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Decision Support System (DSS) for Improving Production Ergonomics in the Construction Sector

Laura Sardinha [1], Joana Valente Baleiras [1], Sofia Sousa [1], Tânia M. Lima [1,2] and Pedro D. Gaspar [1,2,*]

[1] Department of Electromechanical Engineering, University of Beira Interior, 6201-001 Covilhã, Portugal; laura.sardinha@ubi.pt (L.S.); joana.valente.baleiras@ubi.pt (J.V.B.); sofia.s.sousa@ubi.pt (S.S.); tmlima@ubi.pt (T.M.L.)
[2] C-MAST—Center for Mechanical and Aerospace Science and Technologies, 6201-001 Covilhã, Portugal
* Correspondence: dinis@ubi.pt

Abstract: Ergonomics is essential to improving workplace safety and efficiency by reducing the risks associated with physical tasks. This study presents a decision support system (DSS) aimed at enhancing production ergonomics in the construction sector through an analysis of high-risk postures. Using the Ovako Work Posture Analysis System (OWAS), the Revised NIOSH Lifting Equation (NIOSH equation) and Rapid Entire Body Assessment (REBA), the DSS identifies ergonomic risks by assessing body postures across common construction tasks. Three specific postures—X, Y and Z—were selected to represent typical construction activities, including lifting, squatting and repetitive tool use. Posture X, involving a forward-leaning stance with arms above the shoulders and a 25 kg load, was identified as critical, yielding the highest OWAS and NIOSH values, thus indicating an immediate need for corrective action to mitigate risks of musculoskeletal injuries. The DSS provides recommendations for workplace adjustments and posture improvements, demonstrating a robust framework that can be adapted to other postures and industries. Future developments may include application to other postures and sectors, as well as the use of artificial intelligence to support ongoing ergonomic assessments, offering a promising solution to enhance Occupational Safety and Health policies.

Keywords: ergonomics; OWAS; NIOSH equation; REBA; musculoskeletal injuries; decision support system; OSH

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Citation: Sardinha, L.; Baleiras, J.V.; Sousa, S.; Lima, T.M.; Gaspar, P.D. Decision Support System (DSS) for Improving Production Ergonomics in the Construction Sector. *Processes* **2024**, *12*, 2503. https://doi.org/10.3390/pr12112503

Academic Editors: Sheng Du, Li Jin, Pan Yu and Haipeng Fan

Received: 3 October 2024
Revised: 7 November 2024
Accepted: 8 November 2024
Published: 11 November 2024

1. Introduction

The construction sector is characterised by a high dependency on human labour, with frequent reports of injuries and fatalities due to improper postures and heavy loads [1]. An alarming number of workers in this sector are diagnosed with musculoskeletal disorders (MSDs), a risk amplified by factors such as prolonged awkward postures and the repetitive handling of loads [2].

Ergonomics is the science that focuses on improving the development of the physical and mental health of human beings, providing them with a safe, comfortable and healthy environment, and, in turn improving the efficiency of their work. Ergonomics is associated with other sciences such as psychology, sociology, physiology and anatomy, among others. In industrial terms, ergonomics has been used to prevent work injuries and increase worker safety [3]. However, it should be considered that changes made to improve operators' ergonomics should not cause them any kind of inconvenience, such as stress related to interacting with systems and robots [4].

Several factors can negatively influence workers' ergonomics, some of which are physical, demographic and psychosocial [5]. Regarding physical factors, these are characterised by vibrations transmitted to the whole body, incorrect postures, repetitive work movements, constant application of loads and constant force [5]. Moving on to demographic factors, these also have a major influence on the quality of the work carried out. Age, Body Mass Index (BMI), gender, eating habits, previous medical diagnoses, or addictions (such as smoking and alcoholism) have a significant impact on an individual's personal and professional life [5,6]. Factors such as stress, anxiety, burnout, or depression have also been identified as adversities in conducting the work required. These factors are just a few examples of psychosocial factors that can affect workers [5].

Jobs with an important level of human intervention require a high level of ergonomic risk monitoring for operators. One such case is the construction sector, which is directly dependent on human effort and is therefore a highly dangerous industry with a high number of reports identifying deaths and injuries [1,7]. Due to the hard tasks that construction workers perform and the uncomfortable postures in which they work for long hours, they are highly likely to develop musculoskeletal injuries and/or other health problems in the future [1].

Some of the more traditional methods of analysing movements used fixed characteristics, which limited their use and made them ineffective for analysing repetitive movements [8]. Therefore, more effective approaches were developed that included counting repetitions and could be applied to the various movements used in the construction sector [8].

In 2020, according to Eurostat, the construction industry in the European Union was responsible for around a fifth of deaths at work and, according to the European Agency for Safety and Health at Work (EU-OSHA), approximately 50% of European construction workers were diagnosed with musculoskeletal injuries [1].

Analysing the data available on PORDATA, it is possible to see that between 2011 and 2021 the apparent productivity of labour in the construction industry, i.e., the wealth created on average, increased by EUR 3562.85 (apparent labour productivity in the construction industry in 2011 and 2021 was EUR 21,018.81 and EUR 24,581.66, respectively), reaching its maximum in 2020, with a total of EUR 25,000.96 [9]. Regarding full-time employment generated by this sector, between 2011 and 2021 there was a decrease of 52,030 jobs (the full-time jobs created by the construction sector in 2011 and 2021 were 402,700 and 350,670, respectively). In 2014, the minimum value for this time interval was reached (272.49 thousand), with this figure gradually increasing until 2021 [10]. It is also important to note that, despite the current property crisis, the Portuguese National Statistics Institute (INE) reported that construction output grew by 4.7 percent last February, 0.2 percentage points down on the previous month, and that the year-on-year change (which measures the change in an indicator compared to its value in the same period of the previous year [1]) in the wage index saw an increase of 11 cent percent, 0.9 percentage points up on January [11].

Several studies assess workers' postures while performing their activities in the workplace. According to Rajendran et al. [12], musculoskeletal injuries, mainly in the lumbar region, accompanied by the adoption of inadequate postures and repetitive movements are the main cause among construction workers.

In addition, analysing a study conducted by Shaikh et al. [5] helped to identify the main factors and provide a comprehensive view of their impact on workers' health. The study conducted by Ogedengbe et al. [13] also proves that this information allows us to understand the implications of a poor work environment resulting from the physical and mental health of workers.

2. Case Study Definition

This case study aims to assess ergonomic risk in the workplace, specifically in the construction sector. This assessment will be based on using some ergonomic tools that assess workers' body postures, such as the Revised NIOSH Lifting Equation (NIOSH equation), Rapid Entire Body Assessment (REBA) and Ovako Work Posture Analysis System (OWAS), specified in the methodology.

The area covered by the case study is the construction sector. According to the statistics provided by ACT, the Authority for Working Conditions, on the number of investigations and serious accidents at work, the construction industry is the sector with the highest rate, with around 684 investigations. All these statistics are broken down by category, state, whether the inquiries have been concluded or are being investigated, month and day of the week, district, age group and sector of activity, among others. To choose the sector under study more intuitively, statistics relating to the sector of activity from 2020 to 2024 were used [14].

The risk of musculoskeletal injuries currently affects most workers in the construction sector and is considered one of the biggest occupational health problems, according to the European Agency for Safety and Health at Work (EU-OSHA) [1]. This type of injury can affect the muscles, ligaments, tendons and nerves of the human body, and can be intensified by workers' efforts and inappropriate postures [2].

Although we used some data from ACT, which also presents surveys showing the number of accidents to the different parts of the body affected during the execution of tasks in this sector, we used the scientific database Science Direct and others, to define which parts of the body would be analysed in this case study.

Most of the injuries found in industrial workers, particularly in the construction industry, are related to lifting and transporting loads, repetitive movements and inadequate handling of tools from an ergonomic point of view. These activities cause lower back injuries, affecting between 50–70% of workers, and this type of back injury affects more than a quarter of workers in manual labour environments [7,13,15]. All these injuries can lead not only to future health problems for workers but also to lower productivity and competitiveness for organisations [13,16]. MSDs are considered a problem of an individual, social and organisational nature [16].

Since MSDs are a key factor in the fight against occupational diseases, working conditions must be optimal, by adopting more appropriate postures when conducting tasks and improving workers' health, safety and quality of life [16].

This case study will therefore be based on three postures frequently adopted by workers in the construction sector, using ergonomic risk assessment tools. Throughout its development, certain parts of the body will be assessed (trunk, neck, legs, arm, forearm and wrist) so that all the proposed indicators can be calculated.

3. Methodology

Given the relevance of the case study presented above and the negative consequences of adopting an incorrect posture when conducting construction tasks, this chapter will present some previously weighted indicators—the OWAS, NIOSH and REBA—to assess the ergonomic risk associated with these postures.

This weighting arises from the evaluation of the set of tools that are commonly used to assess ergonomic risk (NIOSH [17], Rapid Upper Limb Assessment (RULA) [12], OWAS [12], REBA [12] and Washington Industrial Safety and Health Act (WISHA) [18]) in various work tasks and the assessment of different parts of the human body. However, ergonomic risk assessment is not straightforward, as different people can make different interpretations of the same position and the danger it represents [19]. Furthermore, not all tools can include all parts of the body, limiting the assessment of other risk factors present in work environments, and they are often expensive and difficult to implement [19]. Additionally, the assessments that are usually conducted do not always take into account the body dimensions of the individual performing the task, their physical abilities, or even something as basic as their age [19].

This chapter also presents a decision support system to help assess production ergonomics, in this case using data from the construction sector.

3.1. OWAS

In addition to the fatigue associated with hard construction work, the constant and repetitive incorrect postures that workers adopt while conducting the activities associated with their work can lead to the development of MSDs in the long term. Therefore, from an ergonomic point of view, these postures need to be identified and signalled so that they can subsequently be reduced [20].

There are various tools used to assess incorrect postures, which include the OWAS, RULA and REBA methods. However, when compared to other tools, the OWAS proves to be more effective in assessing postures in complex and unclear workplaces, as is the case in the construction sector. Consequently, this study uses the OWAS as one of the tools to quantify the risks associated with the movements made by operators while conducting their work [20].

The OWAS was designed to assess body positions during working hours and score them according to the strain identified [12]. In this way, the tool is used to carry out a total ergonomic assessment of body postures, taking into account the movements of the trunk, arms and legs, combined with the weight of the load carried, these four points being defined by a code with four variables, respectively [20,21]. Each of these variables has several steps associated with it, which represent the postures adopted while conducting the tasks and the intensity of the operation [20,21]:

- Trunk/back: 1 (neutral), 2 (leaning forwards), 3 (twisted) and 4 (bent/twisted);
- Arms: 1 (both arms below shoulders), 2 (one arm above shoulders) and 3 (both arms above shoulders);
- Legs: 1 (sitting), 2 (standing with both legs stretched out), 3 (standing with one leg stretched out), 4 (standing with one knee bent), 5 (standing with both knees bent), 6 (kneeling/squatting) and 7 (walking);
- Load: 1 (less than 10 kg), 2 (between 10 and 20 kg) and 3 (more than 20 kg).

Subsequently, a total score is calculated, using worldwide consensus tables, called S, which classify the total risk into four levels: (i) S = 1, the postures have no particular ergonomic risk; (ii) S = 2, the postures have a slight risk; (iii) S = 3, the postures have a harmful effect and (iv) S = 4, the postures have an extremely harmful risk [20]. By way of example, if a worker, while conducting their task, is bent over, with both arms below their shoulders, kneeling and unladen, their level of risk will be the maximum level, i.e., level 4.

In the end, the OWAS Index (*OI*) can be calculated using (1), shown below, where a indicates the percentage of observations with a risk assessment of 1 and b, c and d correspond to the observations with a risk assessment of 2, 3 and 4, respectively [21].

$$OI = (a \times 1 + b \times 2 + c \times 3 + d \times 4) \times 100 \quad (1)$$

The minimum value for the *OI* is 100, which corresponds to an activity with no ergonomic risks, and the maximum value is 400, which indicates an activity with a fairly high risk. Louhevaara and Suurnäkki [21] considered that an activity is not ergonomically critical if its *OI* is below 200.

3.2. NIOSH Equation

The NIOSH equation is used to assess ergonomic risk in object lifting and lowering operations, focusing mainly on identifying the risk of the task during its performance. The parameters used in the NIOSH equation are the recommended weight limit (RWL) and the Lifting Index (LI) [15].

The RWL, established as the maximum safe weight to be lifted/lowered by the worker in a given time in a repetitive manner, is the main part of the NIOSH calculation and is defined by a set of specific information about the task to be performed, such as the load that the healthiest workers (those who have no previously diagnosed health problems that could increase the risk of MSDs) could handle over an extended period, such as 8 h of work a day, without causing a long-term injury. Equation (2) shows how *RWL* is calculated [13,15].

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM \quad (2)$$

In the formula, *LC* (load constant) represents the load constant, usually 23 kg; *HM* (horizontal multiplier) and *HV* (vertical multiplier) translate, respectively, the horizontal and vertical location of the object; *DM* (distance multiplier) indicates the distance the object has moved; *AM* (Asymmetric Multiplier) corresponds to the asymmetry factor; *FM* (frequency multiplier) symbolises the frequency of movement and *CM* (coupling multiplier) represents coupling [12,13].

The HM considers the horizontal location (H), which is measured from the midpoint of the line joining the inner bones of the ankle to a point projected on the ground directly below the midpoint of the hands (centre of load).

The HV is defined considering the vertical location (V), defined as the vertical height of the hands above the floor. To determine the MD, the vertical travel distance (D) is used, characterised as the vertical travel distance of the hands between the origin and destination of the lift.

AM considers that asymmetry refers to a lift that starts or ends outside the midsagittal plane. FM is defined by the number of lifts per minute, the time dedicated to the lifting activity and the vertical height from the floor. The lifting frequency (F) refers to the average number of lifts performed per minute [13].

The *LI* provides an estimate of the level of physical stress associated with lifting work. This estimate is calculated using Equation (3), which relates the weight of the load lifted (*L*) to the recommended weight limit (*RWL*) [13].

$$LI = \frac{Load\ Weight}{Recommended\ Weight\ Limit} = \frac{L}{RWL} \quad (3)$$

Thus, based on the values obtained with Equation (3), the risk of a particular activity can be determined. In this way, if the *LI* is less than 1.0, the posture is considered to have a very low ergonomic risk, if the *LI* is between 1 and 1.50 the ergonomic risk is considered low, if the *LI* is between 1.50 and 2 the level of risk is moderate, if the *LI* is between 2 and 3 the ergonomic risk is high and if the *LI* is greater than 3 the level of risk is considered very high [13,15].

It should be borne in mind that the NIOSH equation considers the operator's origin and destination, analysing their entire movement.

3.3. REBA

The REBA ergonomic assessment tool is a rapid whole-body assessment method that is commonly used to analyse the postures adopted by workers when conducting their tasks and the ergonomic risks associated with them [19].

As this method enables a full-body assessment to be carried out, taking into account heavy lifting, repetitive hand movements, and neck and trunk flexion, it is the most widely used indicator in a wide variety of sectors, such as transport, manufacturing, education, agriculture, health and construction [19].

However, calculating the REBA is not as intuitive as other indicators, and it is necessary to follow predetermined steps and consult the scores assigned to each element in existing tables [19]. In other words, initially, it is essential to define what you want to assess to obtain the REBA scores, which depend directly on the angles of each part of the body (neck, trunk/spine, legs, arms and wrist) made while performing the tasks [19,22].

For calculation purposes, the REBA method divides the body parts into two groups: group A, consisting of the neck, trunk and legs, and group B, consisting of the upper arm, lower arm and wrist [19]. Figure 1 shows groups A and B with their respective elements, as well as the angles corresponding to the movements performed. It should be noted that in Figure 1 each angle (or range of angles) has a score assigned depending on the type of movement performed. This will be the score used to conduct the rest of the REBA method calculations [19,22].

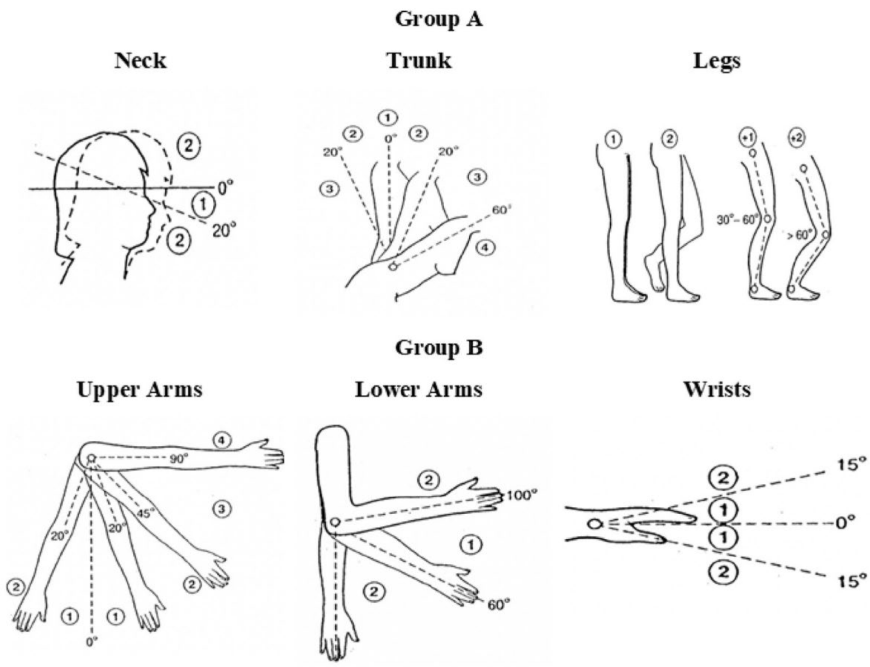


Figure 1. Body elements belonging to groups A and B and their corresponding movement angles [19].

Taking the position of the operator's body parts and their respective scores as a starting point, it is possible to define the next steps and how they will be carried out to obtain a final ergonomic risk score using the REBA method [19].

Group A's scheme of action begins by defining the positions of the constituent elements (neck, trunk and legs), to define a score for each of the assumed angles. Then, with these data, it is necessary to use existing tables to find the score for that posture, thus discovering the score for posture A. The same happens for group B, obtaining the score for posture B [19].

However, to calculate the score attributed to groups A and B, it is necessary to consider the force exerted when acting group A (if applicable) and, in the case of group B, the coupling of objects to the hand. Thus, score A and score B give rise to a new score, determined using a final table relating the two scores. By adding the activity score to the resulting value, the REBA score for the posture in question is calculated and, finally, it is possible to realize the ergonomic risk it represents for the operator [22,23].

Figure 2 shows the calculation diagram that will be used to calculate the REBA score, using all the indicators.

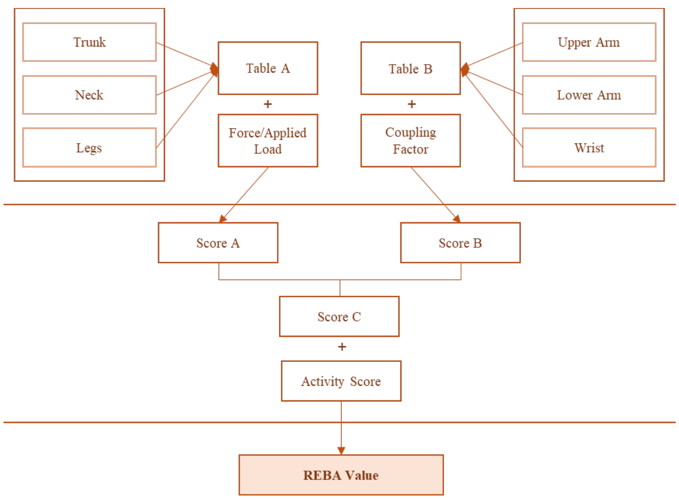


Figure 2. REBA calculation diagram (adapted from [19,23]).

4. Formulation

To put into practice the indicators presented above (OWAS, NIOSH and REBA) for calculating the underlying ergonomic risk of certain postures frequently adopted by workers in the construction sector, a production ergonomics decision support system was built.

This decision support system (DSS) consists of calculating and creating awareness of the ergonomic risk by entering weighted data on the postures that are adopted. It was developed in Microsoft Office Excel to make its implementation in the industry more intuitive and clearer, given that it is one of the most widely used programmes in an industrial environment.

4.1. OWAS

The OWAS values were determined using the table defined by Louhevaara and Suurnäkki [21]. The first step was to identify the variables to be assessed and their respective scores, namely the position of the trunk, arms and legs and the load carried by the worker. The values for the trunk, arms, legs and load are filled in in Table 1, according to the posture the worker performs during their work.

Table 1. OWAS determination table.

Assessment	
Trunk	0
Arms	0
Legs	0
Load	0
OWAS	

With this information, the decision support system determines the level of risk associated with the posture in question and identifies its severity using a colour system. Table 2 shows the association between the possible OWAS values and the level of ergonomic risk, with the corresponding colour coding.

Table 2. OWAS risk levels.

Associated Risk	
OWAS Value	**Risk Level**
1	low
2	medium
3	high
4	very high

4.2. NIOSH

The NIOSH values were calculated using Equations (2) and (3), as previously defined and explained. Thus, in the decision support system developed, it is only necessary to enter the values associated with the calculation, both for the origin and the destination, taken from the tables defined by Waters, Putz-Anderson and Garg [13].

In other words, these values are the load constant, which is 23 kg, the horizontal and vertical multiplier, the distance multiplier, the asymmetry multiplier, the coupling multiplier and the actual weight of the load being transported [13,15].

In this way, the system determines the Lifting Index, which must be less than 1.0. When the LI is within the established limits, the cell in which it was calculated is filled in green. However, when the LI is higher than 1.0, the cell is filled in red, indicating that the posture performed by the worker has a high ergonomic risk. Figure 3 shows the layout of the decision support system, where the values of the variables should be entered.

	LC		HM		VM		DM		AM		FM		CM	
	Origin	Destination	Origin	Destination	Origin	Destination	Origin	Destination	Origin	Destination	Origin	Destination	Origin	Destination
Posture X														
Posture Y														
Posture Z														
Posture VAL														

Figure 3. Decision support system for calculating NIOSH.

With this information, the decision support system will determine the level of risk associated with the posture in question and identify its severity using a colour system. Table 3 shows the association of the possible NIOSH values with the level of ergonomic risk, with the respective colour code, and the recommended actions for each level of risk.

Table 3. NIOSH risk levels and recommended actions.

LI Value	Risk Level	Recommended Actions
$LI \leq 1.00$	Very Low	The load is acceptable for most people and no action is required for the healthy population.
$1.00 < LI \leq 1.50$	Low	The load should be assessed, and medium-term changes introduced. Pay special attention to low frequency/high load conditions and extreme and static postures.
$1.50 < LI \leq 2.00$	Moderate	Reformulate tasks and workplaces according to priorities to reduce LI, analysing the results to confirm the effectiveness of the changes.
$2.00 < LI \leq 3.00$	High	Short-term changes should be introduced to reduce the risk of MSDs. Tasks with this assessment should be redesigned or assigned only to selected workers who will be rigorously monitored.
$LI > 3.00$	Very high	The load presents a risk to most people and action should be taken immediately. This type of task is unacceptable from an ergonomic point of view and should be modified.

4.3. REBA

The decision support system used to calculate the REBA values was developed based on the data and tables suggested by Hignett and McAtamney [24] when developing this indicator, divided into three tables with the addition of some key elements related to the positions chosen. Figure 4 shows the layout of the decision support system for the REBA method, described in the previous chapter, where all the calculation formulas have been entered to obtain the final value for the indicator in question.

The values for the trunk, neck, legs, upper arm, lower arm, wrist, load factor, coupling factor and activity factor are entered manually by the user by assessing the posture adopted by the worker, since different postures can result in different ergonomic risk values.

In addition, score A was obtained by adding the value resulting from table A with the load factor, score B by adding the value resulting from table B with the coupling factor and score C from table C, using the two previous scores. All these values resulting from looking at the tables are obtained automatically by the system, according to the values entered for each body component. So, the operator does not need to spend time analysing the tables, just the postures.

Once the values have been obtained, the system calculates the final REBA value (C score + activity) and issues a visual signal depending on the ergonomic risk presented and the type of intervention required.

The colours relating to the visual signal issued can be found in Table 4, along with the respective ergonomic level and the action that needs to be taken.

The same procedure was conducted for the three postures chosen (X, Y and Z postures).

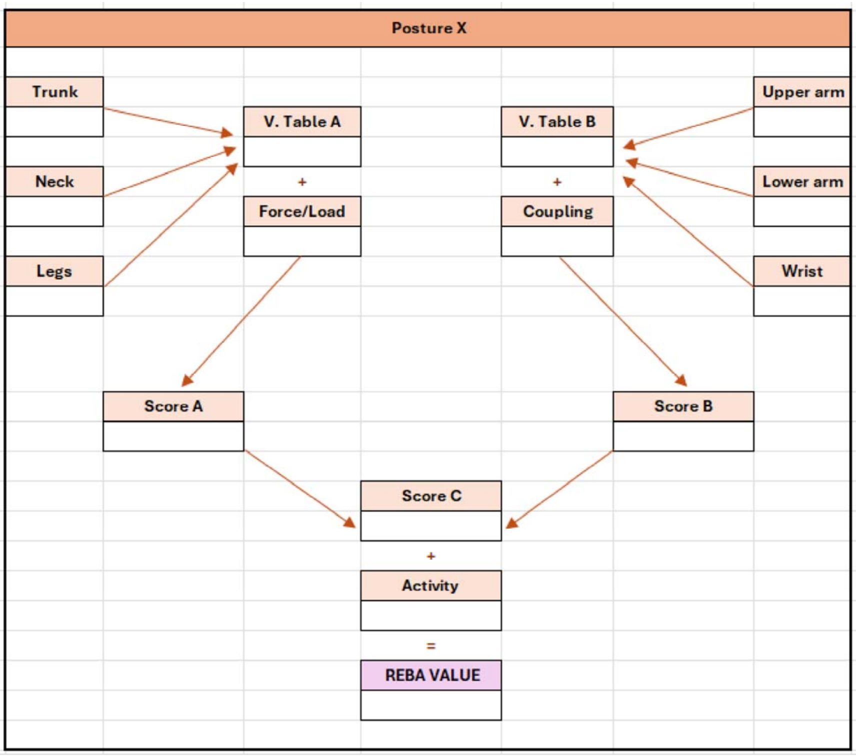


Figure 4. Decision support system for calculating REBA.

Table 4. REBA action levels.

REBA Action Levels			
REBA Value	***Risk Level***	***Action Level***	***Action (After Complementary Action)***
1	null	0	not necessary
2 a 3	low	1	may be necessary
4 a 7	medium	2	necessary
8 a 10	high	3	needed very soon
11 a 15	very high	4	necessary now

4.4. Posture Explanation

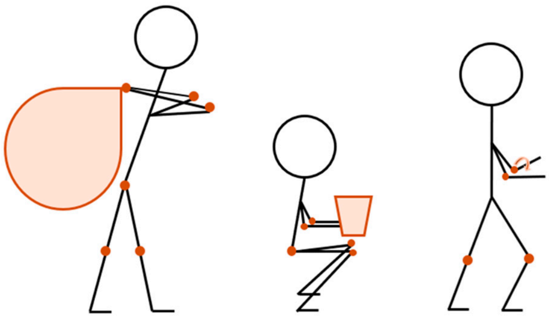
To be able to apply the ergonomic risk assessment tools defined, three postures typically performed by workers in the construction industry were selected. A brief description of each posture will be given below to assess their ergonomic risk.

4.4.1. Posture X

The first posture involves lifting a load above the shoulders. Thus, the worker has a slight inclination of the trunk, of around 20°. In addition, the worker's lower arms are both being used above the shoulders, making an angle of more than 100°, and the arm makes an angle of 90° with the trunk. In this case, the worker's wrist can be in a straight position. To make it easier to understand what has been described above, a representative sketch of posture X has been drawn up, shown in Figure 5.

4.4.2. Posture Y

In posture Y, we tried to represent the worker squatting. In this sense, the worker has a slight inclination of the trunk, about 10°, with the pelvic area below the usual axis when the body is standing and with both knees bent. The thigh makes a 90° angle with the trunk and the knee is bent more than 60°. To make the description easier to understand, a sketch representing the Y posture was made, illustrated in Figure 5.



(a) (b) (c)

Figure 5. Graphic representation of postures: (**a**) posture X; (**b**) posture Y; (**c**) posture Z.

4.4.3. Posture Z

The third and final posture depicts the right hand attaching a tool followed by a rotational movement of the arm to place mortar on a wall. The left lower arm is at a 90° angle to the arm, holding a container with the mortar. In addition, in this posture, the worker is standing with a neutral trunk, without any inclination, and with one knee bent at an angle of between 30° and 60°. As with the other postures, a sketch of posture Z was drawn up, as shown in Figure 5.

5. Results and Discussion

Considering the description of the decision support system developed, this chapter will present and discuss the results obtained for each indicator, by entering the data relating to positions X, Y and Z into the system, as described above.

5.1. Posture X

5.1.1. OWAS

As mentioned in the description of posture X, the worker is leaning with his trunk forward, both arms above his shoulders, standing with both legs stretched out and carrying a 25 kg load, the equivalent of a sack of cement. Thus, the scores used to determine the OWAS were as follows: trunk—2 (leaning forward), arms—3 (both arms above the shoulders), legs—2 (standing with both legs straight) and load—3 (over 20 kg). The level of risk generated by the OWAS is shown in Table 5.

Table 5. OWAS result for posture X.

Assessment	
Trunk	2
Arms	3
Legs	2
Load	3
OWAS	3

Considering the value obtained (3), it can be said that posture X has a high level of risk. This value is essentially due to the position of the arms and the load carried, with these two variables obtaining the maximum score.

5.1.2. NIOSH

To determine the NIOSH values, it was considered that before the worker reaches posture X, the bag of cement is on the floor and that the worker must bend down to get the bag onto his back, so it can be said that the type of coupling he performs is of the bad type, being uncomfortable and entailing some ergonomic risks for the operator. So, for the origin, the calculation variables have the following values: HM—1.00 (H ≤ 25 cm), VM—0.78 (V = 150 cm), DM—0.85 (D = 145 cm), AM = 1.00 (A = 0°), FM = 0.94 (≤ 1 h, V ≥ 75 cm and F = 1), CM = 0.90 (V ≥ 75 cm and Type = Bad) and LW = 25 kg. Regarding destination, the calculation variables have the following values: HM—1.00 (H ≤ 25 cm), VM—0.81 (V = 140 cm), DM—0.85 (D = 145 cm), AM = 1.00 (A = 0°), FM = 0.94 (≤ 1 h, V ≥ 75 cm and F = 1) and CM = 0.90 (V ≥ 75 cm and Type = Bad). The result of the Lifting Index calculation is shown in Table 6.

Table 6. NIOSH result for posture X.

Posture X	
RWL Origin	12.90065
RWL Destination	13.39683
LI Origin	1.937886
LI Destination	1.866113

By calculating the Lifting Index, we can see that its value is 1 at both the origin and destination, which means that, according to this indicator, posture X poses a moderate ergonomic risk to the worker. The task should therefore be reformulated to reduce the LI and the results analysed to confirm the effectiveness of the changes.

5.1.3. REBA

Based on the above description of posture X, in which the worker shows obvious tension in the trunk and arms due to the weight being carried, the following values were assigned to the body elements: trunk—2 (flexion of 20°), neck—1 (flexion between 0° and 20°), legs—1 (no change), upper arm—3 (90° with the trunk), lower arm—2 (flexion >100°) and wrist—1 (no change).

Considering that the operator is carrying a sack of cement weighing around 25 kg, the load factor was given 2 points and the coupling an equal score, because the grip, although possible, is not acceptable. Finally, the activity was scored with 2 points because parts of the body were stationary for more than a minute and because the weight of the load caused an unstable base. Figure 6 shows the final REBA value for this posture, calculated using the decision support system developed.

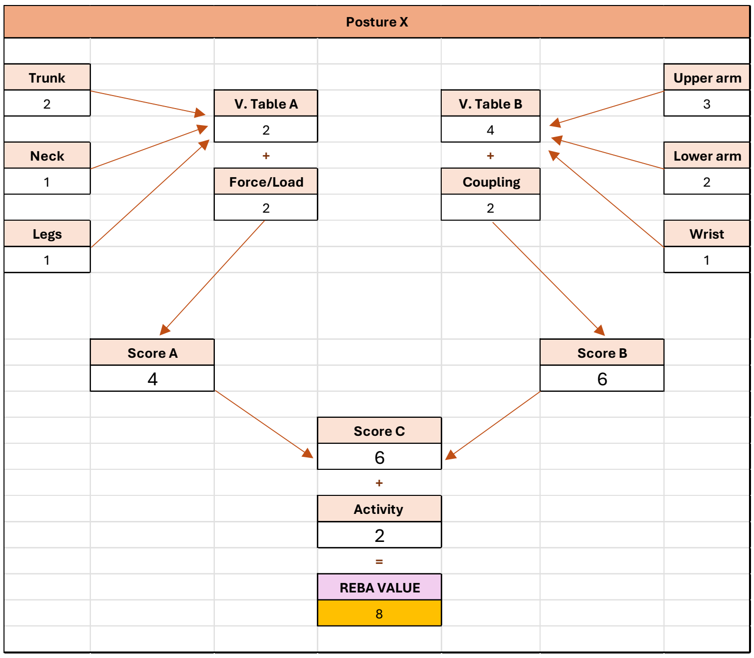


Figure 6. REBA result for posture X.

Looking at Figure 6, this posture has a REBA value of 8, meaning that the ergonomic risk level of this posture is high, which will imply a third level of action, i.e., corrective action, is needed very soon.

In this posture, the factor that has the most implications will be the trunk, given the weight of 25 kg that is exerted on it and the poor positioning of the arms, together with the handle, which is not acceptable and is very harmful to the operator's health.

5.2. Posture Y

5.2.1. OWAS

In posture Y, you can see that the worker has both knees bent but is not standing. In addition, his trunk is slightly inclined, both arms are below his shoulders and the load he is carrying is 5 kg. The decision variables therefore take on the following values: trunk—2 (leaning forwards), arms—1 (both arms below the shoulders), legs—6 (kneeling/squatting) and load—1. The level of risk determined by the decision support system is shown in Table 7.

Table 7. OWAS result for posture Y.

Assessment	
Trunk	2
Arms	1
Legs	6
Load	1
OWAS	2

5.2.2. NIOSH

Before the worker reached posture Y, he had to pick up the bucket from the floor and stoop down. It can be said that the type of coupling he performs is of the regular type, since this movement does not overload the back. Thus, the variables used to calculate the NIOSH for the origin have the following values: HM—0.57 (H = 44 cm), VM—0.93 (V = 50 cm), DM—0.90 (D = 55 cm), AM = 1.00 (A = 0°), FM = 0.91 (≤ 1 h, V ≤ 75 cm and F = 2), CM = 0.95 (V < 75 cm and Type = Regular) and LW = 5.00 kg. However, for the destination, the values used are as follows: HM—0.57 (H = 44 cm), VM—0.84 (V = 130 cm), DM—0.86 (D = 130), AM = 1.00 (A = 0°), FM = 0.91 (≤ 1 h, V ≤ 75 cm and F = 2), CM = 1.00 (V ≥ 75 cm and Type = Regular) and LW = 5.00 kg. The calculation of the Lifting Index is shown in Table 8.

Since the Lifting Index value for both the origin and destination is less than 1.0, posture Y has a very low ergonomic risk for the worker, where the load is acceptable, and no improvements are needed.

Table 8. NIOSH result for posture Y.

Posture Y	
RWL Origin	9.486219
RWL Destination	8.618304
LI Origin	0.52708
LI Destination	0.580161

5.2.3. REBA

The same analysis made of posture X was applied to posture Y, in which the operator is in an unstable position, since all the support is provided by his legs in a very unstable position. The following scores were given to the body parts: trunk—2 (10° flexion), neck—1 (no change), legs—4 (2 unstable posture + 2 flexion > 60°), upper arm—1 (straight with the trunk), lower arm—1 (90° flexion) and wrist—1 (no change).

Given that the operator only supports a weight in both hands of around 5 kg and that the grip is adequate, scores of 1 and 0 were assigned to the load and coupling factor, respectively.

Finally, the activity score reached a value of 3, since one or more parts of the body are stationary for more than a minute, short-range actions are performed with the feet and the posture is highly unstable.

Figure 7 shows the REBA value assigned to posture Y by the decision support system.

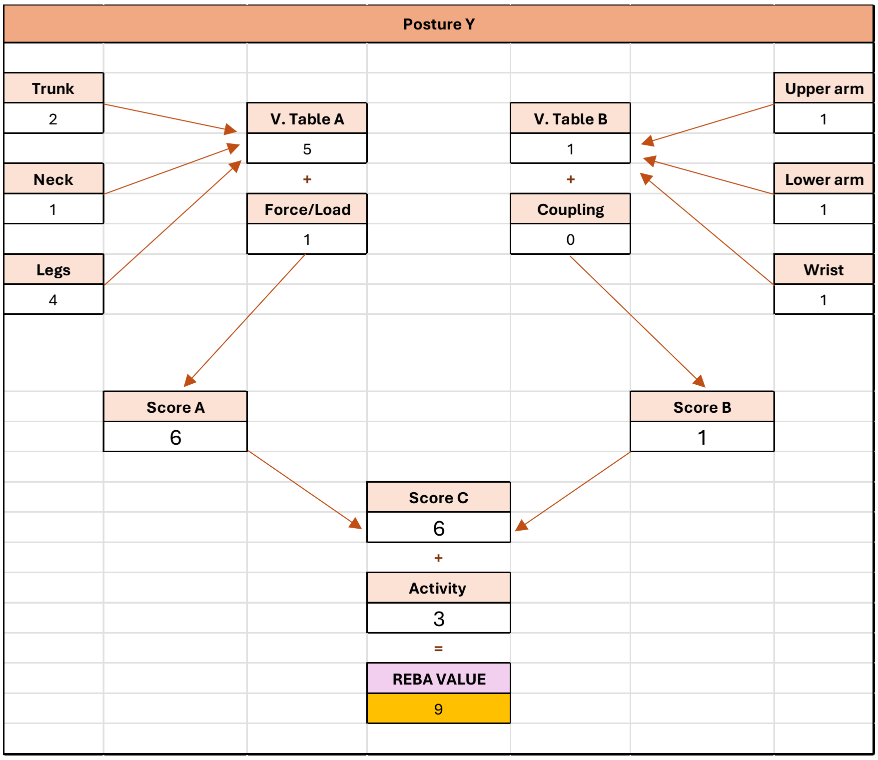


Figure 7. REBA result for posture Y.

Looking at Figure 7, it can be seen that the final REBA value assigned to posture Y was 9, indicating that the risk level is high, and that corrective action is needed very soon, with action level 3.

Comparing the operators' postures and the REBA values for postures X and Y, posture Y has a higher REBA, even if the grip is adequate and there is not as much tension in the trunk and arms as there is in posture X. However, in posture Y, the operator exerts a lot of pressure on the lower limbs, with the weight of the body supported by the legs in an extremely unstable position. As a result, even though the REBA values are relatively similar, the Y posture is more harmful than the X posture.

5.3. Posture Z

5.3.1. OWAS

Considering the description given above, it can be said that the worker's trunk is in an upright position, with no inclination, that both arms are below the shoulders and that the load the worker is carrying is less than 5 kg. However, the worker is standing with one knee bent. Thus, the values associated with the variables are trunk—1 (neutral), arms—1 (both arms below the shoulders), legs—4 and load—1. Thus, the value assigned by the system to posture Z is shown in Table 9.

Although most of the variables have been assigned the minimum value, the risk level of this posture is medium. This value is because the worker is standing with one knee flexed, which causes the leg score to be 4, instantly increasing the OWAS value.

Table 9. OWAS result for posture Z.

Assessment	
Trunk	1
Arms	1
Legs	4
Load	1
OWAS	2

5.3.2. NIOSH

Since the Z posture simulates the worker putting cement on the wall, he had to bend down to pick up the necessary tools and then stand up again, without excessive ergonomic effort. Thus, the NIOSH calculation variables, at source, take on the following values: HM—0.57 (H = 44 cm), VM—0.90 (V = 40 cm), DM—0.93 (D = 40 cm), AM = 1.00 (A = 0°), FM = 0.94 (≤ 1 h, V ≥ 75 cm and F = 1), CM = 1 (V > 75 cm and Type = Good) and LW = 2.5 kg. However, the NIOSH calculation variables at the destination assume the following values: HM—0.57 (H = 44 cm), VM—0.93 (V = 100 cm), DM—0.87 (D = 100 cm), AM = 1.00 (A = 0°), FM = 0.94 (≤ 1 h, V ≥ 75 cm and F = 1), CM = 1 (V > 75 cm and Type = Good) and LW = 2.5 kg. The calculation of the Lifting Index is shown in Table 10.

Table 10. NIOSH result for posture Z.

Posture Z	
RWL Origin	10.3146858
RWL Destination	9.97086294
LI Origin	0.24237287
LI Destination	0.250730555

Since the Lifting Index value for both the origin and destination is less than 1.0, posture Z has a very low ergonomic risk for the worker, where the load is acceptable, and no improvements are needed.

5.3.3. REBA

Finally, of all the postures proposed for analysis, only the Z posture is missing, which represents movements like the operator placing mortar on a wall. In this case, the following values were assigned to the body elements: upper body—1 (as it is straight), neck—1 (no changes), legs—3 (2 unilateral+1 flexion between 30° and 60°), upper arm—2 (one arm aligned with the upper body, but the other rotates), lower arm—1 (flexion between 60° and 100°) and wrist—2 (as well as being straight, the wrist rotates when placing the mortar).

The load and coupling weighting factors were considered satisfactory, given that the tool with which the operator places the mortar is much less than 5 kg, including the "plate" on which it is placed before being applied to the wall. In addition, the grip on these objects is quite acceptable with an equally satisfactory average power.

The activity, on the other hand, was given a score of 2, as there are parts of the body that are stationary for more than 1 min and, in addition, the short-range actions are carried out repetitively.

Figure 8 shows the REBA result for posture Z, obtained by the decision support system developed.

From the result obtained by the decision support system, shown in Figure 8, the REBA value assigned to posture Z was 5, which is considered to present a medium level of ergonomic risk, where corrective action will be required in the future.

Compared to the previous postures, this one present less ergonomic risk because the operator has the correct trunk and neck postures, although the movement of the arms is not the most appropriate, particularly when applying the mortar. The way the operator moves his wrist and arm creates tension in these elements, which could lead to future musculoskeletal injuries.

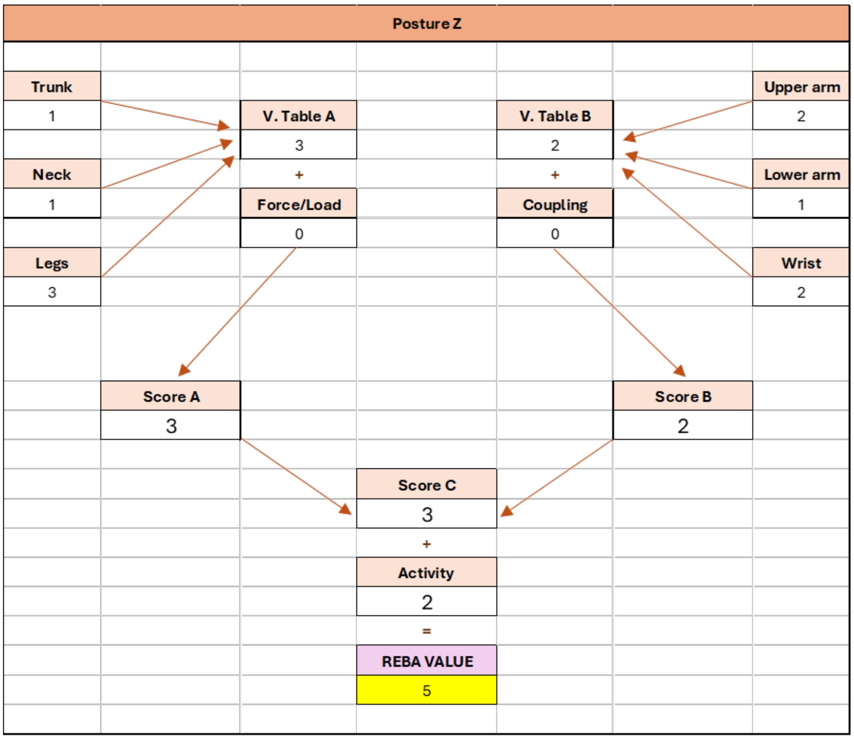


Figure 8. REBA result for posture Z.

Although posture Z exhibited a lower overall risk, the movement involved in applying mortar during the construction tasks (posture Z) revealed the potential for cumulative strain injuries in the arms and wrists. This underscores the importance of regularly rotating workers between tasks to prevent overuse injuries.

5.4. Results Validation

To prove that the decision support system developed was well structured and that all the results presented above are valid, this section presents the application of the system in question to three positions studied in scientific articles.

5.4.1. OWAS Validation Posture

To confirm that the decision support system developed actually works, the skidding posture studied by Enez and Nalbantoğlu [25] will be used. In this posture, the worker is standing with the trunk leaning forwards, both arms below the shoulders and no load. Thus, the values assigned to the OWAS determination variables are as follows: trunk—2 (leaning forward), arms—1 (both arms below the shoulders), legs—2 (standing with both legs straight) and load—1 (less than 10 kg). The level of risk associated with this posture is shown in Table 11.

Table 11. OWAS result for validation posture.

Posture VAL Assessment	
Trunk	2
Arms	1
Legs	2
Load	1
OWAS	2

As can be seen in Table 11, the level of risk attributed to this posture is medium. However, as assigning values to each variable is a subjective activity, the values assigned by the authors of the article to each of the variables is different and are as follows: trunk—1 (neutral), arms—2 (one arm above the shoulders), legs 2—(standing, with both legs stretched out) and load—1 (less than 10 kg). In this way, and with the difference in classification between variables, the risk level for this assessment would be low.

5.4.2. NIOSH Validation Posture

As with the REBA and OWAS validation, the NIOSH validation will use a previously studied posture to validate the decision support system developed. Rajendran et al. [15] carried out an ergonomic assessment of workers during the manual handling of materials. Thus, in this section, the posture used to lift a sealed bag from the bottom shelf of a shelf will be used, where the variables used to calculate the NIOSH, at source, take on the following values: HM—0.50 (H = 50 cm), VM—0.84 (V = 130 cm), DM—0.85 (D = 145 cm), AM = 1.0 (A = 0°), FM = 0.88 (V < 75 cm, > 1 but ≤ 2 h, F = 1), CM = 0.95 (V < 75 cm and Type = Regular) and LW = 8 kg. However, at the destination, the variables take on the following values: HM—0.50 (H = 50 cm), VM—0.81 (V = 140 cm), DM—0.8 (D = 145 cm), AM = 0.71 (A = 90°), FM = 0.88 (V < 75 cm, > 1 but ≤ 2 h, F = 1), CM = 1.0 (V ≥ 75 cm and Type = Regular) and LW = 8 kg. The value for NIOSH calculated by the decision support system is illustrated in Table 12.

Table 12. NIOSH result for validation posture.

Posture VAL	
RWL Origin	6.864396
RWL Destination	4.94701
LI Origin	1.165434
LI Destination	1.617138

Comparing the result obtained at the destination using the system developed (LI = 1.617) with the result achieved by the authors of the initial study (LI = 1.562) [15], it is safe to say that the system developed fulfils all the necessary requirements for the efficient calculation of the LI. Thus, the posture of lifting a sealed bag from a bottom shelf, analysing the result provided by both systems, is a posture that entails a moderate ergonomic risk for the worker, where the task should be reformulated to reduce the LI.

5.4.3. REBA Validation Posture

Taking as an example the third posture studied by Enez and Nalbantoğlu [25] for the purposes of validating the REBA calculation, where the operator is removing/moving tree trunks weighing more than 20 kg in a flatbed truck, the following scores were given to the body elements: trunk—5, neck—2, legs—3, upper arms—3, lower arms—2 and wrist—2.

In this case, only the load factor, derived from the trunks being moved, was considered and given a score of 2, as it was a weight of more than 20 kg. The other factors were not considered in the REBA calculation [25].

So, applying these data to the decision support system developed, Figure 9 shows the REBA result obtained for the posture in question.

As can be seen from Figure 9, the REBA result obtained by the decision support system developed is equal to the value resulting from the application of the scientific article. In fact, this type of posture is extremely harmful to workers' health, as the level of ergonomic risk is very high, requiring immediate action at action level 4.

It is therefore possible to conclude that the decision support system used to calculate REBA fulfils the established requirements and can produce valid and credible final REBA values.

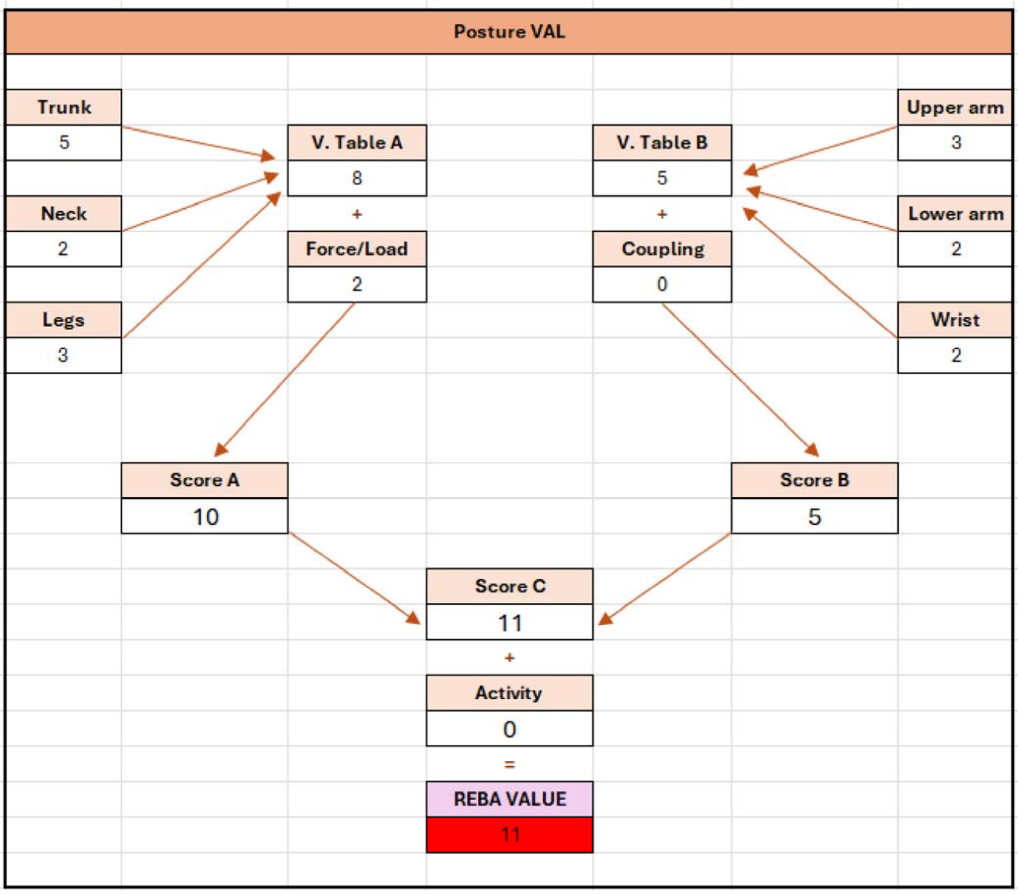


Figure 9. REBA result for validation posture.

5.5. Summary of Results Obtained

After applying the production ergonomics decision support system developed, by calculating the indicators proposed for the postures envisaged, it was possible to compile all the results to compare them.

Table 13 shows all the results obtained for each of the postures, including the validation postures used to gauge the reliability of the system developed.

Looking at Table 13 and excluding the validation postures, it is possible to see that the most critical posture is posture X, which represents the greatest ergonomic risk, as it has the highest OWAS and NIOSH values. However, although the REBA value is not the highest, it does have more weight compared to posture Y, where the OWAS and NIOSH values are lower.

Table 13. Summary of the results obtained for the different indicators for different postures.

	OWAS	NIOSH		REBA
		LI Origin	LI Destination	
Posture X	3	1.93788625	1.866112685	8
Posture Y	2	0.527080388	0.580160535	9
Posture Z	2	0.24237287	0.250730555	5
Posture VAL (OWAS)	2			
Posture VAL (NIOSH)		1.165433929	1.617138368	
Posture VAL (REBA)				11

Therefore, some concern is raised and commitment is needed to correct this type of posture so that it does not have such negative implications for the health of workers in the construction sector, such as the early onset of musculoskeletal injuries, as well as the occurrence of accidents at work that have serious consequences (i.e., serious injuries and even fatal accidents). Analysing these results, there are some strategies that can be adopted by workers. One suggestion for reducing the number of injuries to operators, given the improvement in their body postures, is staff rotation. By implementing this measure, companies are benefiting their workers, as they will not always be in the same position or performing the same tasks. Thus, by rotating operators, i.e., having them change positions, they would enjoy, for example, a few minutes of rest, allowing the upper or lower limbs to stretch, reducing the early onset of injuries during the working period.

Analysing the data relating to the calculation of the OWAS, NIOSH and REBA values, it was concluded that if there were another decision support system, which could be integrated into the one developed, or not, this could automatically evaluate and assign values relating to the body elements of each posture. For this reason, one suggestion for improving the efficiency of this tool would be to use a monitoring device, such as a wristband or other non-invasive mobile device, which would not interfere with the worker's activity.

To support this suggestion, there are already case studies proposing solutions to prevent the risk of musculoskeletal injuries in workers using smart personal protective equipment (PPE) and other monitoring systems [26–29]. This smart PPE emerged from the interaction between Industry 4.0 and International Data Corporation (IoD) technologies [26]. The use of smart PPE enables communication with the environment, as it combines traditional PPE with electronic components and sensors, extracting information about workers and thus reducing the rate of accidents and occupational illnesses [26–29].

The use of these devices is intended to help organisations plan for the long term, with a view to improving Occupational Safety and Health (OSH) policies, using artificial intelligence (AI). In this way, using artificial intelligence algorithms, companies can identify working conditions that are susceptible to accidents. In this way, organisations can maintain safer working environments, with the aim of improving the health and safety of their operators [26–28].

Although this suggestion is a viable option, there are some drawbacks, as these systems can be costly, particularly for small and medium-sized companies. Additionally, another direction for future work could be exploring how this methodology, originally developed for the construction sector, could be adapted and applied to other industries, thus broadening its potential applications beyond construction.

6. Conclusions

The case study presented was aimed at assessing ergonomic risks in the workplace. In this case, the sector in which the case study focused was the construction sector, since it was the area with the highest incidence of serious accidents at work in the last 4 years (from 2020 to 2024).

As presented during the development of this article, some ergonomic indicators that assess workers' postures were used, namely, the OWAS, NIOSH and REBA. To put these indicators into practice, a production ergonomics decision support system was developed by formulating all the data relating to each indicator in Microsoft Office EXCEL.

To validate the system, three pre-defined positions were evaluated: the X, Y and Z postures. In this way, and through scientific validation, it can be concluded that the system developed achieved the objectives set.

To improve working conditions in the construction sector, future studies should focus on using AI techniques to analyse data that can identify which phases of construction pose the greatest risks to workers. The success of this initiative depends on several factors, with the key challenges being the variability of risks and the acceptance of operators.

Author Contributions: Conceptualiszation, L.S., J.V.B. and S.S.; methodology, L.S., J.V.B. and S.S.; software, L.S., J.V.B. and S.S.; validation, T.M.L. and P.D.G.; formal analysis, T.M.L. and P.D.G.; investigation, L.S., J.V.B. and S.S.; resources, L.S., J.V.B. and S.S.; data curation, L.S., J.V.B. and S.S.;

writing—original draft preparation, L.S., J.V.B. and S.S.; writing—review and editing, T.M.L. and P.D.G.; visualisation, T.M.L. and P.D.G.; supervision, T.M.L. and P.D.G. All authors have read and agreed to the published version of the manuscript.

Funding: The authors would like to express their gratitude to FCT—Fundação para a Ciência e a Tecnologia, I.P. and the Centre for Mechanical and Aerospace Science and Technologies (C-MAST) for their support in the form of funding, under the project UIDB/00151/2020 (https://doi.org/10.54499/UIDB/00151/2020; https://doi.org/10.54499/UIDP/00151/2020) (accessed on 7 November 2024).

Data Availability Statement: The data in this study are available from the corresponding author upon request.

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

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