LUMEN ET VIRTUS
ISSN: 2177-2789

ERGONOMIC STUDY OF WORKING CONDITIONS IN AN ELECTRONICS INDUSTRY IN SANTA CATARINA

https://doi.org/10.56238/levv15n43-126

Submitted on: 27/11/2024 **Publication date:** 27/12/2024

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ABSTRACT

The industrialization process intensified the pace of production in the factories and contributed to the prevalence of musculoskeletal diseases in workers. Ergonomics seeks to adapt working conditions to the physical and cognitive characteristics of workers, improve the relationship between the demands of the tasks and individual capacities in to minimize the risk of injury. The study carried out refers to the first stage of the winning project of the Innovation Notice for Industry promoted by the National Confederation of Industry. The development of this research was based on the stages of Ergonomic Work Analysis (AET), involving demand analysis, task analysis, activity analysis, diagnosis elaboration and ergonomic recommendations. Observation techniques, interviews and the application of the Nordic Questionnaire of Musculoskeletal Symptoms were used. Results will be presented regarding data from 15 workers. The results made it possible to identify physical overload on the hands, ankles and feet of these workers. The complaints reported may be related to repetitive movements, fast work rhythm and permanence for long periods in the "standing" posture. Based on this, proposals for improvement were presented to the management, including the use of technology as a resource to reduce physical effort.

Keywords: Musculoskeletal Injuries. Repetitive work. Ergonomics of Work. Workstation. Electronics.

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INTRODUCTION

Work is an activity intrinsic to the human being, being fundamentally associated with the objective and subjective demands of the individual. It is one of the main forms of social, personal and professional evolution, in addition to contributing to the construction of bonds, experiences of pleasure and well-being. In addition, work has a close relationship with quality of life and health, directly influencing the well-being of workers (DOS SANTOS, 2024).

The Industrial Revolution of the eighteenth century provided significant changes to the way society was organized, especially with regard to the labor environment and the use of labor. In addition, this historical milestone also led to a considerable increase in the number of health and safety problems related to occupational health and safety. The increasingly intense implementation of the use of machinery and equipment in the production process, the accumulation of workers in restricted places, added to the long hours of work and the poor sanitary conditions in factory environments, made accidents and illnesses of workers accentuated and increasingly frequent over the next few years (SANTOS, 2011).

In the following decades, the transformation of industrial production lines led to the intensification of the pace of work and the repetition of movements, leading to the collective perception that work was a source of damage to the health and safety of individuals, causing an inevitable and growing mobilization of the State and of the organizations and entities themselves to intervene in the working conditions and well-being of workers (SANTOS, 2011).

One of the great challenges that organizations face is intrinsic to their ability to promote an integrated culture of safety at work, that is, one that is capable of achieving the safety defined in regulatory and normative standards, in field safety, practice. It is through the participation of individuals who work in the production processes of organizations that safety will become an issue below the burden of isolated people in the company, in order to become a shared responsibility among all actors in the work context (ROCHA; VILELA, 2021).

Records of occupational accidents in Brazil in 2022 totaled approximately 612.9 thousand cases with the issuance of CAT (Communication of Occupational Accident), representing an increase of about 2.5% compared to the previous year. Among these, 46.8 thousand accidents occurred in Santa Catarina, corresponding to 8% of the national total and placing the state in fourth position among the federative units with the highest number of occurrences (Smartlab, 2022).

Accidents at work do not occur by chance. In Brazil, on average, 70 accidents per hour and seven deaths per day are recorded, often as a consequence of the negligence of those who have the obligation to provide adequate equipment, effective guidance and a safe environment, but do not fulfill this responsibility. Ensuring a safe, healthy, and upright work environment is essential (Brasil, 2023). Annually, work accidents result in average financial losses of R$13 billion, an amount that includes the benefits paid by the INSS related to accidents. In addition, more than 46 thousand working days are lost, accounting for all the days that workers were away due to accidents (Brasil, 2023).

Many workers, in the medium and long term, tend to suffer some type of ergonomic problem related to work activities considered to be of high risk. This is due to the fact that the individual constantly handles some type of object, machine or equipment, or even requires him to perform activities of reaching, lowering and lifting heavy items, using continuous force and performing repetitive movements (SOUZA; SANTANA, 2011).

In this context, it is common for workers to develop Work-Related Musculoskeletal Disorders (WMSD) which, to a certain extent, can cause the worker to be removed from his or her workplace, reduce his or her work capacity and even leave work or permanently injure him/her. Damage caused by WMSDs "[...] result from an imbalance between the demands of the tasks performed at work and the individual functional capacities to respond to such demands" (LELIS et al., pg. 478, 2012).

According to Lelis *et al.* (2012), WMSDs can have numerous consequences, both for the worker and the employer and the entire production chain, since they can produce functional disability, reduced productivity, increased absenteeism rates and generate high expenses with treatment of those affected due to indemnity lawsuits and social responsibility.

After World War II, the concepts of ergonomics emerged as a way to mitigate the occurrence of musculoskeletal injuries among workers, making the performance of manual and physical activities more appropriate and contributing to the improvement of working conditions, productivity, well-being and performance of the socio-technical system (LIDA, 2005). The implementation of ergonomic projects in industries aims to involve workers in the process of carrying out the Ergonomic Analysis of Work (AET), based on the fact that the individual himself is the specialist in the analyzed activity (IEA, 2021). ELA, in turn, is characterized by the application of knowledge in ergonomics to carry out the analysis, evaluation and correction of certain work situations.

Thus, in order to make workers aware of the risks inherent in the execution of their work activities, ergonomic training can be implemented in the production lines and

production cells of industries. In addition, the practice of this type of training can open space to involve actors/workers in the processes of recognizing and solving the problems that arise in their day-to-day lives (DIEGO-MAS, J.A.; ALCAIDE-MARZALL, J.; OVEDA-BAUTISTA, 2020).

The AET is composed of five distinct stages, namely: (1) demand analysis; (2) task analysis; (3) analysis of activities; (4) diagnosis; and (5) ergonomic recommendations (GUÉRIN et al, 2001). For this purpose, it is possible, in Ergonomic Analysis, to make use of the implementation of ergonomic tools, in order to measure on a qualitative scale the level of effort that a certain work activity exerts on the body of exposed workers, in a more accurate and punctual way.

Ergonomic tools are elaborate protocols that make it possible to analyze a certain group of working conditions, body group and/or nature of the work activity performed (LAPERUTA *et al.*, 2018). By making use of such protocols, consequently, there is a strengthening of the AET. However, such protocols are not a substitute for the more complete ELA process, since the procedures serve to indicate specific situations and do not carry out an analysis of the entire context and the determinants involved in it.

For the organization to have, in practice, a robust and coherent Occupational Health and Safety (OSH) program, its conception needs to go beyond the premise of standardized safety. Therefore, the ideal would be to adhere to an adaptive and dynamic model, which would make it possible not only to consider the current regulations, but also to consider in their practices the experiences of the professionals who are part of the work system (ROCHA; VILELA, 2021).

Therefore, in view of the context in question, the present research defined as a general objective: To develop an ergonomic study of the working conditions in a manufacturing cell of the electronics industry to reduce the risks associated with injuries resulting from unfavorable ergonomic conditions.

In order to achieve the proposed general objective, the following specific objectives were defined:

- Evaluate the production process carried out by the operators of the workstation;
- Analyze the workstation in a macroergonomic way;
- Identify the ergonomic demand of workstation operators.

It is worth mentioning that this research is an excerpt from the winning project of one of the Innovation Notices for Industry of the CNI (National Confederation of Industry), edition of the year 2020. The project was developed by the SESI Innovation Center in Health Technologies - CIS-Tech - which belongs to the Federation of Industries of the State

of Santa Catarina (FIESC), and its mission is to develop innovation projects as a means of promoting health and safety in the Santa Catarina industry. This study refers to the first stage of the project, in which the objective was to characterize the reality of the industry, specifically the work activity and its characteristics.

METHOD

The methodological approach chosen for the development of the project is characterized by being a qualitative research with a descriptive objective. Thus, participant observation was implemented, which allows the researcher to understand more effectively the functioning of the sociotechnical system analyzed, through direct observation of the work activity of the population studied. Through the implementation of such processes, it was possible to listen to the actors involved and generate recommendations for changes in the position in question, aiming to improve safety and efficiency in the work environment (POUPART *et al.,* 2008).

According to Silva *et al.* (2005) From the point of view of its nature, the research can be classified as applied, since it generates practical interventions that range from organizational aspects to the adequacy of the physical arrangement of the work cell under study. The methodological procedures were based on an interactive process, with the delimitation of the following stages that constituted the study carried out: collection of preliminary data, interviews and application of a questionnaire with the workers, observation of the work activity, mapping of the process, analysis of the observed data and formulation of ergonomic recommendations.

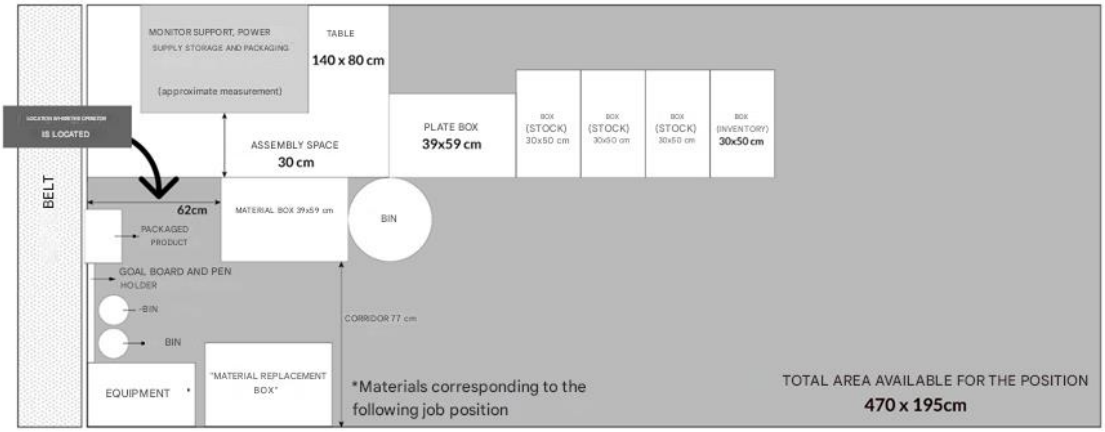
An initial contact was made with an electronic products manufacturing industry located in the state of Santa Catarina. From this contact, the partnership was signed to carry out the project on the production line, and the job to be analyzed was selected, as indicated by the company's own managers.

In the initial survey of the aspects related to the workstation to be studied, characteristics such as the arrangement of items, equipment and materials used in production, the operator's position in the workspace and movements performed during the work activity were recorded. Figure 1 shows a representation of the top view of the arrangement of the items, machines and equipment that make up the workstation, in addition to the space occupied by the operator while performing his activities.

Figure 2 represents the flow, in chronological order, of the activities performed by the worker when allocated to his work shift at the electronic product assembly station. The

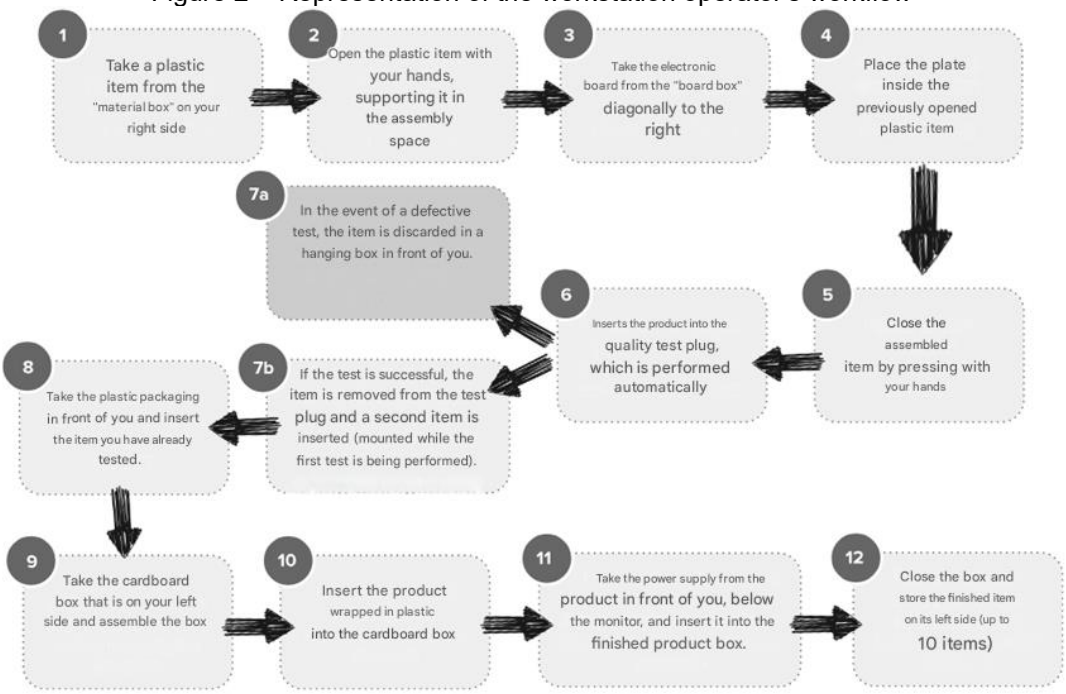
workflow is carried out according to the arrangement of the items in the layout depicted in Figure 1.

Figure 1 – Representative top view of the current physical arrangement of the workstation



Source: Authors, 2023

Figure 2 – Representation of the workstation operator's workflow



Source: Authors, 2023

Based on the stages of the AET, the first step in carrying out the research was to identify the ergonomic demand of the work, through face-to-face technical visits to the company's facilities. The second stage consisted of the analysis of the task prescribed for the workstation, through the examination of documents and procedures that could guide the execution of the activity, in addition to the analysis of the layout of the production cell, table layout, monitors, bench items and raw material. At this stage, the non-existence of such

documents was verified, and was thus complemented through conversations with managers, responsible leaders and workers.

The third step was the analysis of the activity, in which, through observation, the movements and ergonomic postures assumed by the operators during the work activity were identified, added to the study of the duration of the movement times (chronoanalysis). The fourth step consisted of compiling and analyzing the data collected in the previous stages and producing a diagnosis of the working conditions.

In the fifth and final stage, ergonomic recommendations were made necessary to improve the working conditions at the analyzed station, to be implemented at the company's discretion. Chart 1 presents a description of the procedures, stages and activities involved in the method used to carry out this research.

Table 1 – Description of the steps of the methodological procedure applied

PROCEDURE	STAGE		ACTIVITY
Detect the existing problem in a company and characterize it	1	Identification of a company that has an ergonomic problem in a given workstation	Initial contact with the identified company and preliminary meetings with the responsible managers
	2	*Demand Analysis* Definition of the workstation to be analyzed and the risks inherent to it	Technical visits to observe the work process at the post in question
Develop a plan or program to solve the problem detected	3	*Task and Activity Analysis* Gathering information regarding the problem detected	Survey and analysis of the *layout* of the workstation: registration of photos, measurements and arrangement of items
			Interviews with managers and leaders to gather organizational information
			Application of the QNSM questionnaire and interviews with the station operators about their work activity, self-perception and suggestions for improvement
Develop a solution to the problem detected based on the information obtained in the previous step	4	Development of Ergonomic Diagnostics	Compile and analyze the information and data collected about the job
Provide feedback to the company about the study carried out	5	Provide *feedback* to the company about the possibilities of changes in the workstation	Present the result of the previous steps to the managers in charge and operators of the workstation, as well as the recommendations for changes and adjustments to be implemented in the location and processes

Source: Authors, 2023

In the "Task and Activity Analysis" stage, the Nordic Musculoskeletal Symptom Questionnaire (MSQ) was applied (KUORINKA *et al.*,1987) with the operators of the

workstation in question, carried out anonymously. The questionnaire was used to identify the prevalence of musculoskeletal disorders in the performance of activities performed at the workplace.

In order to, at first, complement the analysis by constructing the sociodemographic profile of all those operated at the center, questions regarding age, gender, education and length of experience at the center were applied, in addition to the specific questions of the QNSM. The specific questions, in turn, were intended to identify the workers' perception of the work rhythm, point out the existence of any pain or discomfort when performing the work activity and request possible suggestions for improvement.

Also, in this same stage, semi-structured interviews were carried out with open and closed questions to complement the analysis of the task and activity. The meetings were held in person and according to the availability of the workers, since they worked in shifts and depended on the production demand of the day.

The sample consisted of 15 (fifteen) female workers who performed the activity of assembling the electronic device in the work cell analyzed, working 44 hours a week. The workday is divided into two shifts lasting eight hours and thirty minutes each, with regular breaks for coffee, workplace gymnastics and lunch of 30 (thirty) minutes. In addition, operators rotate their activity, moving to another work cell, in order to avoid their physical overload in a single task. However, despite the recommendation to rotate every two (2) hours of work, it was observed that there is no effective and formal control that they have actually carried out the alternation of activity.

Regarding the age group, all operators are under 34 years old, with an average age of 28.06. All individuals have high school education, and six operators have a technical course. The operators' time in the company is less than five years, with 60% (9) having more than two years in this production line, and 40% (6) less than two years.

RESULTS AND DISCUSSIONS

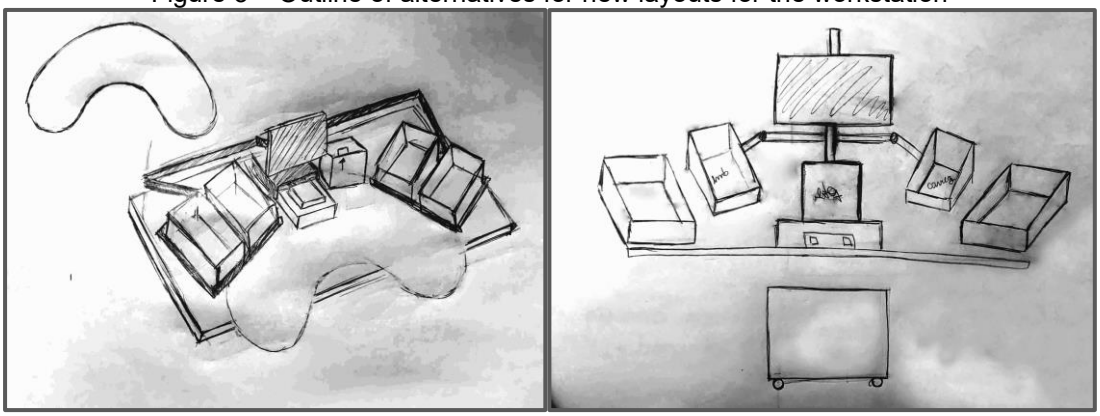
The conclusion of the component stages of the methodological procedures of the research, from the initial analysis of the structure and processes pertinent to the workplace, to the collection of information with the company and the workers, culminated in relevant information for the proposed study.

At the workstation analyzed, the activity of assembling the electronic product is carried out, most of the time, in the "standing" position. However, there is a chair available to each operator so that he can sit while performing his tasks, either 100% of the time or partially. It was also observed by the researchers that the total cycle time to assemble the

product is approximately 33 seconds, with the production goal of approximately 150 (one hundred and fifty) units per hour.

Regarding the arrangement of the workstation items and its *layout*, a sketch of two prototypes of a reformatted work cell was constructed, as shown in Figure 3. The proposal of the new organization of the work cell consisted of balancing the use of the upper limbs of the operators, alternating between the right and left sides. In this way, the individual would be more in the center of the bench and all the materials necessary for assembly would be made available in the range zone of up to 35 centimeters in front of him and diagonally. In this way, it is sought to avoid lateral flexion of the trunk and make spare items available behind the workbench, leaving all items (supplies, monitor and equipment) at the level of the eye line and field of vision.

Figure 3 – Outline of alternatives for new layouts for the workstation



Source: Authors, 2023

However, it was possible to conclude that the current boxes, which contain the materials/inputs used to assemble the final electronic product, have become an obstacle to the development of a solution with a better ergonomic response, since the managers signaled that the current replacement boxes could not be replaced by other types and models.

Regarding the answers to the interviews conducted with the operators, it was possible to obtain information regarding physical discomfort, work rhythm and suggestions for improvement, all related to the work activities performed at the workstation analyzed in this research. Among the workers interviewed, 90% (14) reported feeling pain or discomfort in the performance of the activities at the post, and 55% of them reported feeling pain in their hands and 45% reported feeling pain in their ankles and feet.

When asked about the pace of work required in the production process, the perception of the workers revealed that 40% (6) believe that the pace is adequate. However, 30% said the pace is "rarely adequate", 20% considered it "almost always

adequate" and 10% said it was "not adequate". At the end, a space was opened for each one to make a suggestion that they considered relevant to improve the workplace. However, only five of them agreed to answer this question, with the refusal of the others.

By cross-referencing and analyzing the information collected at the workplace, with the company and the workers, as well as the data from the interviews conducted with them, it was possible to present the results achieved to the managers. Thus, a workshop was held, through the implementation of the *design thinking* methodology – a user-centered methodology, with the aim of sensitizing managers and bringing them closer to the reality of operators (BROWN, 2009).

The answers obtained from the operators, added to the observation of the assembly process of the electronic product, evidenced the possibility of the existence of physical overload in the upper and lower limbs of the workers, which may be associated with the repetitiveness of the movements performed predominantly with the hands and by the performance of the work shift in its entirety in the "standing" position.

A certain tension was also identified in the performance of the work activity by the operators, since it is common for some manager or management individual to be present on the "factory floor" monitoring the assembly process. Another factor that was also observed in the physical layout of the workbench is that the adjustments to the height of the table and monitor are not made by the workers when they take the position in their assembly shift after another operator, with different stature, finishes the previous shift.

Also, as a result of this research, it was proposed to the company to acquire a mechanism responsible for testing the product's LED lamps and closing it automatically. This mechanism, in turn, would be behaved on the bench and would reduce the physical effort on the hands of the operators when performing the test and closing of the electronic product. Thus, the proposed solutions for the project to reformulate the workstation should prioritize the reduction of physical effort on the upper limbs of the workers, as well as involve them in the process of building the new *layout* that best meets their needs during the work shifts.

By making use of *Design Thinking* tools, it was possible to sensitize management and bring it closer to issues that involved the workers and even reported by them. This process included the stages of defining the personas, presenting the results obtained with the study and ending with the *brainstorming* of possible improvements. Thus, the managers, taking into account the workers' statements, proposed to acquire the mechanism that performs the test of the product and its closure, in order to reduce the physical effort on the hands in view of the characteristic of performing repetitive work.

It is worth mentioning that work is considered repetitive when its cycle is less than 30 seconds and when 50% of the working day is occupied with only one type of set of movements (GUIMARÃES, 2011). In the case of the workstation process under study, the cycle totals 33 seconds, is close to the threshold, but it was the use of the same limbs by the operators that characterized it as repetitive.

The pace of work is also an impact factor on the perception of effort. Given that a discrepancy was identified between what individuals reported *versus* what actually happens in the practice of activities, it is necessary to carry out an in-depth study with the use of electromyography to analyze the overload on the individual's body muscles. In this way, it will be possible to obtain more faithful feedback and not only based on self-report, but on a set of information and surveys.

Work-related musculoskeletal disorders are a group of disorders that affect the musculoskeletal system of individuals and can be caused or aggravated by the repetition of movements for long periods of work activities. Often, this type of injury is not identified by workers in their routine activities, as the physical signs are felt in the medium and long term.

These injuries may not impact the performance of work activity in the short term, as their symptoms do not always cause immediate severe pain, which contributes to a late diagnosis. Thus, through the interviews conducted with the workers, it was possible to verify that even though they were exposed to risk factors during the work process, they were not able to clearly perceive and feel the damage caused by the injuries.

In view of the analysis of the working conditions and ergonomic challenges, recommendations were defined that serve as requirements for the next phase of the project, with the aim of improving both the working environment and the efficiency in the assembly process. User requirements, product requirements, and context requirements have been established. These requirements aim not only to meet the ergonomic needs of workers, but also to improve the organization and efficiency of the assembly process, always with a focus on the health, safety, and comfort of workers. With regard to user requirements, it is necessary to encourage and make workers aware of the importance of ergonomic adjustments, promoting the reduction of trunk rotation and lateralization during assembly activities. The reach zones must be preserved in accordance with ergonomic specifications, ensuring more natural and less exhausting movements, in addition to maintaining a minimum ergonomic and functional area of 30 cm for the assembly of the product, in order to avoid overload of movements and facilitate the manipulation of the parts. Another goal is to ergonomically optimize the area intended for storage, in order to facilitate the handling of inputs and improve work dynamics. In addition, it is important to

present solutions that meet the needs of workers with different heights, ensuring that everyone can perform their duties with a lower risk to their health. This implies the development of ergonomic adaptations that allow each worker to adjust his or her workstation according to their physical characteristics, avoiding inadequate postures and overload of effort, and consequently, preventing musculoskeletal injuries and other problems related to occupational health. Implementing these solutions will promote a more inclusive, comfortable, and safe work environment for everyone.

With regard to product requirements, the implementation of an automated bench height adjustment can provide greater comfort and adaptability to the different needs of workers, promoting a more ergonomic work environment. The assembly process needs to be optimized in order to become more logical and intuitive, facilitating the workflow and minimizing the occurrence of operational errors. The optimization of the available space, with ergonomic improvements, aims to reduce the physical effort of workers and improve their posture, contributing to the prevention of injuries and increasing work efficiency. In addition, it is essential to incorporate an intelligent system that is able to automatically recognize the individual and perform personalized ergonomic adjustments, ensuring that each worker has a workstation that is suitable for their physical characteristics and specific needs, which will result in greater comfort and productivity.

Implementing a signaling system is necessary to alert when ergonomic adjustments are inadequate. It is also important to optimize the furniture intended for the stock, offering ease of use for the replacement of inputs and better use of space, increasing the efficiency of the process. Another relevant issue is the evaluation of the possibility of controlling production goals through label accounting, which would provide a more effective control and monitoring solution.

Finally, the context requirements involve the development of the proposal making the most of the space intended for the workstation, aiming to optimize the use of the environment in an efficient and functional way. The arrangement of furniture and equipment must be planned to ensure adequate circulation, facilitate access to inputs and keep the environment organized. In addition, it must be ensured that all components, such as the injection molding machine's plastic bin and parts storage, are located in an accessible manner and without compromising the workflow. The accumulation of product parts in the assembly area should be avoided, ensuring a clean and organized environment. The organization of the space should also include specific areas for defective parts, in order to avoid contamination of the good parts and speed up the sorting process. Carcass and plate

input boxes should be arranged with an angle, allowing a clear view of the contents inside and facilitating access to the necessary materials.

These requirements aim not only to meet the ergonomic needs of workers, but also to promote a substantial improvement in the organization and efficiency of the assembly process, always with a focus on the health, safety and comfort of workers.

To complement the survey carried out in the present study, it is recommended, in the future, the application of ergonomic tools capable of assessing the degree of risk that the work activity exerts on the upper limbs of the operators. In addition, it is also suggested to map the process in order to identify the activities that actually add value, as well as the waste present in the work process of the station.

The studies address the importance of ergonomics in the development of projects in production lines, but there is a difficulty, especially in the design phase, to take into account the use of ergonomics for workers and in the activities they perform in their workplaces (REINERT; GONTIJO, 2021). This issue, in turn, can be observed in the electronic product assembly cell, in which some of the needs and specificities of the workers were suppressed due to the argument that the project would be economically unfeasible.

This scenario reinforces the need to integrate ergonomics more effectively in the early stages of job development, promoting solutions that meet the demands of workers without compromising the feasibility of the project.

CONCLUSIONS

In view of the technological transformations that industries are seeking to become competitive, the Ergonomic Analysis of Work (AET) emerges as a way to subsidize more assertive decisions in order to ensure operational efficiency and safety in the work environment. Participatory ergonomics analyzes the interaction between the human being and the socio-technical system, in order to improve working conditions according to the reality of each organization, listening to all the actors involved. In this way, the involvement of workers in the processes of modernization and innovation of the industrial park becomes valuable. This new dynamic requires the industry to involve workers from the beginning of systematic data collection, through the development and implementation of improvements. Involving the individual in the development of the project can help in greater acceptance by the user himself, actually meeting his real expectations and needs (CARAYANNIS et. al., 2021).

This study represented the first stage of the project and aimed to better understand the needs of the workers in the workplace to be improved and reformulated. The next step

proposed would be to carry out the *actual design* and prototyping of a new workstation based on the recommendations generated, in addition to the application of technology to improve ergonomic *feedback*.

The research developed met the objectives initially proposed, since, through the interviews and analysis of the information collected, it identified that physical overload influences the well-being of individuals. Thus, the study may help to define the new focus of action in the development of the reformulated workstation, which is the reduction of the physical effort of the upper limbs and adaptation of the workbench to work heights in the "standing" and "sitting" positions, allowing more ergonomic comfort for individuals.

Participatory ergonomics is still a topic that brings many challenges to companies and industries, even more so when the origin of the problems is in the pace of production, productivity and return. In addition, there is still a lot of resistance on the part of management to make changes in its production lines that actually consider the needs of its workers. Given this, the study reiterated the importance of implementing a conscious and participatory management, which engages to contribute to the results, and of involving the performing worker himself in the process of modifying or improving the position.

The relevance of educating workers about the ergonomic aspects involved in their work activity was clear in this context. Although they are unable to identify immediate discomfort or pain during their work activity, by receiving information related to ergonomics, operators could experience positions and movements that have a reduced impact on their well-being and physical health. Through the proposed study, it was evident that there are still several barriers and challenges for ergonomics to overcome within organizations and, thus, to actually improve the work environment.

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