders. As of 1 January 2022, Romania's active civilian population was 7.6 million, with 5.5 million of these being employees, according to the Labour Force Balance [30]. Among them, 1.85 million people were employed in industry and construction, while 0.1 million people were employed in agriculture, forestry, and fish farming.

In 2022, the employment rate of labour resources was 62.3%, with higher values for men (66.8%) compared to 57.4% for women [30]. There are many workers in various industrial fields who already suffer from musculoskeletal disorders caused by performing relevant activities.

In general, many diseases are caused by forced positions while handling weights and/or which are maintained for an extended period. For this reason, it is important that these work situations are identified and assessed, so that corrective measures can be taken in due time. Ideally, corrective measures should be taken upon the design of the task, and the ERAI method can also be used as a simulator of a possible work situation, thus avoiding any damage to workers' health.

A very important element to be considered as part of the activities carried out by industrial workers is the physical condition of the workers when they perform and carry out their activities in accordance with their workplace and duties.

The purpose of this paper is to provide an effective work tool for protecting the safety and health of workers by pinpointing ergonomics-related causes that may impact them. To achieve this goal, it is crucial to identify risks that may jeopardize the health of workers.

ERAI helps to correctly diagnose the work situation and to ergonomically reduce any possible injury of the workers as a result of activities carried out under improper ergonomics conditions, and remedial measures can be immediately proposed if necessary. By ensuring good ergonomics at the workplace, the productivity and efficiency of workers are clearly increased.

The ERAI method is systematic and considers a number of factors and parameters in order to achieve its goal of obtaining the most correct diagnosis.

2. Theory and Method

2.1. Ergonomics Approach

In accordance with one of the general principles of prevention: "adapting the work to the individual" [31], the ERAI methodology can identify the work situations which are not adapted to workers as they subject workers to demands close to or even higher than the limits/resources available to them, thus causing them health conditions and even safety problems, because workers may sustain injuries.

Furthermore, the combination of factors acting simultaneously on the worker should be considered since their impact is often much higher than the simple combination of the individual effects of each individual risk factor.

2.1.1. Ergonomics Risk Factors

Ergonomics risk factors are those factors which, in a work situation, can contribute, alone or in combination, to the occurrence of musculoskeletal disorders in workers. These ergonomics risk factors include the posture adopted, the strength/power required, and the frequency/duration of the movements.

2.1.2. Posture

Posture is the position of the body or of a part of the body while carrying out an activity. A posture involving no special demands is as close as possible to the natural free position of the joint. This is the "neutral" posture. The farther the adopted posture is from the neutral posture of the joint, the more uncomfortable the posture is, leading to an increase in the pressure/strain on the muscles, tendons, and ligaments in the area of the joint.

2.1.3. Strength

Strength is the effort exerted by the muscles which is required to perform a certain action considering, as a whole, the position of the joint, the length of the limb or of different parts of the body, as well as the weights involved, etc. Basically, all tasks require a specific strength to be performed. If the strength exerted by a certain muscle is too great for it, damage can occur to the muscle or to the tendons, joints, and other soft tissues involved in the action.

The required strength depends, in addition to the handled weight, on several factors, such as the duration of exerting the strength, the frequency of exerting the strength, and, obviously, the posture of exerting the strength; however, in practice, in certain situations, there may also be favorable factors, such as a support bracket, which can significantly reduce the effort made by the workers.

2.1.4. Repeated Movements

If muscles, joints, and tendons are used repeatedly, with high frequency and short recovery time, the risk of musculoskeletal disorders increases, even if the force needed is reduced and the posture is comfortable.

2.2. Method

Traditional methods such as REBA, RULA, QEC, etc. only partially analyze these aspects, providing only a part of the whole picture.

In the last 6 years, we have developed, tested, and validated the Ergonomics Risk Assessment Methodology in Industry (ERAI), which provides the most complete and precise diagnostic possible for a very wide range of work situations which can be encountered in most industrial fields. To make things easier for those who use the ERAI methodology, we have also developed an ERAI software application (V.02.65).

2.2.1. ERAI's Goals

The ERAI's goals are as follows:

a. identifying the activities and sub-activities carried out by workers, especially the ones leading to complaints of pain;
b. identifying the work postures and work parameters for workers;
c. calculating the level of risk for each part of the body, also taking into account the working conditions;
d. proposing actions to improve the factors which have a negative impact on the workers' health.

The achievement of these goals will ensure the safety and health of workers during the performance of the analyzed activities.

The ERAI methodology also considers aspects such as the alternative use of some sub-activities within a more complex activity. For example, the installation of an element (weighing approximately 3 kg) at shoulder-level height. The operation itself can last 2 min, but taking this element from a box located at the level of the worker's feet and to the side (i.e., bending and rotating the trunk), lifting it to shoulder level and placing it in position (lifting, stretching), and taking the tool needed to fasten it require a number of postures and movements which are part of the same activity and which influence the worker's body, muscles, and tendons. This influence on the body can be positive or negative, and the assessment tool should highlight this. If the movement of the body, together with the effort made and the posture adopted, is correct, their influence on the body is beneficial because any physical activity (such as working) strengthens the muscles and joints, fortifies the bones, increases the level of oxygen in the body, strengthens the immune system, etc. This is because the human body is designed to move, run, jump, handle objects, and exercise in general, and all these are actually physiological needs for the human body.

2.2.2. Develop of the ERAI Methodology

The development of ERAI is based on the principle that a worker is safe when performing an activity if the demands required to carry out that activity do not exceed the physical and mental resources of the worker. Certainly, the limits of the resources available to a worker are influenced, to a greater or lesser extent, by the skills, knowledge, work techniques, etc. possessed by that worker. The steps of the ERAI method are presented in Figure 1.

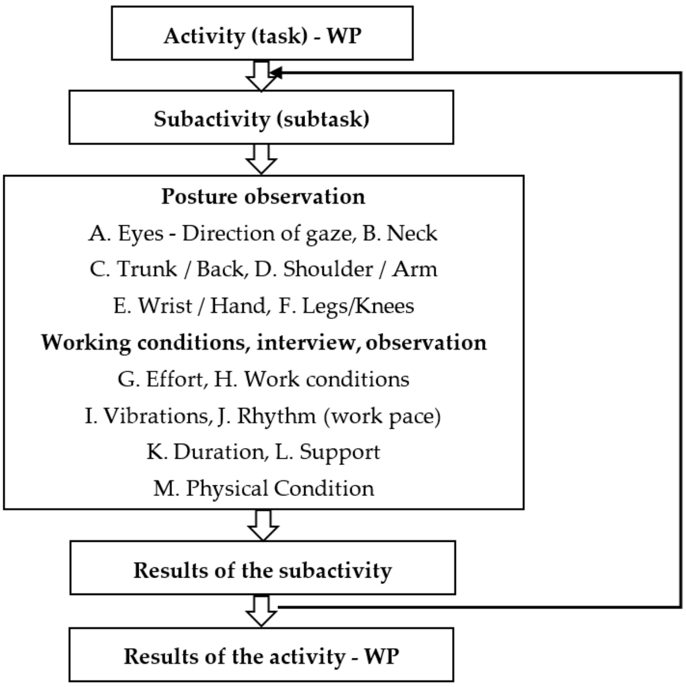

Figure 1. Block diagram with the stages of the ERAI method.

In order to have an efficient, well-structured, and easy to use method, the ERAI method utilizes a form, as presented in Appendix A, and a set of auxiliary calculation tables in Appendix B. Alternatively, one can directly use the ERAI software application that implements the ERAI method. Following this, the data in Table A1 are completed with worker characteristics, and then Table A2 is filled with scores obtained using the ERAI method (utilizing the auxiliary table from Appendix B).

2.2.3. Analysis of the ERAI Evaluation Form

To better organize the information and facilitate its completion, the evaluation form divides work parameters into two categories: body or body-part posture and contributing factors. Considering that many activities or sub-activities generally require great force or a robust stature of the worker, the evaluation form pays special attention, especially regarding the effort—the weight being manipulated—to the gender of the worker (male or female). Naturally, men tend to have a more robust physical constitution than women and may find certain tasks involving physical effort easier to perform. In the evaluation form, the aspects related to posture include:

Eyes—direction of gaze—In many situations where the worker needs to look in a specific direction and/or distinguish details, the worker is forced to adopt an uncomfortable posture to carry out the respective activity.

Neck—It can be bent forward (when it exceeds 10°, tension on the neck becomes significant), extended, rotated (when it exceeds 30°, tension on the neck becomes significant), or inclined laterally (when it exceeds 10°, tension on the neck becomes significant).

Torso/Back—It can be bent forward (when it ranges between 20° and 60°, tension on the spinal column is considerable, and when it exceeds 60°, it becomes significant), extended, rotated (when it exceeds 20°, tension on the spinal column becomes significant), or inclined laterally (when it exceeds 10°, tension on the spinal column becomes significant).

Shoulder/Arm—It highlights how much the shoulder and arm are stressed, observes the posture of the shoulder and arm, and notes the distance of the elbow from the trunk (when it exceeds 45 degrees, tension on the shoulder–arm assembly becomes significant).

Wrist/Hand—It highlights how much the wrist/hand is stressed, observes the posture of the wrist/hand, and notes whether the activity requires a strong grip (if yes, then the tension in the wrist–hand assembly becomes significant).

Legs/Knees—It highlights how much the leg is stressed and notes the posture of the legs.

Contributing factors that are considered include:

Effort—manipulated weight—The worker's response to the question: "Is handling the weight easy?" is recorded. If the answer is no, then the worker's perception of the effort exerted is significant. Depending on the value of the manipulated weight and the gender of the worker (male or female), the corresponding score is taken into account.

Working Conditions/Environment—The conditions in which the worker performs the activity can have a significant impact on health and safety. The ERAI method takes into account the following aspects of working conditions: the presence of dust/vapors, insufficient/excessive lighting, noise, humidity, air currents, vibrations from equipment/tools, temperature, and, most importantly, the size of the workspace. A limited or extremely limited workspace significantly affects the posture in which the worker operates, forcing them into an uncomfortable posture.

Vibrations from Equipment/Tools—If only the upper limbs are subjected to vibrations, severe effects can occur because blood circulation to the extremities is affected (vibration-induced disorders or white finger disease may occur). If vibrations affect the entire body, the effects can be even more serious since internal organs can be affected.

Work rhythm—This is an important indicator of how the worker perceives the flow of the activity. Depending on the worker's response to the question, "Does the work rhythm create problems?", the impact of this rhythm on the worker is highlighted, which can be significant.

Activity Duration—This is an extremely important indicator, and it is directly proportional to the possibility of the worker being affected by the activity. It has been experimentally observed that the duration of performing the activity/sub-activity has an almost identical impact whether all body or limb postures are considered or if each limb's posture is considered individually. This is justified by the fact that, often, if one limb is in an uncomfortable/forced posture for a while, the other limbs may become tense or subjected to greater effort, even if their posture is not forced. In addition, based on factors comprising posture, physical effort, and environmental conditions, the duration must be properly measured. For example, in the case of a forced posture where physical effort is also exerted, the duration is measured in minutes, whereas in the case of a static posture, whether standing or sitting, the duration is measured in hours. In both situations, musculoskeletal disorders may occur, but in the first case, the disorder may be felt immediately, while in the second case, the disorder may develop over time (months, years).

Support—This parameter is extremely important in real activity and is not highlighted in traditional established ergonomic methods. When the body posture is forced, and the worker supports a limb or part of the body on a stable object, the perceived effect is significantly reduced. For this reason, the "support" parameter, if it exists, is a risk mitigation parameter, with the greatest positive effect on the back and the spinal column in particular.

Worker's Physical Condition—This parameter is also extremely important but is not found in established ergonomic risk assessment methodologies. The worker's physical condition represents the worker's ability to perform certain movements, exert certain efforts, and respond to the surrounding environment. It is directly influenced by the worker's health. In many activities, even those in which handling masses is not relevant, or especially if it is, it has been found that if the worker is in good or even athletic physical condition, this mitigates the risk of musculoskeletal disorders. In contrast, a weak physical condition of the worker can increase the risk of musculoskeletal disorders. The evaluator assesses the worker's physical condition based on discussions with the worker and direct observation of how easily the worker performs the respective activity/sub-activity and by referring to the fitness assessment documents provided by an occupational medicine physician. This physical condition can also be temporary. Sometimes, the worker may appear to have a robust physical condition but may already suffer from certain conditions (a lumbar hernia in Phase I, disc instability, or muscle-related conditions due to past strain) that may cause pain during the activity but subside during rest. The worker's physical condition can be influenced by age, anatomical characteristics, genetics (men have greater strength, women have better flexibility), the individual's capacity to endure effort, etc. The worker's physical condition is classified into the following categories: normal—the worker has a general physical condition similar to that of the absolute majority of the population; athletic—the worker is in good health, has well-developed muscles and body appearance, with high resistance to effort, excellent strength, speed, and flexibility; good—the worker is in good health, with reasonable flexibility, strength, and endurance; poor—the worker may already suffer from certain conditions and tires very easily, with weak strength and flexibility.

The scores allocated in the ERAI method for each identified characteristic are experimental, resulting from a long series of applications and adjustments.

3. Practical Application Research of Ergonomic Risk Based on the ERAI Methodology

3.1. Research Condition

An important first step is to analyze if the activity in which ergonomic risk assessment is performed can be divided into relevant sub-activities. For example, if a panel that slightly exceeds the worker's height needs to have a series of components/parts mounted at the top, the activity of "mounting components/parts on the panel" can be broken down into sub-activities. For instance, one sub-activity can be related to picking up a component from a box located in a specific position in front of the worker, requiring bending and rotating the trunk, grasping the component with one or both hands, lifting and maneuvering it to the appropriate level on the panel, and fastening it to the panel using certain tools or fastening systems.

Another sub-activity could be related to another component/part located in a different place, requiring the worker to reach with their arms and rotate the trunk to pick it up, having a different weight and dimensions, and then mounting it in another location on the panel, at a height below the worker's waist (42 cm). This would involve the worker bending and/or flexing their knees and require its own fastening system. These sub-activities may have significantly different execution durations. In the given example, the average duration of the action is 1 min and 50 s, with a frequency of 12 actions per hour.

For illustrative purposes, we selected a group of 18 workers who perform such an activity.

In summary, the activity involves picking up parts from various boxes and supports, positioning and securing them on the panel, and then adjusting them. The activity in the selected example is divided into 3 sub-activities/sequences: lifting the HR5 part, placing the HR5 part on the panel, fixing and adjusting the HR5 part.

The worker, standing facing the panel, bends down to pick up the HR5 piece, which weighs 2.8 Kg, from the box on the left side. During this operation, the worker has the trunk bent over 60 degrees, rotated more than 20 degrees, and inclined more than 10 degrees.

The characteristics of the workers performing this activity are listed in Table 1.

Table 1. The characteristics of the workers.

Code	Gender	Age	Height = Hw (cm)	Physical Condition	Seniority in Activity (No Years)
L1	M	35	169	N	5
L2	M	27	173	G	2
L3	M	35	167	N	6
L4	M	30	160	N	4
L5	F	28	161	N	3
L6	F	29	163	A	3
L7	M	42	172	P	8
L8	M	31	168	N	6
L9	F	28	171	A	2
L10	M	38	178	N	6
L11	F	31	167	G	5
L12	M	29	168	A	1
L13	M	44	178	G	5
L14	M	37	182	N	8
L15	F	31	165	N	4
L16	F	28	169	P	4
L17	F	34	164	P	6
L18	M	31	174	G	4

Note: Code: Ln (Worker); Gender: M (Male); F (Female); The worker's physical condition is: N (Normal); A (Athletic); G (Good); P (Poor).

The work schedule of the workers (electromechanical) is from Monday to Friday, 8 h/shift (with a 1 h break), 2 shifts per day.

In Table 1, it can be observed that this activity is performed by both men and women, with ages ranging from 27 to 44 years, heights ranging from 1.60 to 1.82 m and job tenure for this position ranging from 1 to 8 years.

Regarding the physical condition of the workers, it can be noted that 8 workers have a normal physical condition (N), 4 workers have a good physical condition (G), 3 workers have an athletic physical condition (A), and 3 workers have a poor physical condition (P).

The height of the work surface can also impact the health and efficiency of the workers in performing the respective activity.

For this reason, to analyze its impact, we used our own calculation formula, named by us as optimal work surface height (OWSH).

For a simplified estimation of the optimal work surface height (OWSH) based on the worker's height, we have used the following Formula (1):

$$\text{Hpo} = 0.65 \times \text{Hw} \pm 0.05 \quad (1)$$

where Hpo represents the optimal work surface height, Hw represents the worker's height.

The factor of 0.65 in Equation (1) reflects an approximation of the optimal work surface height as a percentage of the worker's height, with 65% being an estimate of the average height of the worker's elbow during work.

The margin of ±0.05 m (5 cm) can be used to adjust the work surface height based on individual preferences and specific working conditions.

The implementation of Equation (1) can be found in the software application, as presented in Figure 2.

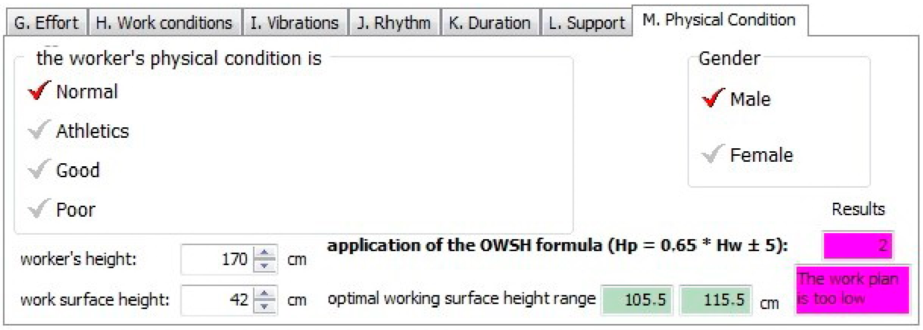

Figure 2. Implementation of the OWSH formula in the software application.

3.2. Estimation and Evaluation of Ergonomic Risk in the ERAI Methodology

Considering that a body part can be affected by multiple factors, not just direct posture-related factors, calculations need to take into account all the parameters involved in affecting that particular body part. For each body part, the posture is identified, but that body part is directly affected proportionally by both the duration of maintaining that posture and the effort exerted while adopting that posture, taking into account the worker's physical condition.

For example, a worker with good physical condition operates a 2.5 kg power drill with their right hand to tighten screws. Vibrations occur during the activity, and the work pace is quite fast, taking about 2 min to complete the task (tighten 8 screws). The arm is extended about 90 degrees from the body, and the hand is approximately at shoulder level. The motion is repeated every 2 min for 3 h. All these factors contribute to the stress on the hand, wrist, shoulder, back, and even the legs, neck, and eyes.

To calculate the total score of the parameters at the shoulder/arm level, in accordance with the score specified in the worksheet in Appendix A and the calculation formulas specified in Table 2, we perform the operations in Equation (2).

$$D + G + I + J = [(3 + 2 + 2) + 1 + 3 + 3] \times (6 + 0) = 14 \times 6 = 84 \quad (2)$$

where D, in this formula, represents the direct score for shoulder/arm, D = 3—shoulder raised and flexed + 2—arm near/at shoulder level + 2—distance from body: 45°, and G represents the score for effort—mass handled. G = 1 because the manipulated mass is 2.5 Kg and the worker is a man. I from the formula represents the score for vibration equipment/tools. I = 3—only arms, caused by the power tools used to grip the part. J represents the score for work rhythm. J = 3—the pace of work creates problems occasionally. Also, the effort of the shoulders/arms is directly proportional to the duration of the activity, K = 6, i.e., the duration is between 2 and 4 min, as well as to the physical condition of the worker, M, which in the given example is equal to 0, i.e., the physical condition of the respective worker is normal.

Table 2. The level of risk for each body part.

No.	Body Part	Formula	Low = 1	Medium = 2	High = 3
1	A. Eye	= (A + Hi) × K	≤12	13–42	≥43
2	B. Neck	= B × (K + M)	≤24	25–36	≥37
3	C. Trunk	= (C + G + Hs + I + L) × (K + M)	≤60	61–126	≥127
4	D. Shoulder/Arm	= (D + G + I + J) × (K + M)	≤33	34–84	≥85
5	E. Hand/Wrist	= (E + G + I + J) × (K + M)	≤42	43–78	≥79
6	F. Leg/Knee	= (F + G + Hs + $I^{(IF\ I = 5)}$) × (K + M)	≤72	73–135	≥136
7	Stress	= (H + G + I + J) × (K + M)	≤126	127–238	≥239

Where Hi represents the score for “Inadequate or excessive lighting” within the working conditions or environment, Hs represents the score for “Workspace,” which can be sufficient, limited, or extremely limited.

From Equation (2), it can be observed that the ERAI method takes into account not only the direct score related to posture but also several other factors that impact that specific body part. The score of 84 resulting from Equation (2) is right on the border between the medium- and high-risk levels, with a risk level of 2, but it is clear that the work situation needs improvement.

The cumulative calculation formulas for each analyzed body part and for stress, as well as the risk levels for each body part, are shown in Table 2.

Upon analyzing Table 2, it becomes evident that each body part is influenced diversely by other factors. Some of these factors add up, while others, with a more significant impact, are multiplied. Most factors are multiplied by the sum of K—activity duration and M—worker’s physical condition. Summing the values of these two parameters highlights their importance and impact on ergonomic risk management. As shown, both the duration a worker spends in a specific posture, especially if it is forced, and the worker’s physical condition at the time of performing the activity are determinants in ergonomics and directly or indirectly affect all parts of the body while contributing to the worker’s stress level.

It is important to note that, in the ERAI method, the scoring for each component was established based on how much that component affects the particular body part. This assessment is based on a series of tests, adjustments, and validations.

In contrast to other established methods for assessing ergonomic risks, in the ERAI method, a parameter can have a value of 0, which is assigned when that parameter does not influence the score. This is considered a natural value. The authors chose to assign a value of 0 instead of 1 because a value of 1 would artificially increase the score, given the summation, and would bias the evaluation result. The lower the score, the less the worker is affected by performing the activity.

If the evaluation is carried out on a printed form, the table in Appendix B can be used to facilitate the calculations.

By summing the values obtained from Table 2, an overall level of ergonomic risk can be determined, as presented in Table 3. This helps highlight the importance of the risk and prioritizes risk mitigation measures. The total value will be found on the “Final Score” column in the range on the correspond-ing row, the risk level will be identified, which can be low, medium, or high and, depend-ing on the risk level, the risk will be evaluated as acceptable, tolerable, or unacceptable.

Table 3. Risk level, final score, and action level or WERA tool.

Risk Level	Final Score	Action
Low	7–9	Acceptable situation. No additional measures are required
Medium	10–15	Tolerable situation. Permanent surveillance measures are necessary
High	16–21	Unacceptable situation. Remedial measures will be taken urgently

The risk levels can be tailored to specific criteria and requirements, allowing the evaluation team to adjust risk levels before conducting the actual assessment. These adjustments are made in line with the company’s health and safety policies, legal regulations, and relevant industry standards.

3.3. Research Results

The workers bend down to a height of 42 cm from the floor, and the duration of this posture is over 1 min in the analyzed case. Therefore, Equation (1) needs to be applied. The results are shown in Table 4.

Table 4. The results obtained from applying the ERAI method.

Code	A. Eye	B. Neck	C. Trunk	D. Shoulder/Arm	E. Wrist/Hand	F. Legs/Knees	Stress	Total	Total r.	F.QWSH	R.OWSH
L1	6	18	21	39	33	18	18	129	8	104.85	2
L2	6	12	14	26	22	12	12	86	8	107.45	2
L3	6	18	21	39	33	18	18	129	8	103.55	1
L4	6	18	21	39	33	18	18	129	8	99	1
L5	6	18	24	42	36	21	21	141	8	99.65	1
L6	6	6	8	14	12	7	7	47	7	100.95	1
L7	6	36	42	78	66	36	36	258	10	106.8	2
L8	6	18	21	39	33	18	18	129	8	104.2	2
L9	6	6	8	14	12	7	7	47	7	106.15	2
L10	6	18	21	39	33	18	18	129	8	110.7	2
L11	6	12	16	28	24	14	14	94	7	103.55	1
L12	6	6	7	13	11	6	6	43	7	104.2	2
L13	6	12	14	26	22	12	12	86	7	110.7	2
L14	6	18	21	39	33	18	18	129	8	113.3	2
L15	6	18	24	42	36	21	21	141	8	102.25	1
L16	6	36	48	84	72	42	42	282	10	104.85	2
L17	6	36	48	84	72	42	42	282	10	101.6	1
L18	6	12	14	26	22	12	12	86	7	108.1	2

The result of applying Equation (1), in the workers' working posture (Figure 3), shows that the work surface height, in relation to their height, is lower than the comfortable working height.

Figure 3. Worker's posture during the activity.

If the difference between the minimum height allowed by the formula QWSH (1) and the actual work surface height exceeds 0.65 m, the working situation becomes critical and immediate remedial measures must be taken.

In Table 4, values of 1 have been noted to indicate that the work surface height is outside the range defined by the QWSH formula, and 2 signifies that it unacceptably exceeds this range. The applied algorithm is presented in Equation (3).

$$\text{IF } 0.65 \times \text{Hw-5} > \text{Hp} + \text{c} \times \text{Hw, THEN Rowsh} = 2 \text{ ELSE Rowsh} = 1 \quad (3)$$

where Hw represents the worker's height (from Table 1) in cm, Hp represents the work surface height (in the analyzed case, Hp = 42 cm), c is a constant with a value of 0.37, determined experimentally, signifying that if the difference between the minimum optimal work surface height and the actual work surface height is greater than 37% of the worker's height, the worker's posture is forced.

Table 4 presents relevant values related to the scores obtained for each worker. To calculate the sum of the scores in the "Total " column, in order to obtain relevant results, only the scores obtained for neck, trunk, shoulder/arm, wrist/hand, and leg/knee were considered. The scores for eyes (although there might be a correlation between the worker's height and the work surface height, with the direction of gaze depending on this correlation, such situations are very rare in practice, and can be considered negligible) and stress were ignored (as this parameter is already influenced by the other parameters under consideration). Therefore, the expressed total is related to posture but takes into account other parameters like lifted weight, action duration, and the worker's physical condition.

The "Total r" column represents the reduced total calculated according to Table 4, where the risk level for each body part is determined based on the range in which the sum of the scores for each body part falls. A graphical representation of these parameters is shown in Figure 4.

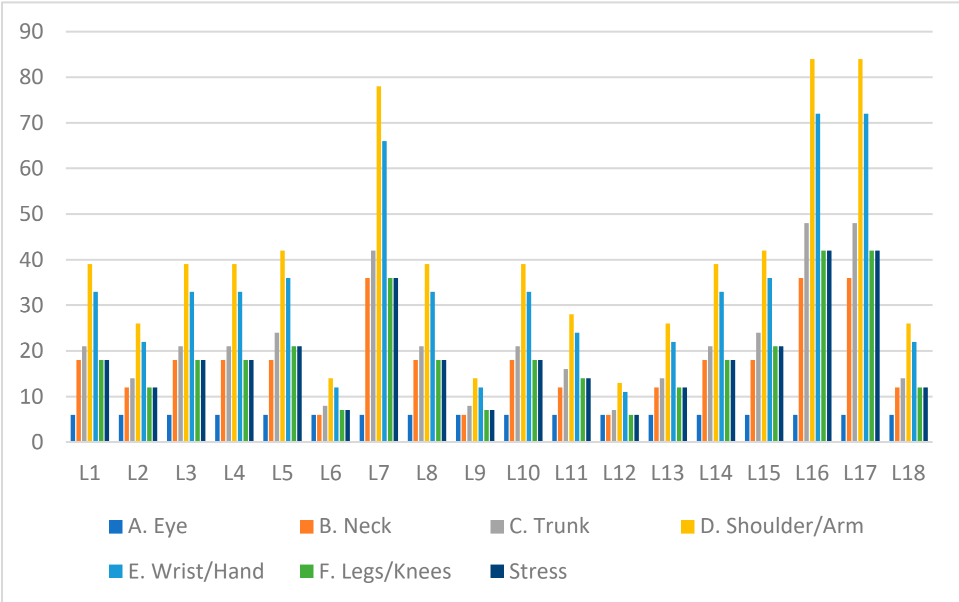

Figure 4. Graphic representation of the score for each body part.

As can be seen from the graph presented in Figure 4, certain body parts are more affected, such as the arms and the back. However, to understand why some workers (L7, L16, L17) have significantly higher scores compared to other workers while performing the same activity, it is necessary to consider other parameters related to each worker's individual characteristics.

For instance, in Figure 5, the total score for each worker, their height, and physical condition have been represented.

Although a worker's height could be a representative factor in relation to the work surface height, which, in our example, is too low, the high scores that stand out for these three workers are caused by their weaker physical condition. Any effort they exert has a much more pronounced effect on them due to their poorer physical condition.

A closer look at the results confirms that, in the case of these workers, physical condition is the most important factor. All these data have been input into the ERAI V02.65 software application, and a screenshot of the application is presented in Figure 6.

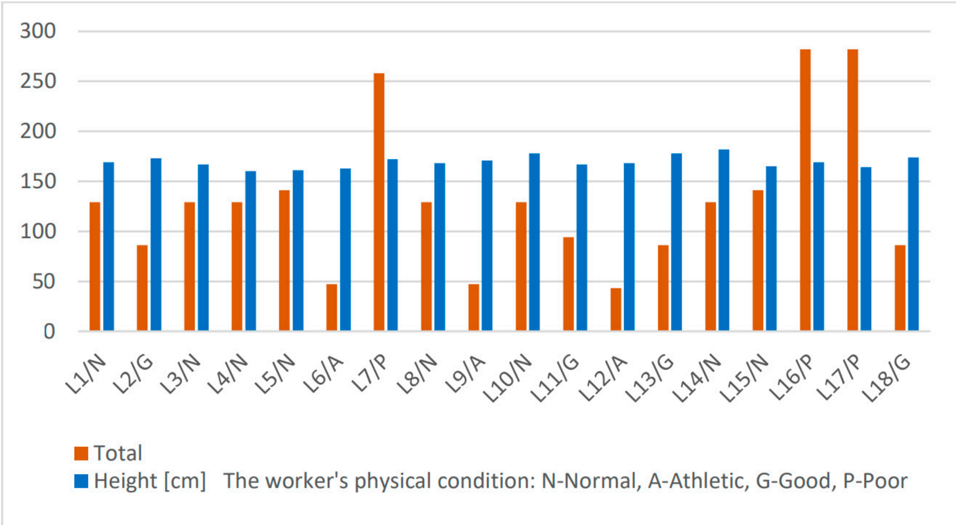

Figure 5. Total score, height, and physical condition of the workers.

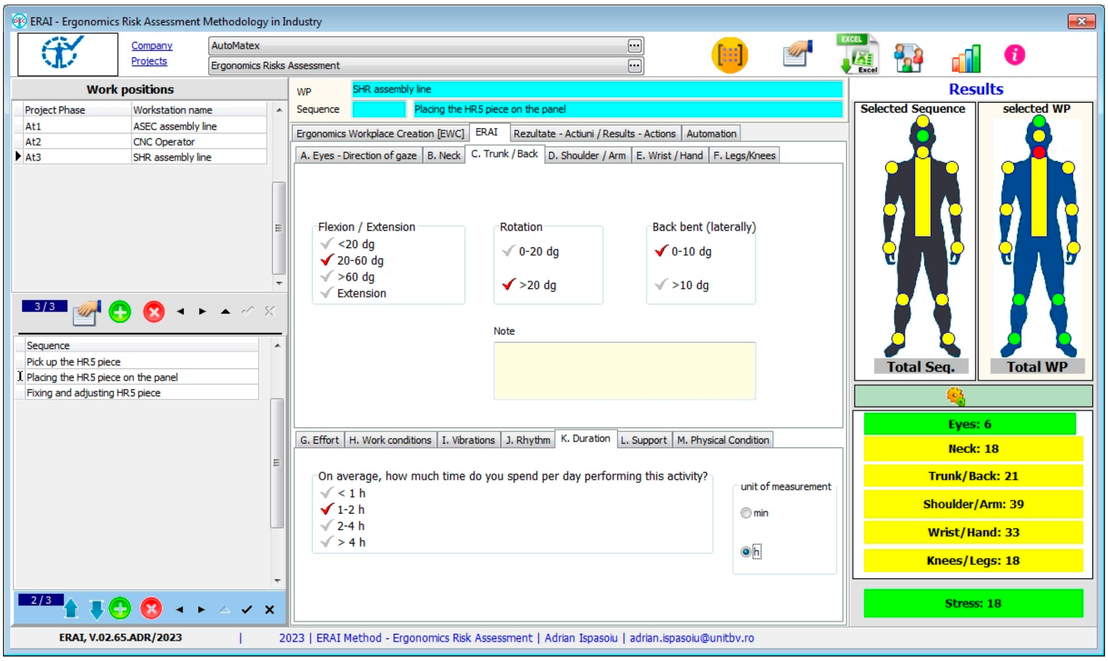

Figure 6. Capture from the ERAI software application.

The ERAI V02.65 application software allows for the management of the entire ergonomic risk assessment project. In the application, main activities and sub-activities are input. Then, for each worker performing that activity, their specific characteristics are added, and the posture of each body part, working conditions, exerted effort, physical condition, etc. are evaluated.

The application automatically calculates scores for each sub-activity and provides a general score for the activity. Finally, various reports, including statistical data, can be generated.

3.4. Evaluation of the Reliability, Validity, and Usability of the ERAI

The ERAI method effectively identifies the level of exposure in various body areas, such as the neck, torso/back, shoulders/arms, wrists/hands, and legs/knees. The results obtained through ERAI offer an accurate diagnosis, enabling the implementation of effective ergonomic interventions to mitigate exposure levels.

Evaluators can choose to use the ERAI methodology by completing a paper-based evaluation form found in Appendix A or by utilizing dedicated software. It is recommended that the form be filled out after interviewing the worker to create a relaxed atmosphere. However, the exact approach may vary depending on the evaluator's technique. In terms of approach and components covered, the ERAI method shares similarities with the Quick Exposure Check (QEC) method, which assesses exposure in four key body areas (back, shoulder/arm, wrist/hand, neck) with the highest risk of work-related musculoskeletal disorders (WMSDs) [31]. However, ERAI extends its scope to factors contributing significantly to WMSDs and provides a more detailed analysis, enhancing its accuracy.

The versatility of the ERAI method allows it to be applied across various industries. Its potential to provide precise diagnoses is particularly valuable in industrial settings with high and evident risks of musculoskeletal disorders for workers.

4. Conclusions

The assessment of ergonomic risks using the ERAI method is effective in obtaining a correct diagnosis of the work situation. The ERAI method takes into account, in addition to the position adopted by the workers during the activity, anthropometric data of the workers, conditions of the working environment, the physical condition of the worker, and factors that can be mitigating such as the support that the worker can have during the activity.

Depending on the complexity of the activity, the method allows dividing it into sub-activities, thus being able to identify more precisely the possible factors that can affect the workers. The ERAI method can be used both by completing a form, presented in Appendix A, with the table in Appendix B as the calculation grid, and by using a dedicated software.

Therefore, the application of the ERAI methodology is simple but requires a systematic approach to the work situation, with attention to details, as well as a good understanding of the ergonomic risk factors that can affect workers.

The results provide evidence for the validity of the ERAI method and are expected to provide a new ergonomics risk assessment tool, with a solid experimental validation over time.

The results presented above show that, for workers, the physical condition is the most important factor, as confirmed by the facts.

The future development of the ERAI method aims to add new elements which correlate with the already existing ones and provide a more complete picture of ergonomics during activities, identifying as accurately as possible the causes of musculoskeletal disorders and stress for workers and facilitating the finding of the best measures to prevent and control ergonomics risks.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Ergonomics Risk Assessment Methodology in Industry—ERAI. WORKSHEET.

Ergonomics Risk Assessment Methodology in Industry			**WORKSHEET**
Activity:			**Date:**
Workplace/Equipment:			**Assessor:**
Body or limb posture	( ) Male	( ) Female	**Contributing factors**

A. Eyes—Direction of gaze |_|
( ) [0] Neutral position (0–16°)
( ) [2] Lateral/side direction (angle > 16°)
( ) [2] Eyes looking up
( ) [2] Eyes looking down
[ ] [3] Visual precision (observing details)

B. Neck |_|
Bent forward/Extension
( ) [0] 0–10° ( ) [2] > 10°
( ) [4] Extension
Rotation
( ) [0] 0–30° ( ) [2] > 30°
Inclined laterally
( ) [0] 0–10° ( ) [2] > 10°

C. Torso/Back |_|
Bent forward/Extension
( ) [0] < 20° ( ) [2] 20–60°
( ) [4] > 60° ( ) [5] Extension
Rotation ( ) [0] 0–20° ( ) [2] > 20°
Inclined laterally
( ) [0] 0–10° ( ) [2] > 10°

D. Shoulder/Arm |_|
Shoulder
( ) [0] Neutral ( ) [3] Raised & flexed
( ) [2] Raised ( ) [2] Flexed
Arm
( ) [0] Neutru ( ) [4] Extension
( ) [1] Near/at chest level
( ) [2] Near/at shoulder level
( ) [3] Above shoulders
Distance from the body
( ) [0] 0–45° ( ) [2] >45°

E. Wrist/Hand |_|
Flexed/Extension
( ) [0] Neutral ( ) [2] Flexed ( ) [2] Extension
Strong grip
( ) [0] No ( ) [3] Yes

F. Legs/Knees |_|
( ) [1] Seated
( ) [1] Standing with straight legs
( ) [2] Standing with 1 straight leg
( ) [2] Standing with bended legs
( ) [3] Standing with one bended leg
( ) [3] Standing on one or both knees
( ) [2] Seated bended forward
( ) [1] Walking

G. Effort—Manipulated weight |_|
[ ] [2] No—Is handling the weight easy?
( ) [0] < 1 Kg
( ) [1/2] 1–5 Kg
( ) [2/4] 5–10 Kg
( ) [4/7] 10–20 Kg
( ) [6/10] > 20 Kg

If the person is a woman, the values are chosen after the sign /

H. Working conditions/environment |_|
[ ] [2] Dust/Vapors
[ ] [2] Hi. Insufficient/excessive lighting
[ ] [1] Noise
[ ] [1] Humidity
[ ] [2] Air currents
Hs. Work space
( ) [0] Sufficient
( ) [3] Limited
( ) [6] Extremely limited
Temperature
( ) [3] Low
( ) [0] Acceptable
( ) [2] High

I. Vibrations from Equipment/Tools |_|
( ) [0] No
( ) [3] Only arms
( ) [5] Body

J. Does the work rhythm create problems? |_|
( ) [0] No
( ) [3] Yes, occasional
( ) [5] Yes, frequent

K. Activity duration |_|
( ) [1] < 1 min
( ) [3] 1–2 min
( ) [6] 2–4 min
( ) [9] > 4 min

L. Support |_|
( ) [0] Without support
( ) [−2] Forearm support
( ) [−1] One arm support
( ) [−2] Both arms support
( ) [−2] Support in the pelvis or trunck area

M. Worker's Physical Condition |_|
( ) [0] Normal
( ) [−2] Athletic
( ) [−1] Good
( ) [3] Weak

Appendix B

Table A2. Overall calculus.

No	Body Part	Equation [Min, Max]	× (K + M)	Results	Low [1]	Medium [2]	High [3]
1	A. Eyes	= A + Hi [0.5] =	× K		≤12	13–42	≥43
2	B. Neck	= B [0.8] =	× (K + M)		≤24	25–36	≥37
3	C. Trunk/Back	= C + G + Hs + I + L [0.26] =	× (K + M)		≤60	61–126	≥127
4	D. Shoulder/Arm	= D + G + I + J [0.25] =	× (K + M)		≤33	34–84	≥85
5	E. Hand/Wrist	= E + G + I + J [0.21] =	× (K + M)		≤42	43–78	≥79
6	F. Legs/Knees	= F + G + Hs + $I^{(If\ I = 5)}$ [0.17] =	× (K + M)		≤72	73–135	≥136
7	Stress	= H + G + I + J [0.33] =	× (K + M)		≤126	127–238	≥239

Method of use: For each part of the body, the corresponding formulas will be applied and the calculations will be performed. The results will be recorded in the "Results" column. Then, depending on the value of the result, the value from that column will be written accordingly: 1, 2, or 3.

The total will be compared with the values in the "Final Score" table, and the interval where it is found represents the risk level.

Table A3. Calculation grids for intermediate values.

G + I + J											
J	**I**	**G**									
		No(2)	**0**	**1[M]**	**2[F]**	**2[M]**	**4[F]**	**4[M]**	**7[F]**	**6[M]**	**10[F]**
0	0	2	0	1	2	2	4	4	7	6	10
	3	5	3	4	5	5	7	7	10	9	13
	5	7	5	6	7	7	9	9	12	11	15
3	0	5	3	4	5	5	7	7	10	9	13
	3	8	6	7	8	8	10	10	13	12	16
	5	10	8	9	10	10	12	12	15	14	18
5	0	7	5	6	7	7	9	9	12	11	15
	3	10	8	9	10	10	12	12	15	14	18
	5	12	10	11	12	12	14	14	17	16	20

Method of use: If the values for G. Effort—Manipulated Mass, I. Vibrations of Equipment/Tools and J. Work Pace are initially known, then the corresponding score will be identified from the table. For example, if the worker is male and G = 4, I = 3, and J = 5, the intersection between column 4[F] and rows 5 (for J) and 3 (for I) will have a score of 12.

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