Approach of a Risk Weighting Method of Ergonomic Tools Based on the Combination of the Concepts of FMEA, Risk Matrix and Company Specifications

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Abstract. The use of methods and tools in ergonomic risk assessment presents variations of the interpretation of its results, being more or less restrictive on the measurement related to the severity of the risk. This happens because of many reasons: it begins with the choice of the method, going through the content and limitations of each tool, the underlying factors, such as the interpretation of the analyst and the peculiarities of the activity, of the system and of the organization of the company itself, which leads to doubts regarding the accuracy of the final conclusion. The objective of this paper is to propose the approach to a risk weighting method of the ergonomic tools based on the combination of FMEA concepts, risk matrix and company specifications, considering, besides the final result of the ergonomic tool, other factors involving the existing probabilities and controls, with greater emphasis on the method of ergonomic assessment, thus respecting the company particularities and those of the workers who constitute it, where both receive a greater protagonism role on the final result of the assessment and in the commitment with the improvements.

Keywords: Ergonomic risk assessment · Weighting of ergonomic tools FMEA and risk matrix

1 Introduction

Ergonomics is a science that relies on a wide range of different methods, tools and models to aid in the analysis of tasks, projects and on the interaction between man and work systems. This multiplicity implies in some challenges both for those who develop the methods and for those who use them [1].

According to Stanton et al. [1], the challenges regarding the development and application of ergonomic methods are:

- Develop methods that integrate with other methods;
- Methods that have a connection with the ergonomics theory;
- Facilitate the use of these tools and methods;
- Provide proof of reliability and validity;
- Show that the results of ergonomic tools and methods lead to economically viable interventions;

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- Encourage the ethical application of methods;

The author classifies ergonomic methods into two types: analytical methods and evaluative methods. The former helps the analyst to understand the mechanisms underlying the interaction man × machine. The evaluative methods estimate pre-selected interaction parameters between this man and machine relation. In this way, we can say that ergonomic tools can be qualitative, quantitative or a combination of these two forms, semi quantitative. These two types of methods can be divided into 5 basic categories in data design, as shown in Table 1. The darker highlight represents the primary research in the data design; the lighter represents the secondary research, or what contributes to the data design.

Table 1. Wilson's map of five basic types of design data, [1]

	Data about People	Systems Development	Human Machine Performance	Demand and Effects on People	Ergonomics Management Programs
Physical					
Phychophysiological					
Behavioral - Cognitive					
Team					
Environmental					
Macroergonomics					

The division presented in Table 1 contributes to the understanding of the lack of ideal or complete method that is able to satisfy every demand that an activity may require. In addition, when the analyst selects a single tool, method or even summarizes the result of an ergonomic risk assessment to a checklist, in detriment of the overall situation and the specificity of the company, the analysis result as well as the recommendations for improvements suggested based on this data will be distorted and questionable, [2]. Another problem involving the use of ergonomic tools are the questions asked by a part of the users. According to Stanton et al. [1], the most frequently asked questions of users of ergonomic tools are:

- How deep should the analysis be?
- Which methods of data collection should be used?
- How should the analysis be presented?
- Where is the use of the method appropriate?
- How much time and effort does each method require?
- How much and what type of expertise is needed to use the method?
- What tools are there to support the use of the method?
- How reliable and valid is the method?

Once both of the two problems previously exposed are solved:

1. Do not work the ergonomic tool in isolation, as the only solution to find all the answers that an analysis can offer and,
2. Reflect deeply on the doubts that involve the application of a method or tool.

Another challenge is to obtain a better understanding regarding the consistence reliability and validation of an ergonomic tool and its reflection on the accuracy regarding the conclusion of the ergonomic risk, which in many cases is the main argument for the implementation of improvement actions. It even serves as a kind of validation of the recognition of the workers' verbalizations, which further increases the responsibility of the ergonomist to base his conclusions and proposal for solutions only in the result of a tool.

For Guérin et al. [2], the conclusion about the effectiveness of an ergonomic action is not simple, since it involves the judgment and perception of several actors (direction, management, operators and others). Every action can put a lot at stake, which ends up involving the reliability of the technical capacity and the effectiveness of the specialist's practice. Concluding or not the risk is part of an ergonomic action, and as such will be subject to this judgment.

What makes a tool or method valid and reliable is the ability to satisfy three criteria: It needs to have framework: It needs to be relevant and able to encompass content; it needs to be applicable. Besides these characteristics, the method needs to be tested and replied over time by different people [1].

All differences in the results of the tools and methods should occur entirely due to the specifities of the system, company, project or activity being evaluated and not by different interpretations depending on the expertise or even the personal interests of the evaluators or the expectations of the agents around them [1, 2].

Contrary to what is practiced in Occupational Safety, there is no reference standard in Ergonomics for the classification of the ergonomic risk. An example is what happens in the United States, where there are objective criteria, such as the TLV from ACGIH, when it comes to Occupational Hygiene [3].

By the very objective and purpose of ergonomics, which seeks to preserve the health and well-being of the worker [4], verifying the comfort, without being limited by aspects of limits of tolerance, as in Occupational Hygiene, the conclusion about the ergonomic risk and/or the choice of method that assists in this action is optional to the ergonomist. When the analyst chooses to complete an ergonomic analysis, addressing the issue of risk, he can do so starting with his empirical knowledge, or based on the results of an ergonomic method or tool. In both cases, unlike in Occupational Safety, there are no universal limits established.

For Bird Jr. and Germain [5], risk can be understood as the product of the multiplication between the factors of likelihood of occurrence of a dangerous event and its severity in relation to injuries, wounds or health damage. The representation of this association through a ranking constitutes a relevant technique for analyzing the factors that surround the risks of an activity, and can be done as suggested by the author through a matrix.

In addition to the concepts of definition and schematization through a risk matrix, the approach proposed in this study makes use of the concepts of the Failure Mode and Effect Analysis (FMEA) method.

The FMEA method evaluates the relative risk of a failure and its effects through the analysis of three factors: severity, probability and detection. Using the data, the knowledge of the process, the mode of occurrence of a failure and its effects, it is established a rating for each of the three factors, on a scale ranging between 1 to 10, from low to high. By multiplying the ranking of the three factors (severity × probability × detection), it is found the risk priority number (RPN) for each potential of failure mode and effect. The higher the score, the higher it's priority.

This paper has the objective of purposing an ergonomic risk weighting approach, based on the concepts of FMEA, risk matrix and company specifications, considering, besides the final results of the ergonomic tool, other factors involving the probabilities and the controls existing in the systems, projects, workstations and their activities. Thus, this approach respects the particularities of the company and those of the workers who constitute it, where both receive a greater protagonism role on the result of the analysis and in the commitment with the improvements.

2 Methods

2.1 Previous Studies

In the previous studies, an ergonomic risk assessment of the work involving a nursing activity was carried out, where the nurse performs the change of decubitus of the bedridden patients. In addition to the ergonomic risk assessment of the work, the ergonomic tool Rapid Entire Body Assessment (REBA) was used, with the results presented in image 1 and Table 2, below (Fig. 1).

Company activity: Hospital
Activity analyzed: Change of decubitus in bedridden patients
Ergonomic tool used: Rapid Entire Body Assessment (REBA)
Tool score: Discomfort, difficulty or fatigue **(corresponding to a medium risk)**
Interpretation of the score and action recommended by the tool: Table 2.

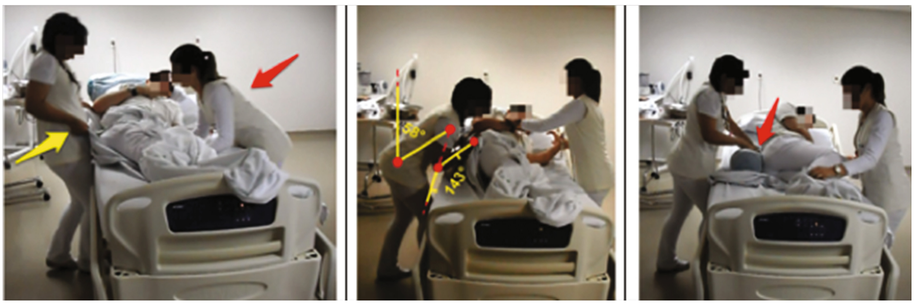

Fig. 1. Evidence by photographic records of the ergonomic risk assessment of the nursing activity

Table 2. REBA action levels, [1]

REBA Score	Risk Level	Action Level	Action (including further assessment)
1	negligible0	none necessary	
2 - 3	low	1	may be necessary
4 - 7	**medium**	**2**	**necessary**
8 - 10	high	3	necessary soon
11 - 15	very high	4	necessary now

2.2 Definition of a Table with the Indicators and Factors of Probability and Control of the Ergonomic Risk Through Literature References

According to Chengalur et al. [8], there are indicators of possible ergonomic problems and risk factors that make jobs difficult. These indicators and factors are presented in the table below.

Based on the indicators and factors described in Table 3 and other findings in the literature, the FMEA rating concepts were combined for a definition of relevance criteria of each indicator or factor that contributes to the relevance of the probability of presence of ergonomic risk. A scale ranging from 5 to 1 was defined, from the highest to the lowest.

Table 3. Indicators of possible issues and risk factors that make jobs difficult (Chengalur et al.), [6].

Ergonomics issues indicators	
Accident and incident history on the job	Frequent rework of product
Medical restrictions needed often	High turnover on job
Quality problems on the job	Above-average absenteeism
Second person needed to assist frequently	Few women or older workers
Long training times	Production bottlenecks
Lack of flexibility to meet production needs	Frequent overtime worked
Risk factors that make jobs difficult	
Sustained awkward working postures	Heavy manual handling
Low operator control over job pattern	High forces required
Very repetitive hand/foot work with force	High external pacing
Environmental stressors (heat, glare, noise)	Complex tasks; multiple tasks done simultaneously

After that, criteria were defined for the evidences of existing controls or for those that could be implemented in order to eliminate or mitigate the ergonomic risks. For these criteria, the scale ranges from 5 to 1, but in this case, from the lowest to the highest control, in order to decrease the weighting.

The premise used to define the values used in the weighting, besides respecting the hierarchy of importance evidenced in the literature, considered the logic that the factors with greater weight were those of quantitative or semi-quantitative origin. Those of smaller weight are the ones of more qualitative and/or subjective aspect. Having a common point, that in both cases it is possible to prove the origin of the information.

2.3 Elaboration of a Table, with the Determination of the Indicators and Factors of Probability and of Control of the Ergonomic Risk, with Different Weights

2.4 Analysis and Selection of the Indicators and Factors of Probability and Control in the Company that Was Part of This Study

Through an interview with the actors of different sectors of the company (management, supervision, operation), indicators and factors that contribute to the probability and control of ergonomic risks were identified, as presented in Table 4, taking care that all information could be evidenced by the company. In addition to this database, the questions in the table were considered, which could be evidenced by means of the ergonomic risk assessment, in order to find answers to the other indicators and factors that were not known to the company. From the highlighted questions, both on the interviews and through the ergonomic risk assessment, those with greater weight were considered, other results being disregarded, for the purposes of application in the method. It was identified as a probability factor the duration of the activity longer than 8 daily hours, which represents a score = 5. The identified control factors concern the possibility of the worker being able to regulate his rhythm, which represents a score = 3.

Table 4. Indicators and Probability Factors and of Control of Ergonomic Risk [2, 3, 8, 10,]

Indicators and probability factors of ergonomic risk	
Weight 5	Medical leave with proven link Non-compliance of legal requirements Very repetitive work (cycle < 6 s or = 10 times per minute) Environmental stressors (heat, glare, noise) – as referenced in the literature or norms Activity period longer than 8 h per day Other non-specified (that are referenced in the literature)
Weight 4	Few women or older workers Frequent overtime worked Production bottlenecks Second person needed to assist frequently High external pacing Complex tasks, multiple tasks done simultaneously Verbalization of discomfort, difficulty or fatigue related to the work Absence of the possibility of short pauses (physiological needs)

(*continued*)

Table 4. (*continued*)

Indicators and probability factors of ergonomic risk	
Weight 3	Medical restrictions needed often Accident and incident history on the job Absence of mandatory training for the development of the activity Lighting below the required limits – as referenced in the literature or norms Other non-specified (that are referenced in the literature)
Weight 2	History of medical leaves related to musculoskeletal and/or ergonomic problems Quality problems on the job Frequent rework of product High turnover on job Above-average absenteeism Low operator control over job pattern Other non-specified (that are referenced in the literature)
Weight 1	Absence of indicators or probability factors
Indicators and control factors of ergonomic risk	
Weight 5	Absence of indicators or control factors
Weight 4	Women or older workers can do the activity without difficult Other non-specified (that are referenced in the literature and which are possible to prove their efficiency)
Weight 3	The worker can regulate his pace (lung area, flexibility, autonomy). Ergonomics training (acting committee, or efficient ergonomic training programs) Other non-specified (that are referenced in the literature and which are possible to prove their efficiency)
Weight 2	Absence of verbalizations of discomfort, difficulty or fatigue Labor gymnastics programs Other non-specified (that are referenced in the literature and which are possible to prove their efficiency)
Weight 1	Possibility of manual handling of loads by 2 workers (NIOSH) Duration of the activity in percentage = or < that 10% of the working day Duration of work shift equal to or less than 6 h per day Rotating and/or pausing system with proven effectiveness Activity allows postural variation between seated × standing work in an efficient way Good anthropometric conditions and possibilities of adjustments (furniture, equipment, machines) Automation systems or ergonomic devices (pantograph table, manipulators, hoists) Other non-specified (that are referenced in the literature and which are possible to prove their efficiency)

2.5 Application of the Risk Matrix (Probability × Control) to Obtain the Weighted Rating

Once the most representative score between the indicators and factors of probability and control of the ergonomic risks was identified, this number was multiplied using the concept of the risk matrix, represented by the multiplication of the probability

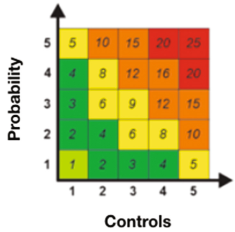

Fig. 2. Matrix for the determination of the score resulting from the multiplication between the most representative weight and of the indicators and factors of (probability × control)

factors × control factors. As a parameter to identify the value of this weighting, a 5 × 5 matrix was used (Fig. 2).

2.6 Determination of the Rating, from the Color Corresponding to the Result of the Risk Matrix (Probability × Control)

As shown in Fig. 3, the score resulting of the multiplication between the most representative weight of the indicators and factors of probability and control are correlated in the table Probability × Control with five different colors, which represent weights from 1 to 5, as in: light green = 1, dark green = 2, yellow = 3, orange = 4 and red = 5.

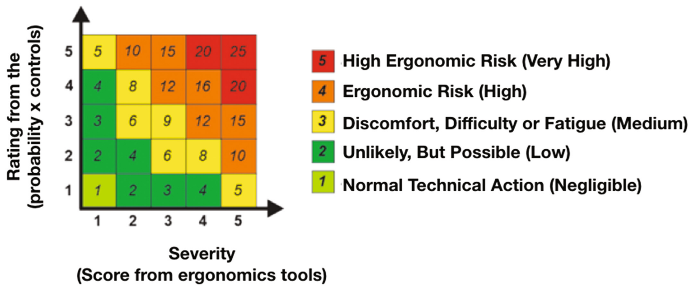

Fig. 3. Matrix for the determination of the classification of ergonomic risk weighting

2.7 Weighted Risk Rating Through the Risk Severity Factor (Score of the Ergonomic Tool Results) and of the Rating Corresponding to the Risk Matrix Weighting

Once the weight indicated by the risk matrix is defined, the results of the ergonomic tools (considered by the method as the risk severity factors) are used, which must be correlated with the definition of risk described on image 4, which goes from a high ergonomic risk (5 Red/High) to a normal technical action (1 Light Green/Negligible).

2.8 Risk Weighting from the Tool and Weight Obtained Through the Risk Matrix

Weight = 4 (Probability (5) × Control (3) = 15 = Weight 4/orange color)
Result of the tool = Equivalent to Weight 3 (Discomfort, difficulty or fatigue/ yellow color/Medium (relation between Table 4 and the corresponding in Fig. 3)
Weighted Risk = (4 × 3) = 12.

The risk went from (Discomfort, Difficulty or Fatigue/Yellow Color/Medium) to (Ergonomic Risk/Orange Color/High).

2.9 Projection of a Future Scenario

The main advantage presented by the method proposed in this paper is the possibility of the company to know what are the main influences between the existing factors of probability and control, which contribute to the increase of the risk, and using this information, to be able to take more assertive actions, considering the overview of all the actors involved in the process of the analysis construction. In addition, ensuring that the actions proposed in the ergonomic analysis of the work will mitigate the ergonomic risk, through the control factors. It is possible through this to design a future scenario.

2.10 Extrapolation of the Weighting

If the result of the weighting, up or down, shows a difference of two scales or more, for example: risk weighted from green to orange or vice versa, the analyst should review the tool used (severity factor), or review the criteria used in the weighting, concerning the information of the existing factors of probability controls. This type of error can occur when the analyst chooses a physical/postural type tool (REBA, RULA or OWAS, for example), and the demand for ergonomic concern is predominantly behavioral/cognitive or psychophysiological, or when the chosen tool is not very sensitive (has simplified content which does not cover a number of relevant factors such as: duration, frequency and occupancy rate, for example). Another possibility is that the analyst has missed some relevant information regarding the probability and control factors or the company has not provided all the necessary data.

There can be no inconsistency in the choice of factors that will be weighted in the measure between probability and control. Table 5 should be used by the analyst for pre-analysis purposes before filling out the probability and control factor worksheets. The lightest highlights represents the secondary relation between the factors and the ergonomic tool chosen by the analyst, and the darker the primary/more intimate relation.

Table 5. Matrix of the connection between the probability and control factors and the type of ergonomic tools

	Probability Factors ↓	Types Ergonomics Tools: Biomechanics Posture	Biomechanics Hold/Gripp	Psychophysical	Behavioral Cognitive	Weight	Controls Factors ↓	
Light	•Lightning below the 80% limit of the value defined by the norm.							
							•Automation systems or ergonomic devices, like pantograph table, manipulators, hoists.	Autom.
Law	•Prize / bonus payment for productivity or any other type of incentive.							
Freq.	•Very repetitive work (cycle <6s or = 10 repetitions per minute).							
Time	•Activity duration > 8h/day •Frequent overtime •Frequent rework that is related to ergonomic concerns in the activity. •Absence of possibility to take small breaks for hydration and / or sanitary use						•The worker can regulate his pace (lung area, flexibility, autonomy). •Duration of activity in percentage = or <that 10% of daily work •Shift duration = or <than 6 hours per day. •Rotation and/or Pause with effectiveness in mitigating the constraints of the activity.	Time
Environ.	•Stressing environments (vibration, heat, cold, noise). •High external stimulus (problems with: technology, machines, maintenance, raw material, material, labor).						•Furniture, equipment or machines having effective adjustment means.	Environ.
People	•Restrictions on female workers or above 45 years of age. •Verbalization of difficulties related to work. •High turnover. •High rates of absenteeism.						•Elderly workers and women develop activity without difficulty. •Absence of verbalizations of work-related difficulties	People
Health	•Medical leave with proved link. •Ergonomic-related medical restrictions to work in this activity. •Historic of medical leaves with CIDM which activity related to biomechanical risks.							
Manag.	•Production bottleneck, absence of lung area, rhythm imposed by the system. •Complex activities, multiple tasks done simultaneously. •Low operator control without working standard. •History of accident related to the activity and with ergonomic factors. •Absence of mandatory training for the development of activity. •Quality problems that are related to ergonomic concerns of this activity.						•Ergonomics training •Efficient Labor Gymnastics Program •Activity allows postural variation between sitting or semi-sitting work x standing work and / or use of anti-fatigue mat.	Manag.
Effort	•Frequent necessity of a second person to develop the activity.						•Possibility of the MMC to be done by 2 workers.	Effort

3 Results and Discussion

3.1 Results

The results found after the ergonomic risk weighting, both for the current situation (primary analysis – before) and for the improved situation (secondary analysis – after) can be observed in the images below (Table 6):

Table 6. Results of the weighted risk on the primary and secondary analysis

	BEFORE	AFTER
(A) Severity (REBA)	**3 (medium)**	**3 (medium)**
(B) Probability	**5**	**1**
(C) Control	**3**	**1**
(D) (B x C)	**5 x 3 = 15 (15 = Weight 4)**	**1 x 1 = 1 (1 = Weight 1)**
(E) Weight (as in Fig. 3)	**4**	**1**
Multiplication (A x E)	**3 x 4 = 12 (12 = Weight 4)**	**3 x 1 = 3 (3 = Weight 2)**
Final Result	**Weight 4 (High)**	**Weight 2 (Low)**

In the primary analysis (before), the high probability factor (score 5), due to the fact that the duration of the activity was greater than 8 daily hours, multiplied by the medium control, greater margin for maneuver by the nurses (score 3), resulted in a risk weighting up, from yellow (medium risk) to orange (high risk). In the secondary analysis (after), after the implementation of improvement actions by the company, in the implementation of efficient rotation programs, which reduced the duration of work in the analyzed activity and the absence of probability factors, resulted in scores of 1 for both factors, which resulted in a weight also equal to 1. In this new scenario the weighting went from yellow (average risk) to green (low risk).

3.2 Discussion

In this paper, a method of approaching ergonomic tools risk weighting was proposed, through the combination of the concepts of FMEA, risk matrix and the specifities of the company. This combination allows a much more in-depth analysis, where all actors involved with the demands of the analysis participate in its construction, not limiting the conclusions to simple applications of ergonomic tools. However, the main disadvantage of this method is the delay in collection and compiling the data. The time required for collecting the data is inversely proportional to the level of control and history that the company possesses.

It is important to consider some cautions regarding the application, results interpretation and restrictions on the application of the method proposed in this article. There is a restriction regarding the weighting in the cases where situations of extrapolated ergonomic factors are shown, according to references found in the literature, in norms, internal procedures or when the ergonomic tool itself displays an over range result, for example: high intensities in manual movement of load, very high frequency, displacements in push/pull activities that exceed the maximum limits set in tables. Another restriction in the use of the weighting method may exist when the company does not provide the information related to the probability factors, or when it is not possible to prove the veracity of the records. This usually occurs because of lack of traceability of the information, lack of records or even because the company does not want to provide evidence against itself.

The results obtained in the case study of this paper show the care that the ergonomist should have, both in the choice of the ergonomic tool or method, and in the conclusion that is obtained through the interpretation of its results. The weighting through a data collection effort that contemplates the specifities of the company and its various actors is not limited to a restricted method, pre-defined from the results applied in similar situations, but often do not represent in the slightest the existing condition in the moment the ergonomist needs to fulfill a certain demand for ergonomic analysis, where each actor has their own expectation regarding the final conclusion about the presence or not of an ergonomic risk. Finally, the method suggested in this paper is not defined as a restricted method. On the contrary, it constantly seeks to consider the whole globality that ergonomic actions demand.

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