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Anthropometric And Ergonomic Analysis Applied To An Industrial Production Manual Insertion Line In The Electronics Segment

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Abstract:
Background*: The principle of ergonomic work analysis is to identify and try to prevent possible illnesses that develop slowly due to repetitive movements, unfavorable postures, uncomfortable furniture and visual discomfort, resulting in loss of productivity for the company, employee dissatisfaction and increased costs. The work environment and unsuitable furniture can also lead to a reduction in productivity in companies, because if it is not adjusted to the biotypes it can lead to the occurrence of work-related illnesses. One of the great challenges of ergonomics applied to work is to design or adapt workstations and tools to the morphological diversity of the population. Accurate analysis of the various segments is carried out using anthropometric techniques, which is the study of the physical measurements of the human body. The aim of this research was to apply ergonomic work analysis to the production line of a company in the electrical and electronics sector in order to promote improvements in the workplace with a view to the quality of life, well-being and safety of employees.*
Materials and Methods*: The study's methodology included a population survey of the company's biotypes by means of an anthropometric assessment; an analysis of the movements of the human body with an emphasis on the upper limbs according to the conditions of their workstation; the implementation of ergonomic concepts on the production line; the adaptation of workstations to employees; and finally the monitoring, follow-up and comparison of productivity results after the implementation of ergonomic improvements. To analyze the results of this research, a sample of 375 employees was carried out, focusing on the manual insertion production line.*
Results*: The anthropometric analysis showed that there is a difference between the male and female biotypes. With females more concentrated around the average and males showing a greater tail of the distribution. After implementing the improvements, the ex-post analysis showed that the targets proposed by the company for productivity, quality and absenteeism were achieved, with averages of 780.2 units/hour, 281.4 pieces/million and 1.8%, respectively.*
Conclusion: *The ergonomic work analysis identified the need to adapt, alter and change the company's workstations, starting with the equipment and extending to the posture of the employees working on the production lines. The combination of anthropometry and ergonomic analysis was the fundamental basis for innovation in the sectors, jobs, production process and work routine.*
Key Word*: Ergonomics, Productivity, Anthropometry, Absenteeism, Electronics industry.*

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I. Introduction

The human being was once considered a complement to the production line, which had to adapt to the new realities of the industrial revolution, which meant that the worker had to fit in with the machine or the function, without taking into account physiological factors, individual characteristics, the environment and inadequate working conditions (MOURA, 2019).

With this industrial revolution, the business mentality came to understand that work should not only be a means of survival, but also a motivation, allowing for both physical and mental satisfaction. This change helped to see man as a fundamental part of the production system, altering concepts and giving rise to the need to adapt work, equipment and the environment to man (ABRAHÃO, 2009).

This process generated new perceptions, and the search began for the promotion of workers' health and quality of life, which would consecutively result in increased productivity. In the 1940s, Ergonomics emerged as one of the tools concerned with the human body and how it adapts to the environment, in other words, how people adapt to their daily activities (SILVA, 2010).

Ergonomics has since been applied to improve the working environment, bringing greater productivity and employee satisfaction within the work organization. It is primarily concerned with the physiological aspects of work, where the workplace is adjusted to suit people and their conditions, and these aspects are identified through ergonomic work analysis (WILSON, 2002).

The aim of this research was to apply ergonomic work analysis and anthropometric analysis to the production line of a company in the electrical and electronics sector in order to promote improvements at workstations with a view to improving the quality of life, well-being and safety of employees.

II. Review of Literature

Ergonomics studies the relationships between individuals and other varieties of elements in the work system with the aim of applying theoretical principles, data and methods to promote human well-being and performance at work. Its main feature is its interdisciplinary nature, which makes it possible to increase safety and health in the workplace by associating the well-being of workers with a reduction in unnecessary or incorrect efforts in daily routines (ABRAHÃO, 2009).

The work environment exposes workers to numerous chemical, physical and ergonomic risk factors (LUZ et al., 2013). Ergonomic risk involves repetitiveness, inappropriate postures, furniture, work pace, physical effort, psychosocial and organizational factors, among others. These risk factors can lead to the development of work-related illnesses, which currently account for 80% of workers' sick leave in Brazil (BRASIL, 2001).

Ergonomics and human engineering encompass debates and studies with the application of tools and methods that are important for understanding the relationship between man and the work environment with a focus on preventing accidents and musculoskeletal diseases in business organizations. For Bentley (2020), occupational risks in ergonomics can be diagnosed and treated appropriately and preventively by companies.

Fantozzi (2020) believes that a healthy environment provides greater worker satisfaction and results in internal motivation, leading to increased production and quality, among other goals to be achieved. Companies need to exploit technological resources to apply ergonomic measures that promote quality for employees.

The search for effective ergonomics can be understood as modifying the work environment in order to promote quality for employees. For Neumann (2021), this modification requires technology and the organization of components, enabling analysis of human demands in Industry 4.0 environments in order to contribute to successful digital modification that prevents risks, considering human factors.

III. Material And Methods

This work falls under the exploratory method, which aims to provide greater familiarity with the problem in order to make it explicit or to build researchable hypotheses for further studies (GIL, 2008).

In terms of approach, the research sought to integrate qualitative and quantitative analysis (BRYMAN, 1988)

In qualitative research, the environment in which the study took place was the source for collecting data directly. The instrument used for qualitative research was the interview.

Study Location: The research site was a company operating in the electrical and electronics segment in the industrial hub of Manaus, Amazonas, Brazil. The production stage studied was carried out on manual insertion lines.
Study Duration: The project was carried out between the years 2019 to 2022.
Statistical analysis: The data were entered into a spreadsheet in Microsoft Office Excel 2013 and later, the graphs were plotted through Excel, and Software free R.

Procedure methodology

ERGONOMIC WORK ANALYSIS (EWA)

As indicated by Brasil (1999), EWA will follow the following steps:

a) Analysis of the demand and, where applicable, reformulation of the problem;
b) Analysis of the functioning of the organization, processes, work situations and activity;
c) Description and justification for defining the appropriate methods, techniques and tools for the analysis and their application;
d) Establishment of a diagnosis;
e) Recommendations for the work situations analyzed; and
f) Feedback of the results, validation and revision of the interventions carried out when necessary, with the participation of the workers.

ANTHROPOMETRIC EVALUATION

The anthropometric assessment was carried out in the production process and production office areas to survey the company's population in order to classify the different biotypes of frontal shoulder grips and depth, with the aim of adapting and designing workstations for upper and lower limbs.

The tools used for the anthropometric study were:
- Welmy anthropometric scale: for assessing weight and height.
- ANTROPROJETO software (Federal University of Juiz de Fora (UFJF)), which made it possible to determine the other body dimensions based on knowledge of an individual's height.

IV. Result

Anthropometric Analysis Of The Company's Biotypes

The presentation of results was based in the anthropometric analyses applied in the company, as well as an analysis of the suggested implementation before and after it was applied to the production stations.

The purpose of the anthropometric assessment was to survey the company's population in order to classify the different biotypes of frontal shoulder grips and lower limb depth, with the aim of adapting and designing workstations for upper limbs and lower limbs. A sample of 377 employees was interviewed and data collected.

Table 1 shows the summary statistics for the "height" variable of the employees assessed.

Table 1. Summary statistics for the employee height variable.

N	Minimum (m)	1º.Quartile (m)	Median (m)	Mean (m)	SD[1] (m)	3o.Quartile (m)	Maximum (m)
377	1.44	1.56	1.60	1.62	0.09	1.68	1.95

[1]Nota: SD = standard deviation

Source: Author's data (2022)

It shows in figure 1 the result by gender of the percentage of employees who have the right or left dominant limb.

Figure 1. Dominant members of the workforce by gender, male and female

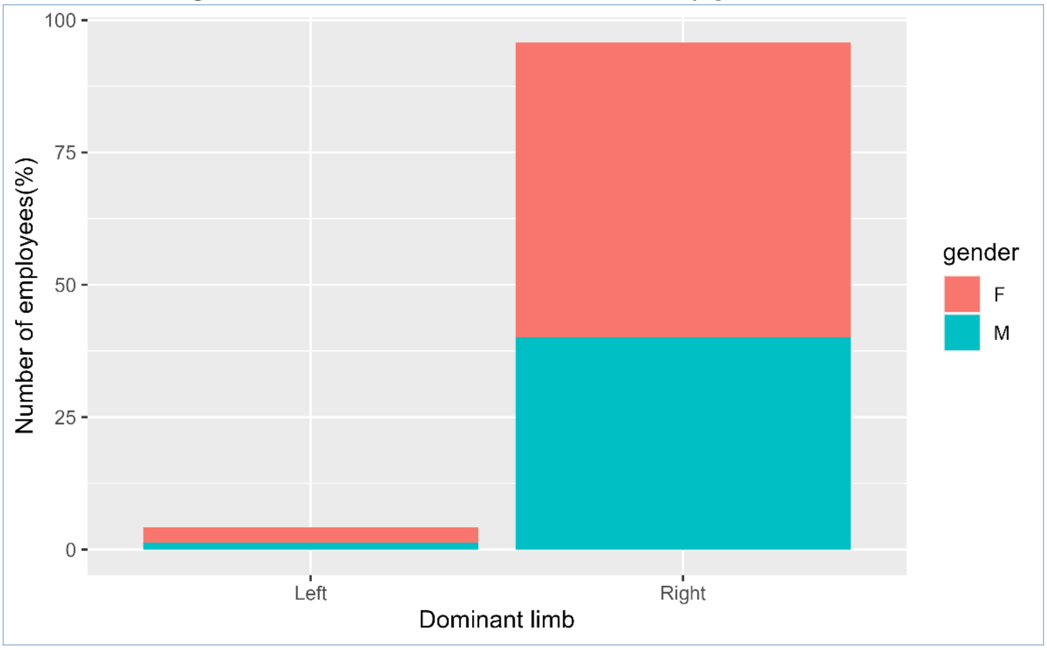
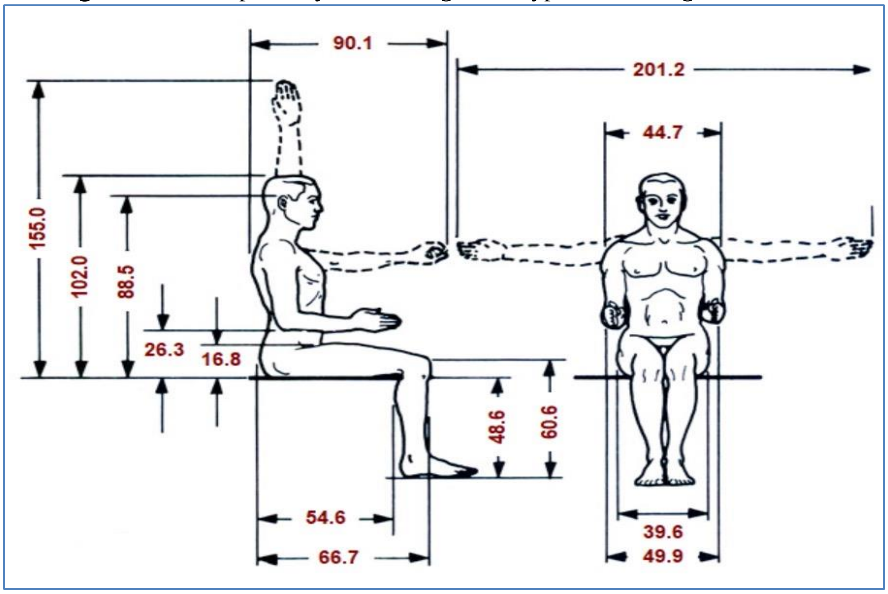


Figure 1 shows that the dominant limb is the "right limb" for both sexes. With a percentage of less than 5% for the left limb.

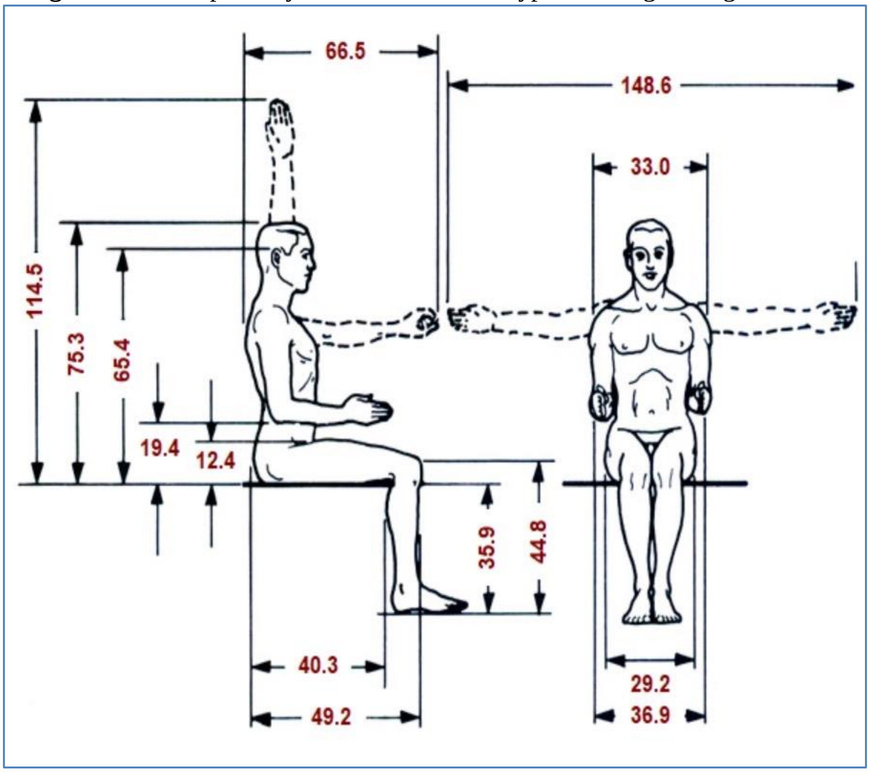
Based on the data in Table 1, the anthropometry for the smallest (1.44m) and largest (1.95m) biotypes is shown below, with reference to the worker's height (Figures 2 and 3).

Figure 2. Anthropometry for the largest biotype with a height of 1.95 m.



Source: anthroproject software (2003) with data from the author, 2022.

Figure 3. Anthropometry for the smallest biotype referring to height 1.44 m.



Source: antroprojeto software (2003) with data from the author, 2022.

All the anthropometric values estimated by the software will be compared with the actual values of the measurements taken on the workers. As shown in the following analyses of the variables: Height; shoulder girth; height from buttocks to floor; and popliteal height.

Figure 4 shows the graphical analysis for the height variable.

Figure 4A shows the maximum and minimum height values for females and males. The lowest value was 1.44m (female) and the highest was 1.95m (male), with an average of 1.62m (Table 1). Figures 4C and 4D show the distribution of these values. Men's heights are distributed over a wider range, while women's heights are concentrated around the average (1.62 m).

Figure 4. Maximum and minimum values (4A), boxplot (4B), histogram by sex (4C) and violin graph (4D) for the variable height.

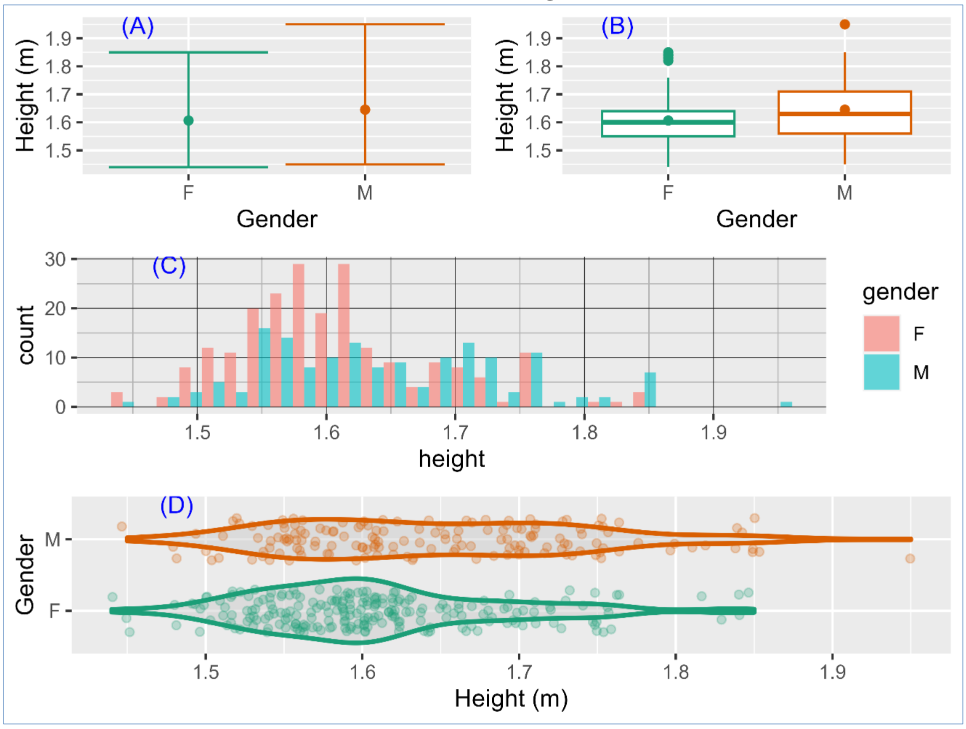


Table 2 shows the summary statistics for the "shoulder footprint" variable for the sample of employees assessed.

Table 2. Summary statistics for the variable "shoulder grip" of employees.

N	Minimum (cm)	1º.Quartile (cm)	Median (cm)	Mean (cm)	SD[1] (cm)	3o.Quartile (cm)	Maximum (cm)
377	66.50	72.10	73.90	74.88	4.04	77.60	90.10

[1]Nota: SD = standard deviation
Source: Author's data (2022)

Figure 5 shows the graphical analysis of the values for the "shoulder grip" variable.

Figure 5. Maximum and minimum values (5A), boxplot (5B), histogram by gender (5C) and violin graph (5D) for the shoulder grip variable**.**

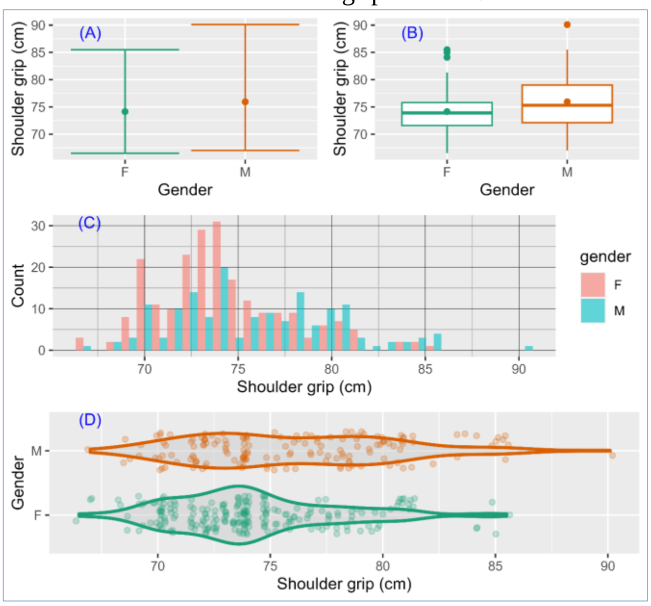


Figure 5A shows the maximum and minimum values of the shoulder grip for males and females. The lowest value was 66.50 cm (female) and the highest was 90.10 cm (male), with an average of 74.88 cm (Table 2). Figures 5C and 5D show the distribution of these values. Also for this variable, the values for men are distributed over a wider range, while for women they are concentrated around the average (74.88 cm).

The software was also highly accurate in estimating the shoulder footprint, with 66.5 cm and 90.1 cm for the values corresponding to the lowest and highest height, respectively (see Figures 2 and 3).
Table 3 shows the summary statistics for the variable "elbow height" for the sample of employees assessed.

Table 3. Summary statistics for the variable "sitting elbow height" of employees.

N	Minimum (cm)	1º.Quartile (cm)	Median (cm)	Mean (cm)	SD[1] (cm)	3o.Quartile (cm)	Maximum (cm)
377	19.40	21.10	21.60	21.89	1.18	22.70	26.30

[1]Nota: SD = standard deviation
Source: Author’s data (2022)

Figure 6 shows the graphical analysis of the values for the "elbow height" variable.

Figure 6. Maximum and minimum values (6A), boxplot (6B), histogram by gender (6C) and violin graph (6D) for the elbow height variable.

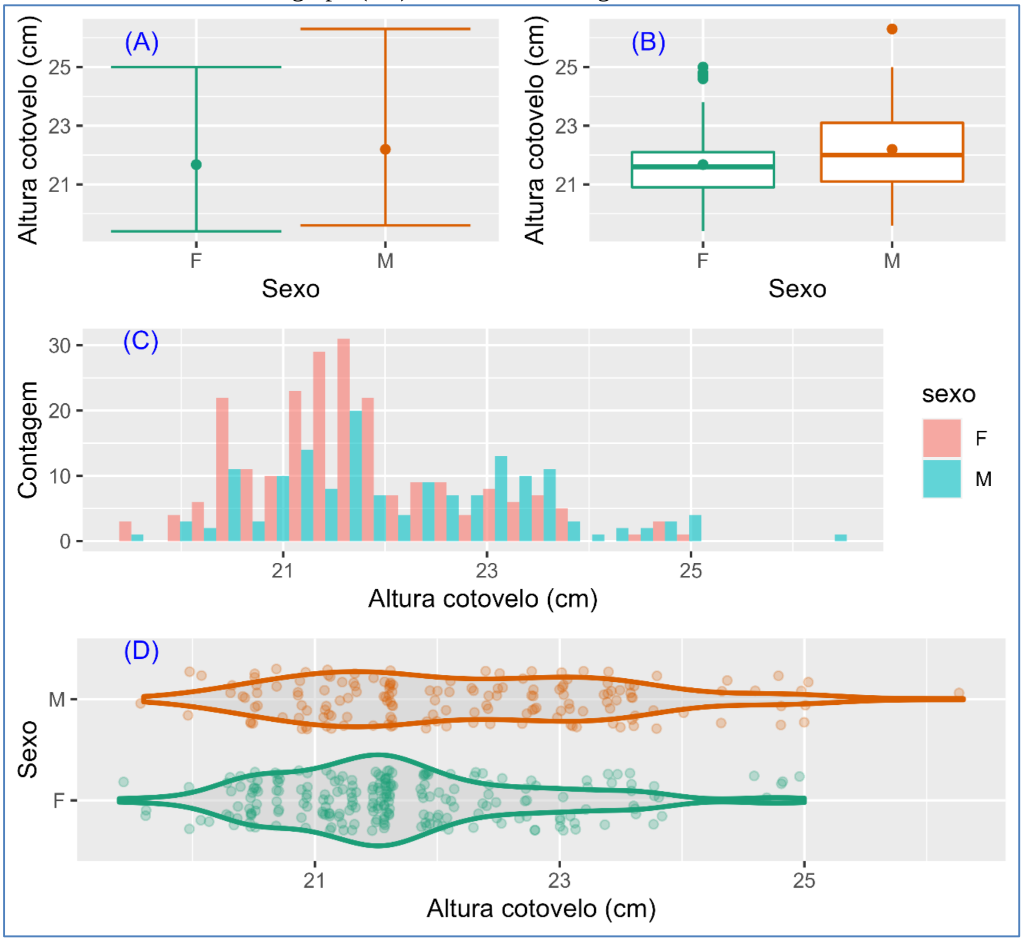


Figure 6A shows the maximum and minimum elbow height values for males and females. The lowest value was 19.40 cm (female) and the highest was 26.30 cm (male), with an average of 21.89 cm (Table 3). Figures 6C and 6D show the distribution of these values. There is great variability between biotypes. Also for this variable, the values for men are distributed over a wider range, while for women they are concentrated around the average (21.89 cm).

Table 4 shows the summary statistics for the variable "height from buttock to floor" for the sample of employees assessed.

Table 4. Summary statistics for the variable "buttock-floor height" of employees

N	Minimum (cm)	1º.Quartile (cm)	Median (cm)	Mean (cm)	SD[1] (cm)	3o.Quartile (cm)	Maximum (cm)
377	44.80	48.50	49.80	50.42	2.72	52.20	60.60

[1]Nota: SD = standard deviation
Source: Author's data (2022)

Figure 7 shows the graphical analysis of the values for the "buttock-floor height" variable.

Figure 7. Maximum and minimum values (6A), boxplot (6B), histogram by sex (6C) and violin graph (6D) for the variable "buttock-floor height".

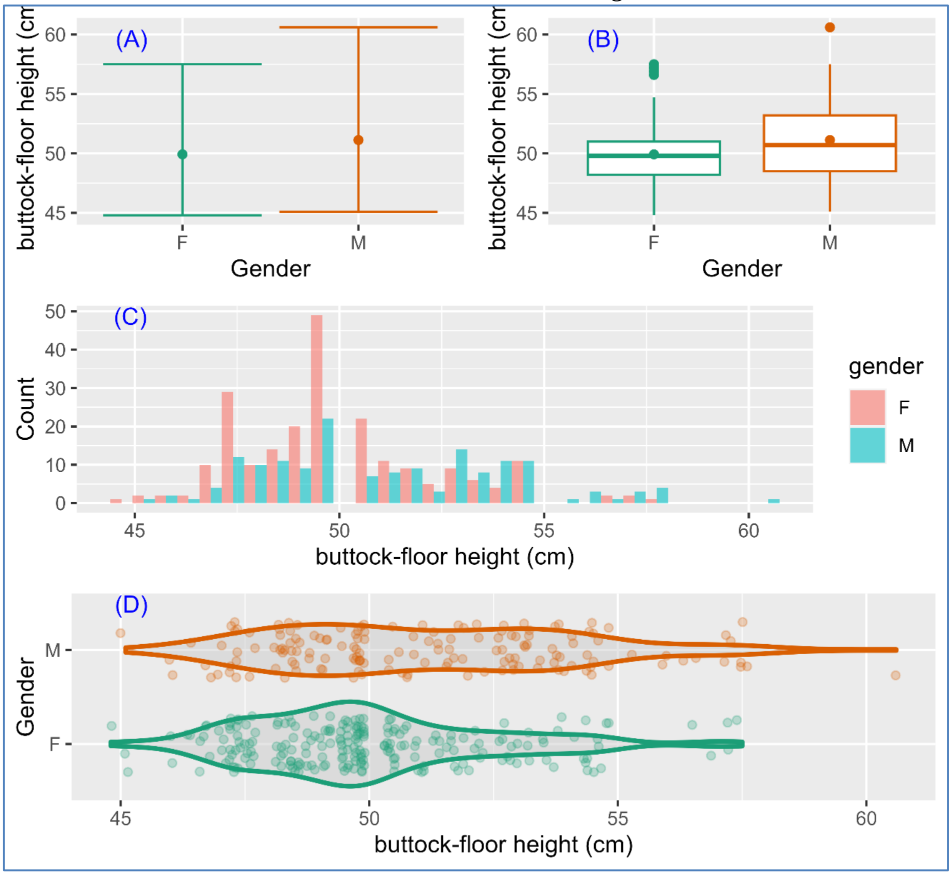


Figure 7A shows the maximum and minimum values of buttock height for males and females. The lowest value was 44.80 cm (female) and the highest was 60.60 cm (male), with an average of 50.42 cm (Table 4). Figures 7B, 7C and 7D show the distribution of these values. There is great variability between biotypes. Also for this variable, the values for men are distributed over a wider range, while for women they are concentrated around the average (50.42 cm).

Table 5 shows the summary statistics for the "height" variable for the sample of employees evaluated.

Table 5. Summary statistics for the variable "height" of employees

N	Minimum (cm)	1º.Quartile (cm)	Median (cm)	Mean (cm)	SD[1] (cm)	3o.Quartile (cm)	Maximum (cm)
377	35.90	38.80	39.80	40.35	2.19	41.80	48.60

[1]Nota: SD = standard deviation
Source: Author's data (2022)

Figure 8 shows the graphical analysis of the values for the "poplietal height" variable.

Figure 8. Maximum and minimum values (6A), boxplot (6B), histogram by sex (6C) and violin graph (6D) for the variable "poplietal height".

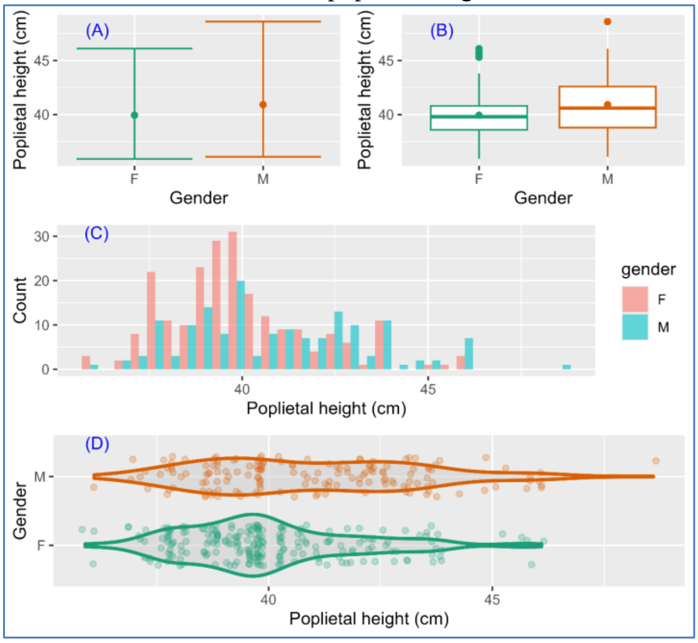


Figure 8A shows the maximum and minimum popliteal height values for males and females. The lowest value was 35.90 cm (females) and the highest was 48.60 cm (males), with an average of 40.35 cm (Table 5). Figures 8B, 8C and 8D show the distribution of these values. There is greater variability for male biotypes, while for women, the values are concentrated around the average (40.35 cm).

The software was also highly accurate for this variable, estimating exactly the same values for the maximum and minimum heights, 35.90 and 48.60 cm respectively (Figures 2 and 3).

Ergonomic Analysis of Work

A diagnosis was made of the inadequate situations observed and non-compliance with NR. 17 of the workstations on Line 2 - Manual Insertion, with the respective comments and recommendations that not only comply with this standard, but also serve as guidelines for improving working conditions and the quality of life of workers.

Characteristics of line 2 - Manual Insertion

Line 2 at Manual Insertion is responsible for producing electronic circuit boards (Power Boards) of various sizes, mainly for the production of monitors and televisions. The line has 18 workstations, some of which have more than one worker, from labeling the board to packaging the assembled and soldered board. Production takes place on a motorized, continuous-motion conveyor belt, with raised shelves housing the various components for insertion, specific equipment, tools and chairs available for the workers (Figure 9).

Figure 9. Characteristics of the manual insertion line (IM) 2.

Production target

According to the line leader, there is a significant variation in production targets depending on the board model produced. This is due to the complexity of each model, which may have more or fewer components inserted. At the time of the analysis, the production target for the LE32D5520 model evaluated was 350 pieces per hour.

Relay

According to the workers, there is no systematic rotation between jobs, i.e. a schedule. According to them, the rotation takes place when a worker gets tired of working in one job and moves to another for periods agreed between them, such as 2 hours or half the working day.

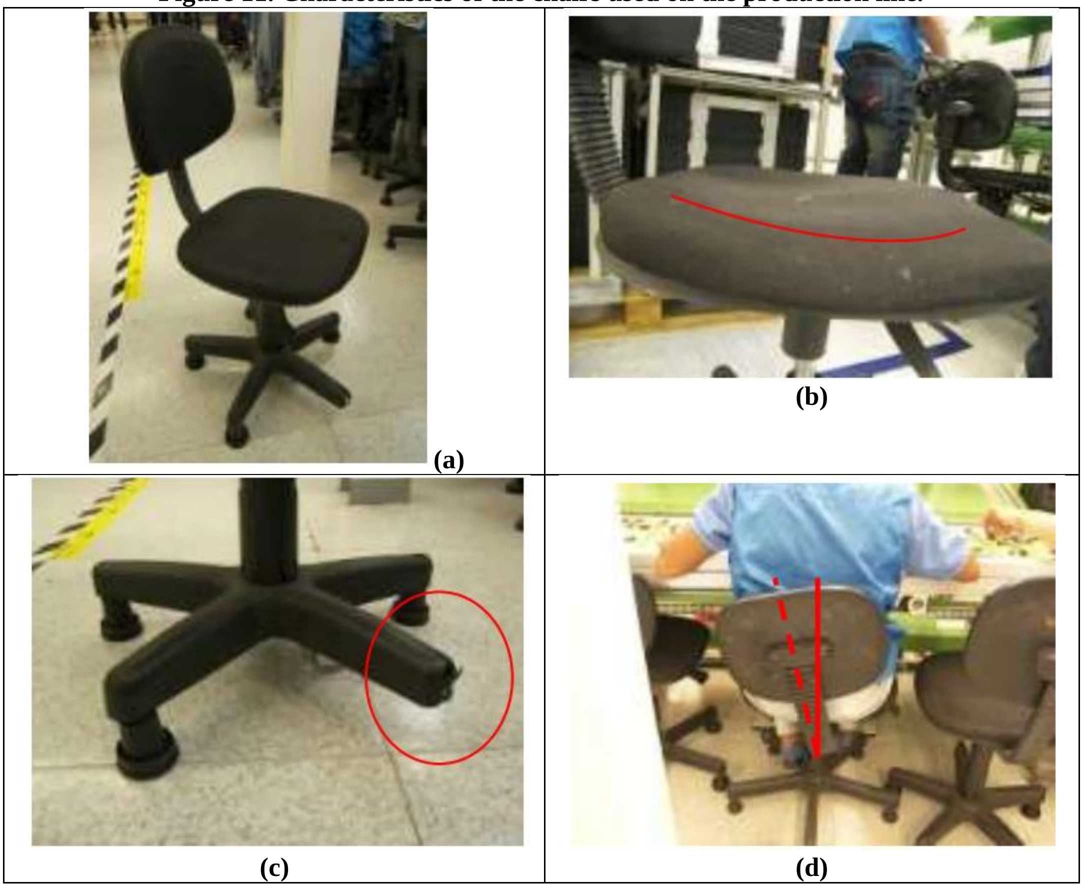
Environmental conditions

The production line is housed in a centrally air-conditioned shed with a temperature set at around 23 degrees, which according to the workers is comfortable. The lighting is artificial, with general luminaires at a height close to the ceiling of the shed, and individual luminaires closer to the line, which according to the majority of workers is sufficient. They also say that internal noise is low and considered adequate. Specific complaints are listed under each workstation.

Seat analysis

Most of the chairs used in the line have low-density injected foam in the seat and back, with sliders, seat height adjustment and backrest height adjustment (Figure 11a). In general, the chairs have problems such as seat deformation (Figure 11b), lack of sliders or castors (Figure 11c), broken backrests (Figure 11d), among other items that compromise the quality of use by the worker. However, according to the company, new units of chairs, of a higher quality standard, are being purchased and all the units in the line will be gradually replaced (Figure 12).

Figure 11. Characteristics of the chairs used on the production line.



(a) **(b)** **(c)** **(d)**

Figure 12. New chair models.

Footrest

The footrest provided by the company has a platform with sufficient depth and width to accommodate the feet, non-slip material on the platform, rubberized feet to prevent slipping and anteroposterior movements (Figure 13).

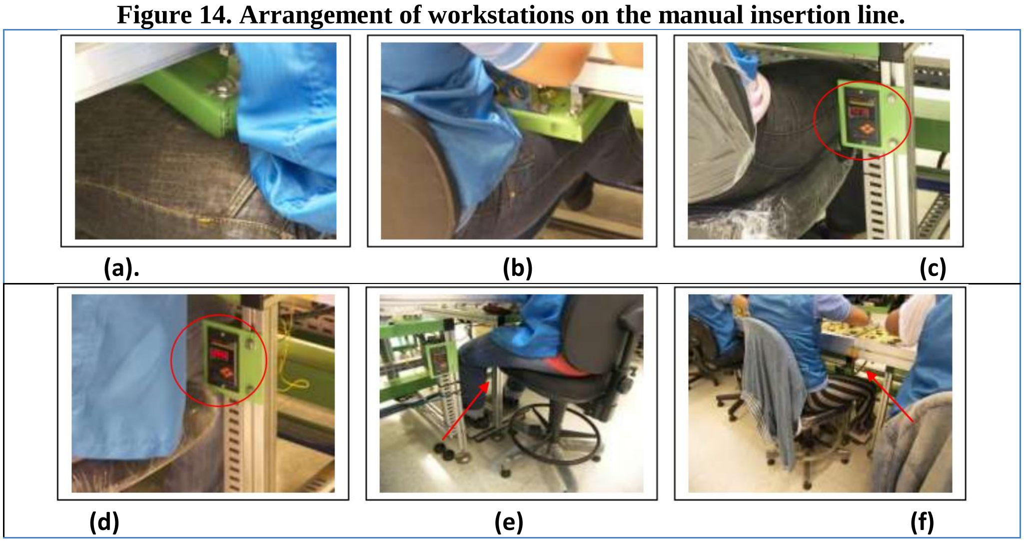
However, as the model does not have height adjustments, it was observed that for workers of shorter stature, the device becomes inadequate, as it is not possible to support the feet (Figure 13).

Figure 13. Footrest model.

Workstation Layout

It was observed that the layout of the workstations along the manual insertion line was configured in such a way that the joints, speed control devices and depth adjustment mechanisms of the belts are directly in contact with the worker's body, causing mechanical compression of the upper thigh (Figure 14a and 14b) and lateral (Figure 14c and 14d) structures, as well as not allowing free movement and accommodation of the legs (Figure 14e and 14f).

Figure 14. Arrangement of workstations on the manual insertion line.



Outreach Areas

In almost all of the workstations, containers, boxes and areas for placing parts were found to be far from the workers' reach, causing them to raise and bend their arms (Figure 15a).

Equipment and accessories are also positioned far from the workers' reach, sometimes low, leading to arm flexions (Figure 15a), sometimes sideways, leading to arm extensions (Figure 15b), sometimes high up, leading to arm elevations (Figure 15b). It was also observed that the configuration of some workstations leads workers to adopt inappropriate postures, such as adopting a sitting position to use equipment added to the line, which leads to trunk flexion (Figure 15c) or the absence of an area to accommodate the legs (Figure 15c).

Figure 15. Worker outreach areas.

Productivity results after implementing ergonomic improvements

The presentation and interpretation of the data produced by this study demonstrated the positive effect of applying ergonomic interventions to the company's production process. This can be seen in the significant reduction in absenteeism among the company's workers over the two-year period from 2021 to 2022 (Figures 16 and 17).

Figure 16. Target and current target for Absenteeism, year 2021.
Source: data from AUTHOR (2022)

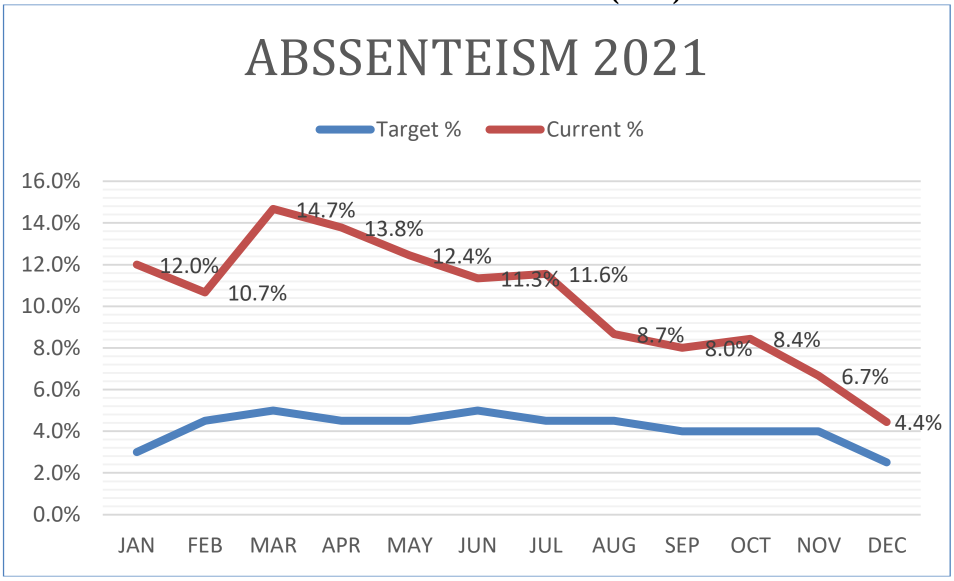
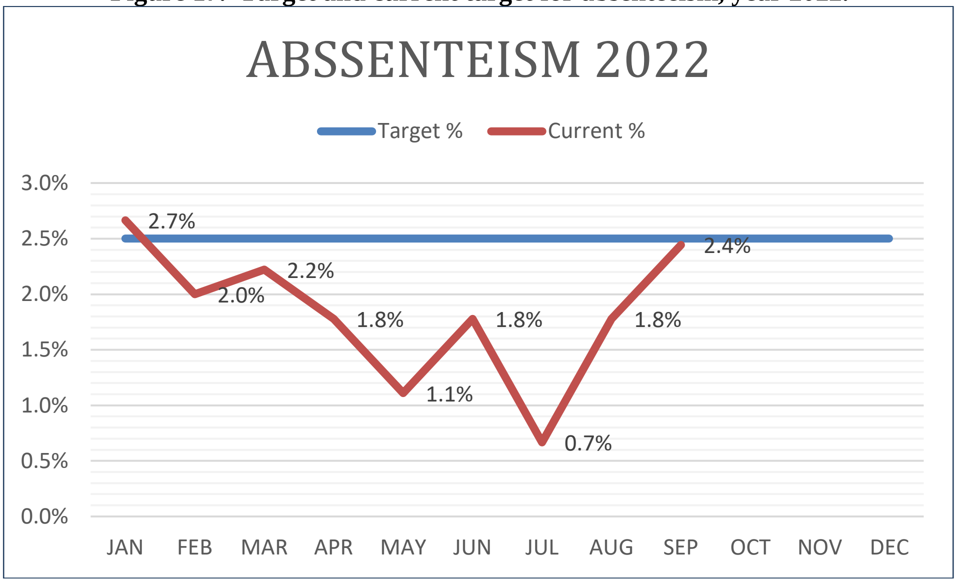


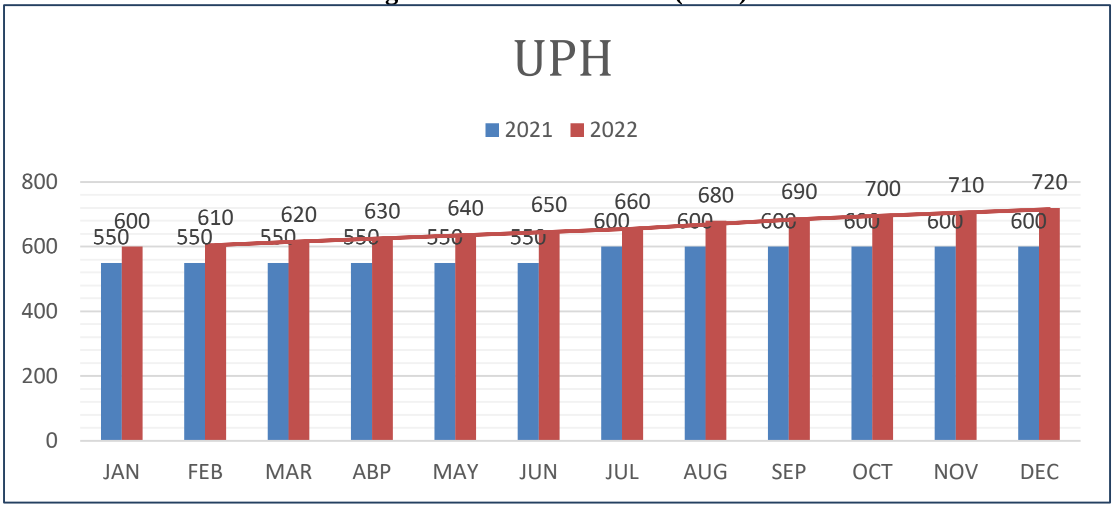
Figure 17. Target and current target for absenteeism, year 2022.



Source: data from AUTHOR (2022)

Another improvement observed after the implementation of the recommendations at the workstations is related to the increase in productivity per piece/hour (Figure 18).

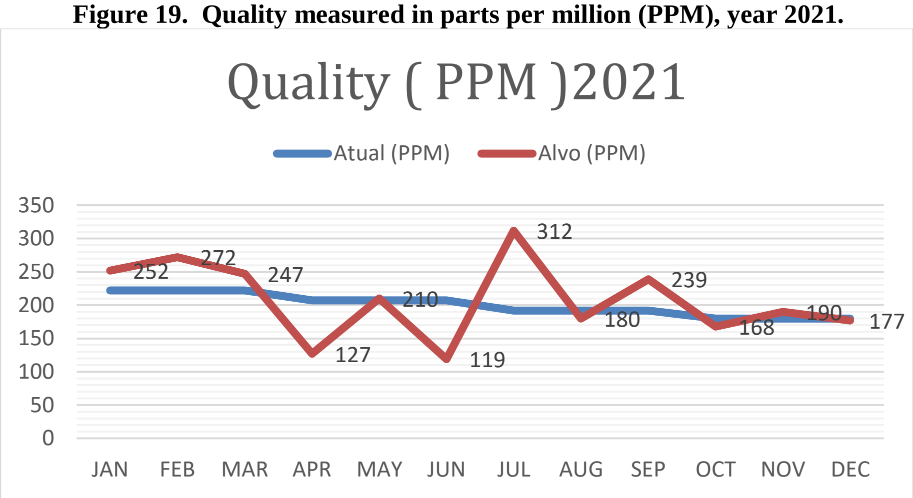
Figure 18. Unit Piece Hour (UPH).



Source: data from AUTHOR (2022)

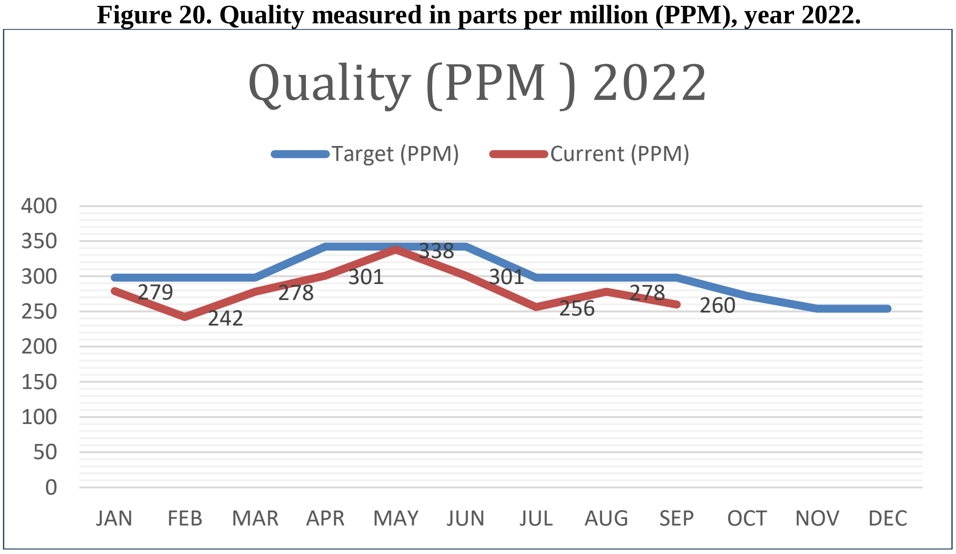
With regard to quality, it can be seen that there has been an improvement when comparing the years 2021 and 2022 (Figure 19 and 20).

Figure 19. Quality measured in parts per million (PPM), year 2021.



Source: data from AUTHOR (2022)

Figure 20. Quality measured in parts per million (PPM), year 2022.



Source: data from AUTHOR (2022)

After the ex-post analysis, with data from September 2022 (Figures 17, 18 and 20), the targets proposed by the company for productivity, quality and absenteeism were achieved with 780.2 pieces/hour, 281.4 pieces/million and 1.8%, respectively.

V. Discussion

This work aims to present an ergonomic work analysis (EWA) carried out in a company in the electronics sector. In this context, data was collected on the company's biotype through anthropometric assessment and analysis of the risk factors that interfere with productivity, with an emphasis on the upper limbs. This information was used to recommend and implement improvements to workstations.

Anthropometric and ergonomic analyses complement each other in order to improve the various stages of the production process, whether during the correction of a workstation, the change, adaptation or even its design, adding value and benefits both for the users of that workstation and also for the company that adopts these measures.

In summary, the conclusions presented here are in line with the proposed objectives and the results can be applied with benefits for ergonomic improvement in the manual insertion line of a company in the electronics sector.

VI. Conclusion

The anthropometric analysis showed that there is a difference between the male and female biotypes. Female anthropometric measurements are concentrated around the mean, while male anthropometric measurements show greater variability in relation to the mean, with an outlier well above the normal behavior of the sample.

The ergonomic work analysis (EWA) identified the need to adapt, alter and change the company's workstations, starting with the equipment and extending to the posture of the employees working on the production lines. The combination of anthropometry and AET was the fundamental basis for the innovation applied to the sectors, jobs, production process and work routine.

After the ex-post analysis and implementation of the ergonomic recommendations at the company's workstations, an improvement in the quality and performance of its functions was identified, reducing absenteeism, increasing productivity and operator satisfaction.

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