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ERGONOMIC IMPLICATIONS OF THE MATERIALS STORAGE PROCESS PRACTICED BY AN ORGANIZATION IN THE MANAUS INDUSTRIAL HUB

IMPLICAÇÕES ERGONÔMICAS DO PROCESSO DE ARMAZENAGEM DE MATERIAIS PRATICADO POR UMA ORGANIZAÇÃO DO POLO INDUSTRIAL DE MANAUS

IMPLICACIONES ERGONÓMICAS DEL PROCESO DE ALMACENAMIENTO DE MATERIALES PRACTICADO POR UNA ORGANIZACIÓN EN EL PARQUE INDUSTRIAL DE MANAUS

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Abstract

Contemporary ergonomics encompasses the adaptation of work to human capabilities, integrating physical, cognitive, and organizational dimensions, especially in complex industrial environments influenced by Industries 4.0 and 5.0. There is a lack of systemic approaches that analyze, in an integrated way, the storage process, considering its multiple stages and combined risks, particularly in real-world contexts such as the Manaus Industrial Hub. Thus, this study aimed to analyze the ergonomic implications of the material storage process, identifying risks at each stage and their impacts on workers' health and performance. The method used was qualitative, descriptive, and cross-sectional, with direct observation and interviews, and analyzed each stage of the storage process, listing its ergonomic implications. Physical, chemical, and cognitive risks were identified across all stages, with particular emphasis on manual labor, high temperatures, chemical substances, and the risk of serious accidents, often cumulatively. The conclusion shows that the process presents high ergonomic complexity and weaknesses that compromise safety and

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operational efficiency, which require structural interventions. The study goes further by proposing an integrated analysis of ergonomics in warehousing, highlighting the interdependence between risks and reinforcing the need for systemic approaches in industrial management.
Keywords: Materials storage; Ergonomics; Ergonomic aspects of warehousing; Logistics in the Amazon; Manaus Industrial Hub.

Resumo

A ergonomia contemporânea compreende a adaptação do trabalho às capacidades humanas, integrando dimensões físicas, cognitivas e organizacionais, especialmente em ambientes industriais complexos e influenciados pelas Indústrias 4.0 e 5.0. Há ausência de abordagens sistêmicas que analisem, de forma integrada, o processo de armazenagem, considerando suas múltiplas etapas e os riscos associados, sobretudo em contextos reais, como o Polo Industrial de Manaus. Assim, este estudo teve como objetivo analisar as implicações ergonômicas do processo de armazenagem de materiais, identificando riscos ao longo das etapas e seus impactos na saúde e no desempenho dos trabalhadores. O método utilizado consistiu em pesquisa qualitativa, descritiva e transversal, com observação direta e entrevistas, analisando-se cada etapa do processo de armazenagem e listando-se suas implicações ergonômicas. Foram identificados riscos físicos, químicos e cognitivos em todas as etapas, com destaque para esforços manuais, altas temperaturas, substâncias químicas e riscos de acidentes graves, frequentemente de forma cumulativa. A conclusão mostra que o processo apresenta elevada complexidade ergonômica e fragilidades que comprometem a segurança e a eficiência operacional, o que exige intervenções estruturais. O estudo avança ao propor uma análise integrada da ergonomia na armazenagem, evidenciando a interdependência entre os riscos e reforçando a necessidade de abordagens sistêmicas na gestão industrial.
Palavras-chave: Armazenagem de materiais; Ergonomia; Aspectos ergonômicos da armazenagem; Logística na Amazônia; Polo Industrial de Manaus.

Resumen

La ergonomía contemporánea abarca la adaptación del trabajo a las capacidades humanas, integrando las dimensiones físicas, cognitivas y organizativas, especialmente en entornos industriales complejos, influidos por las Industrias 4.0 y 5.0. Falta un enfoque sistémico que analice de manera integrada el proceso de almacenamiento, considerando sus múltiples etapas y los riesgos asociados, en particular en contextos reales como el Parque Industrial de Manaus. Por lo tanto, este estudio tuvo como objetivo analizar las implicaciones ergonómicas del proceso de almacenamiento de materiales, identificando los riesgos a lo largo de sus etapas y sus impactos en la salud y el desempeño de los trabajadores. El método empleado consistió en una investigación

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cualitativa, descriptiva y transversal, con observación directa y entrevistas, así como en el análisis de cada etapa del proceso de almacenamiento y en la enumeración de sus implicaciones ergonómicas. Se identificaron riesgos físicos, químicos y cognitivos en todas las etapas, con énfasis en el esfuerzo manual, las altas temperaturas, las sustancias químicas y los riesgos de accidentes graves, a menudo acumulativos. La conclusión muestra que el proceso presenta una alta complejidad ergonómica y debilidades que comprometen la seguridad y la eficiencia operativa, lo que requiere intervenciones estructurales. El estudio va más allá al proponer un análisis integrado de la ergonomía en el almacenamiento, destacando la interdependencia entre los riesgos y reforzando la necesidad de enfoques sistémicos en la gestión industrial.

Palabras clave: Almacenamiento de materiales; Ergonomía; Aspectos ergonómicos del almacenamiento; Logística en la Amazonía; Parque Industrial de Manaus.

1. Introduction

In recent years, ergonomics has established itself as a central scientific field in the design of human-centered production systems, especially amid the transformations brought about by Industry 4.0 and 5.0. Unlike traditional approaches, which prioritize adapting the worker to the demands of the job, contemporary ergonomics emphasizes the principle that work should be designed to fit human capabilities, limitations, and needs. This human-centered perspective has been widely discussed in recent literature, which highlights the integration of physical, cognitive, and organizational factors in building safer and more efficient work environments (Płaza et al., 2025; Naranjo et al., 2025; Díaz Martínez et al., 2025; Sakti & Khairunniza, 2025; Carmo et al., 2025). These studies show that ergonomics plays a strategic role in reducing occupational risks, increasing productivity, and promoting worker well-being. Furthermore, they point out that technological advancement does not eliminate the need for ergonomic intervention but, rather, expands its relevance. The incorporation of technologies such as wearable sensors, artificial intelligence, and intelligent systems requires new forms of human-machine interaction. In this context, ergonomics becomes a structuring element in the design of sustainable production systems. Thus, current scientific concerns reinforce the need to align work with human capabilities. This

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consolidates ergonomics as one of the pillars of contemporary production engineering.

This concern also extends to internal logistics within organizations, especially in warehousing, where workers, equipment, and materials interact intensively. Recent studies indicate that stages such as receiving, handling, storage, and shipping entail high physical and cognitive demands, making them environments conducive to ergonomic risks (Carmo et al., 2025; Naranjo et al., 2025; Płaza et al., 2025). The literature highlights that manual handling of loads, repetitive tasks, and adverse environmental conditions are recurring factors in these contexts. The increasing digitalization of logistics processes introduces new cognitive demands related to the use of information systems and real-time decision-making, making internal logistics a relevant field for ergonomics, especially given the need to balance operational efficiency and occupational health. Another important aspect refers to the integration between logistics and production activities, which can intensify exposure to various risks. Thus, warehousing ceases to be a purely operational activity and becomes a systemic endeavor. In this sense, the literature reinforces the need to incorporate ergonomics into logistics planning, underscoring the importance of in-depth analyses of these implications.

Despite theoretical advances, significant gaps remain in the literature and in practice in the ergonomic analysis of warehousing processes in complex industrial contexts. Many studies focus on isolated activities, such as cargo handling or material selection, without considering the integration between the different stages of the production process; there is a predominance of approaches that analyze only physical ergonomics, neglecting cognitive and organizational aspects; and another important gap is the scarcity of empirical studies conducted in real industrial environments, especially in regions with specific characteristics, such as the Manaus Industrial Hub. From a practical point of view, many organizations still do not incorporate ergonomics strategically, limiting themselves

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to compliance with regulatory standards. This results in punctual interventions that do not account for the complexity of production systems, as the integration between logistics and production activities has been little explored from an ergonomic perspective. These gaps highlight the need for studies that adopt a systemic, context-based approach. Thus, it is fundamental to investigate how ergonomic factors manifest throughout the entire warehousing process to advance knowledge and improve organizational practices.

Given this context, the present study aims to analyze the ergonomic aspects of the material storage process in an industrial company, considering its various stages and their implications for workers' health and performance. Specifically, it seeks to identify the ergonomic risks associated with the activities performed, understand their distribution across the process, and evaluate their impact on operational efficiency. The study also intends to contribute to the literature by integrating the physical, cognitive, and organizational dimensions of ergonomics into a single analytical model applied to internal logistics. From a practical point of view, the results can support improvements in storage processes, promoting greater safety and productivity. Another relevant contribution is the broadening of understanding about the interaction between logistical and productive activities in industrial environments. The study also aims to support managerial decision-making, especially in occupational risk management. Thus, it is expected that the findings will contribute to both scientific advancement and the practical application of ergonomics. Finally, the study reinforces the importance of integrated approaches to analyzing production systems, highlighting the potential of ergonomics as a strategic tool in industrial management.

2. Literature Review

Ergonomics is the science that seeks to adapt work to the physical, cognitive, and organizational characteristics of human beings, aiming to promote

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health, safety, comfort, and performance in the workplace. This interdisciplinary area integrates knowledge from engineering, physiology, psychology, and design and is fundamental for analyzing interactions among workers, machines, and production systems. Recent studies demonstrate that ergonomics plays a strategic role in preventing occupational diseases and improving productivity by reducing unnecessary effort and optimizing working conditions (Sisodia; Zaini, 2025; Carmo et al., 2025; Oliveira et al., 2025). Furthermore, ergonomics is directly associated with reduced musculoskeletal disorders, fatigue, and occupational stress, all of which significantly impact organizational performance. Recent literature also emphasizes that ergonomically adequate environments contribute to greater worker engagement and lower absenteeism. In this context, ergonomics ceases to be merely a regulatory requirement and becomes a strategic element of competitiveness. The adoption of ergonomic practices has been driven by the technological transformations of Industry 4.0 and 5.0, which require new forms of human-machine interaction (Trstenjak et al., 2025; Plaza et al., 2025). Thus, contemporary ergonomics assumes a central role in the construction of sustainable and efficient production systems.

From a broader conceptual perspective, ergonomics also involves the analysis of cognitive and organizational aspects of work, going beyond physical and biomechanical issues (Latip et al., 2025; Islam et al., 2025). This includes factors such as mental load, decision-making, work pace, and task organization, which directly influence human performance. Recent studies indicate that inadequate ergonomics can lead to operational errors, accidents, and reduced process quality (Sisodia; Zaini, 2025; Carmo et al., 2025; Oliveira et al., 2025). Furthermore, ergonomics seeks to balance the demands of the production system with human capabilities, avoiding physical and mental overload. The literature highlights that simple ergonomic interventions, such as layout adjustments and tool improvements, can have a significant impact on workers' health. Another relevant point is the integration of ergonomics with emerging technologies, such as sensors and automation, enabling real-time risk monitoring. Thus, modern

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ergonomics positions itself as an essential element of occupational risk management, as a systemic approach that aims to harmonize productivity and well-being at work, especially across the stages of the warehousing process.

The warehousing process comprises a set of interdependent steps that ensure the efficient flow of materials within organizations. In general, the literature indicates that the most common stages are receiving, internal handling, storage, and shipping, which may vary depending on the type of logistics operation (Carmo et al., 2025; Sisodia; Zaini, 2025; Oliveira et al., 2025). Receiving involves checking and recording materials, a critical step to ensure product quality and traceability. Internal handling refers to the movement of materials within the warehouse, using equipment such as forklifts or manual transport. Storage consists of allocating materials to appropriate locations, considering criteria such as safety, accessibility, and turnover. Finally, shipping involves the separation, packaging, and delivery of products to their final destination. These stages form a continuous flow that requires coordination and operational efficiency. The literature highlights that failures in any of these phases can compromise the entire logistics chain, which is why the storage process must be carefully planned and monitored (Pereira et al., 2025; Silva et al., 2025).

Beyond these traditional steps, recent studies indicate that activities such as order picking, inventory control, and information processing are essential components of modern warehousing. Picking, for example, is considered one of the most critical activities, as it involves significant physical effort and repetitiveness and accounts for a significant portion of operational costs (Carmo et al., 2025; Oliveira et al., 2025; Sisodia; Zaini, 2025). Inventory control, in turn, involves the continuous monitoring of material levels, which requires precision and attention from workers. Information processing involves using digital systems to record and track operations. The integration of these activities highlights the complexity of the contemporary warehousing process. Furthermore, increasing automation has transformed these steps, introducing new ergonomic challenges. The literature emphasizes that the combination of manual and technological

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activities requires constant adaptation on the part of workers. Thus, the warehousing process becomes increasingly dynamic and complex. This reinforces the need for more comprehensive ergonomic analyses. Finally, it is important to note that the stages of the warehousing process are directly related to working conditions and occupational risk exposure. Each phase presents specific characteristics that influence the type and intensity of efforts required of workers. For example, cargo handling may involve intense physical effort, while inventory control may demand a greater cognitive load. Recent studies indicate that task variability in the warehousing process can increase the complexity of ergonomic management (Sisodia; Zaini, 2025; Oliveira et al., 2025; Carmo et al., 2025). In addition, the lack of standardized activities can lead to inconsistencies in working conditions. The literature also highlights that layout and technology use directly influence operational ergonomics. In this context, analyzing the process stages is fundamental to identifying critical risk points. Thus, understanding the warehousing flow is essential to assessing its ergonomic implications. This allows proposing improvements that increase safety and operational efficiency, implying that ergonomics has important implications for the storage process.

Manual handling of loads is one of the main ergonomic implications in the warehousing process and is widely associated with the development of musculoskeletal disorders. This activity involves lifting, transporting, and positioning materials, often performed without adequate support from mechanical equipment. Studies indicate that overload on the lumbar spine and upper limbs is a direct consequence of this type of task, especially when performed repeatedly and under inadequate conditions (Zhao et al., 2022; Nguyen, 2024; Nasir, 2025). Furthermore, the variability in material weight and shape increases the biomechanical complexity of the activities. The literature indicates that workers exposed to these conditions have a higher incidence of occupational injuries and work absences. Another relevant factor is inadequate training, which can exacerbate the adoption of incorrect lifting techniques. In this context, ergonomics proposes interventions such as the use of auxiliary equipment and reorganizing

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the layout. These measures aim to reduce the physical load and improve operational efficiency. Therefore, manual handling of loads constitutes one of the main ergonomic challenges in the warehousing environment. This reinforces the need for preventive strategies based on scientific evidence.

Inadequate postures adopted during warehousing activities also imply an important ergonomic issue, especially in tasks such as picking and stocking. These activities often require workers to perform trunk flexion, spinal twisting, and to raise their arms above shoulder level, which can contribute to muscle fatigue and chronic pain. Recent studies demonstrate that prolonged maintenance of these postures is directly related to the emergence of musculoskeletal problems (Nasir et al., 2024; Hidayat et al., 2025; Yankova-Yordanova et al., 2025). In addition, inadequate warehouse layout, such as shelves at non-ergonomic heights, intensifies these risks. The repetition of these postures throughout the workday intensifies the negative effects on workers' health. The literature also indicates that the lack of individualized workstation adjustments exacerbates the situation. Ergonomic interventions, such as furniture redesign and the use of adjustable equipment, have proven effective in reducing these impacts. Thus, posture analysis is fundamental for risk identification. This highlights the importance of considering workers' anthropometric characteristics. Therefore, inadequate postures constitute a recurring and relevant problem. Table 1 summarizes these implications.

Table 1. Most common ergonomic implications of the storage process

Ergonomic implications	Description	References
Manual handling of loads	Lifting, transporting, and moving heavy materials, overloading the lumbar spine and upper limbs, and a high risk of musculoskeletal disorders.	Zhao et al. (2022); Nguyen (2024); Nasir (2025)
Inadequate postures	Frequent adoption of forced positions, such as trunk flexion and arm elevation, can cause muscle fatigue and chronic pain.	Nasir et al. (2024); Hydayat et al. (2025); Yankova-Yordanova et al. (2025)
Repetitiveness	Continuous execution of standardized movements, especially in picking, contributes to RSI/WRULD and reduced functional capacity.	Suherman et al. (2025); Ugurtay et al. (2026); Turgay; Özyurt (2025)

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Cognitive load	Excessive mental demands related to inventory control, digital systems, and decision-making can generate stress and operational errors.	Lucchese et al. (2025); Hilmi et al. (2025); Karim et al. (2025)
Environmental conditions	Exposure to factors such as noise, heat, and inadequate lighting impacts comfort, concentration, and performance.	Trstenjak et al. (2025); Cosma et al. (2025); Kamala et al. (2025)
Work organization	Intense pace, prolonged workdays, and lack of adequate breaks, increasing fatigue and the risk of accidents.	Bahari et al. (2025); Nilsson et al. (2025); Nuryanto et al. (2025)

Source: data collected by the authors.

The repetitiveness of tasks is another critical factor in the ergonomic implications of the warehousing process, especially in order picking and continuous material handling operations. These activities involve the constant execution of the same movements, which can lead to the development of repetitive strain injuries and work-related musculoskeletal disorders. Studies indicate that continuous repetition without adequate breaks compromises workers' functional capacity over time (Suherman et al., 2025; Ugurtay et al., 2026; Turgay; Özyurt, 2025). Furthermore, the pressure to increase productivity often shortens muscle recovery time, exacerbating the effects of repetitive work. The literature highlights that the combination of repetition and applied force significantly increases the risk of injury. Another relevant aspect is the monotony of tasks, which can affect workers' motivation and attention. Strategies such as job rotation and scheduled breaks are recommended to mitigate these effects. Ergonomics also suggests the partial automation of repetitive tasks. Thus, repetitiveness constitutes a significant risk factor in the warehousing environment. This requires organizational and technological interventions to mitigate it.

The cognitive load associated with warehousing activities also stands out as an important ergonomic implication, especially in environments that use digital inventory control and logistics management systems. These tasks require constant attention, quick decision-making, and the processing of complex information, which can lead to mental overload. Recent studies indicate that high cognitive load is associated with increased operational errors and workplace

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accidents (Lucchese et al., 2025; Hilmi et al., 2025; Karim et al., 2025). Poorly designed interfaces can hinder interaction between the worker and the system, increasing task execution time. The literature indicates that inadequate training intensifies these problems and that the simultaneous execution of tasks can overload human processing capacity. Therefore, cognitive ergonomics seeks to optimize system design to make systems more intuitive, thereby reducing mental stress and improving performance. Thus, cognitive load should be considered in ergonomic analysis, which highlights the importance of integrating cognitive factors into work management.

The storage environment's environmental conditions also play a significant role in ergonomic implications, directly influencing workers' comfort and performance. Factors such as inadequate temperature, noise, and lighting can compromise health and productivity. Studies indicate that environments with high or very low temperatures can cause thermal discomfort and fatigue (Trstenjak et al., 2025; Cosma et al., 2025; Kamala et al., 2025). In addition, excessive noise can hinder communication and increase stress levels. Insufficient lighting, in turn, can impair the performance of tasks that require visual precision. Literature highlights that the combination of these factors can increase the risk of accidents. Interventions such as improved ventilation, noise control, and adequate lighting are recommended. Environmental ergonomics seeks to optimize these conditions to improve worker well-being. Thus, the physical environment must be considered in ergonomic analysis. This reinforces the need for continuous monitoring of these variables.

Work organization is a determining factor in the ergonomic implications of the warehousing process, influencing both the physical and mental workload of workers. Prolonged work hours, an intense work pace, and inadequate breaks are frequently associated with increased fatigue and an increased risk of accidents. Recent studies indicate that poor work organization is directly related to the development of occupational diseases (Bahari et al., 2025; Nilsson et al., 2025; Nuryanto et al., 2025). Furthermore, pressure for productivity can lead to the

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adoption of unsafe practices. The literature highlights the importance of organizational policies that balance productivity and well-being. Strategies such as regular breaks, balanced task distribution, and proper time management are fundamental. Organizational ergonomics seeks to align work demands with human capabilities, thereby reducing risk and improving performance, making work organization a central element of ergonomic analysis. This highlights the need for a systemic approach to warehouse management.

3. Research Methodology

This study is a descriptive, qualitative research study conducted in an organization operating in the Manaus Industrial Hub. The general objective was to analyze the ergonomic implications of the material storage process, focusing on the internal logistics stages, the ways workers perform activities at each stage, and the ergonomic implications of their execution. The data collected were nominal in nature, with each stage of the storage process as the unit of analysis, at the process level, because the explanation encompasses the entire process, and from a synchronic analysis perspective, also called transversal, whose challenge was to elaborate a description of the current moment of reality (Nascimento-e-Silva, 2020; 2021a; 2021b; 2021c). This methodology was designed to specifically answer three guiding questions: What are the stages of the material storage process in the analyzed company? How are the stages of the material storage process operationalized? What are the possible ergonomic impacts on the activities of the storage process?

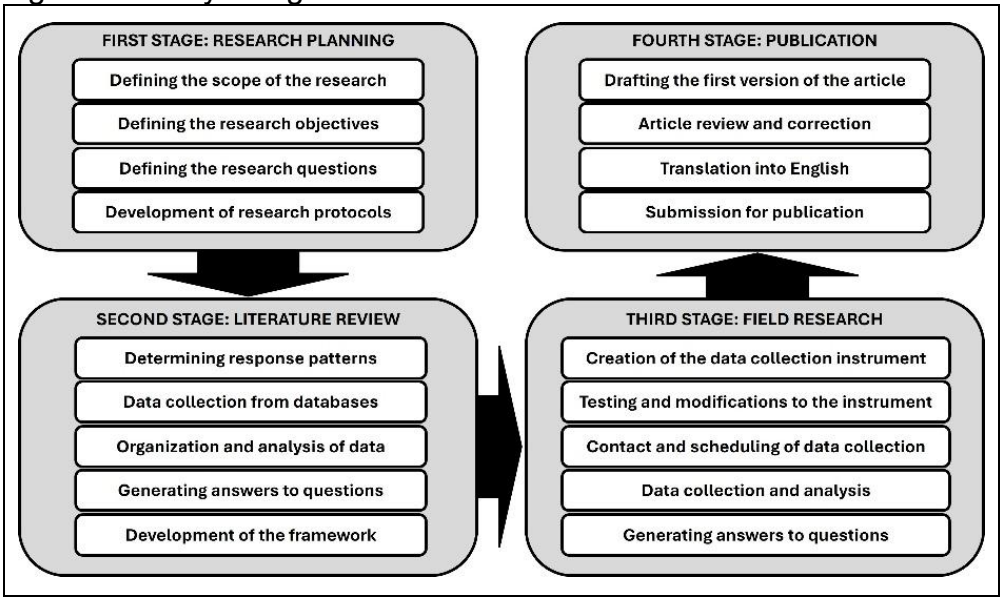
3.1 Study Design

The results of this study were obtained through the execution of four groups of activities. The first was the study planning, in which the scope and objectives of the research were defined, along with its research questions, and the protocols for both the literature review and field research were developed. Figure 1 shows the stages and the main activities that comprise them.

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Figure 1. Study design.



Source: prepared by the authors.

The second was the literature review, which began with the determination of response patterns for each guiding question, the collection of data based on scientific principles, as recommended by the scientific-technological method (Nascimento and Silva, 2023), the analysis and organization of the data, followed by the generation of answers to the guiding questions and the elaboration of the theoretical framework of the most common ergonomic implications for storage processes.

The third group of activities related to field research, which began with the development of the data collection instrument based on a literature review, continued with the testing of the instrument and the implementation of necessary changes; then contact was made with the organization's managers to schedule both the observation of the storage process and the interview, followed by data collection, which was then reviewed and analyzed. The results were organized into summary tables, as presented in the results section of this article, and finalized in the final research report. The fourth and final group of activities began

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with transforming the final report into a scientific article, continued with revising the text, style, and reference standards, then moved to the English version, and culminated in submission for publication.

3.2 Object of the study

The object of this study (unit of analysis) consisted of the stages of the storage process of an industrial organization operating in Manaus. This organization allowed the study to be conducted at its facility, provided anonymity was maintained so that its clients and competitors could not recognize it. Each stage was analyzed individually, in accordance with the observation protocol developed and previously approved by the organization's management, so that it was possible to accurately determine when each stage began and ended, as well as the procedure for connecting to the next and the preceding stage, so that the ergonomic implications could be properly detected and described. Although the explanation generated encompasses all stages, namely the storage process as a level of analysis, the focus of the investigation was the stage and its ergonomic implications.

3.3 Data Collection Instruments and Collection Strategy

Two data collection instruments with the same item structure were used, in accordance with the guiding questions of the research: a) the stages of the storage process; b) how each stage is operationalized in the organization; and c) the ergonomic implications of each stage. The first instrument was a direct observation guide of the production process, through which we sought to understand how storage activities are performed in the work environment. During data collection, the following were observed: a) what was done; b) how it was done; c) the equipment used; and d) the possible ergonomic risks present in each activity. When there were doubts regarding any of these four aspects, the professional accompanying the researcher provided detailed explanations,

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enabling the elaboration of answers to the research's guiding questions (Nascimento-e-Silva, 2023).

3.4 Data Organization and Analysis

After collection, the data were organized in a word processor, with the structure starting with the steps of the storage process sequentially. The organization began with identifying the first step performed, when it started, when it ended, and what step followed. The same procedure was applied to identify each step until the last one was properly mapped. Then, the map was filled in with the remaining data, starting with the operational method. The equipment used, and culminating in the identification of risks potentially associated with each step.

The analysis procedure was carried out to, firstly, describe the reality under study through the data and, secondly, explain what the data mean and indicate. For this reason, the analyzed data generated summarizing tables for each of the research's guiding questions, so that the logic revealed by the data could be visualized and made explicit in the paragraphs above and below each table. The results of the analyses are in the results section.

3.5 Generation and Interpretation of Results

The results were generated as a subsequent step to the data analysis. The results regarding the question about the steps of the storage process consisted of presenting each step in chronological order of execution; the results regarding the procedures consisted of a synthetic description of how each step is performed, so that an exact understanding of each procedure could be obtained; finally, the results regarding the ergonomic implications of each step appear in the form of items, since the purpose here was only to know each of them in connection with each step.

The interpretation of the results was carried out by comparing the field research findings with the theoretical framework of the literature review. The company's storage process steps were compared with the general scheme of the

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theoretical framework, highlighting differences and similarities, and what this may mean from an ergonomic perspective. The operational steps followed the same comparative procedure, but with an ergonomic focus, based on the greater or lesser intensity of the use of the human body in the execution of the activities. The interpretation of ergonomic implications also followed comparative parameters from the literature, primarily seeking to understand the reasons for the differences and similarities. The interpretation of the results is in the discussion section.

4. Results and Discussion

The overall objective of this study was broken down into three guiding research questions, whose purposes were: a) to identify the different stages of the storage process; b) to describe the execution of each stage; and c) to identify the possible ergonomic implications in each stage of the process. This sequencing was used here to present the findings, culminating in the discussion of the results.

4.1 Stages of the material storage process

The company's warehousing process follows a pull production system, in which storage is temporary, carried out in extremely short periods, and executed simultaneously at each stage of the production process. This process is organized into six distinct phases, corresponding to the transformation of raw materials into the final product: reception, injection, introduction of the sand core, finishing, heat treatment, and sandblasting. It is observed that the described process goes beyond the traditional notion of storage, incorporating activities typical of industrial transformation, which evidences an integrated production flow. Each step is presented in sequence, indicating a linear production logic in which the material passes through different phases until it reaches its final state. Reception marks the beginning of the process, being responsible for the entry and verification of materials, while the following steps involve the physical and chemical transformation of the parts. The introduction of the sand core and finishing highlights the presence of intermediate preparation and adjustment activities. The

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heat treatment and sandblasting processes indicate final phases focused on the product's resistance and aesthetics. This organization reveals a continuous production chain, with strong interdependence between the steps. Furthermore, the division into steps allows for clear visualization of the process's transition points.

Table 2. Steps in the material storage process

Stage	Stage Name
First	Reception
Second	Injection
Third	Introduction of sand core
Fourth	Finishing
Fifth	Heat treatment processes
Sixth	Sandblasting

Source: Data collected by the authors.

These results provide an essential basis for understanding where and how risks can manifest themselves throughout the production flow. The presence of multiple stages with distinct characteristics implies different physical and cognitive demands on workers, thereby increasing the complexity of the ergonomic analysis. For example, initial activities may involve moving loads, while later stages may require attention to thermal or chemical processes. This diversity of conditions suggests that ergonomic risks are not homogeneous, but vary according to the nature of each phase. Furthermore, the interdependence between stages can generate cumulative effects of fatigue and exposure to risks. The clear identification of the stages enables more targeted analyses and more effective interventions. It also highlights that ergonomics should be treated systematically, not piecemeal. Thus, the table directly contributes to achieving the research objective by delimiting the analysis's operational scope. Finally, it reinforces the need for an integrated assessment of working conditions throughout the entire process.

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4.2 Operationalization of Each Stage of the Storage Process

Regarding how each step of the process is executed, the results showed that in the receiving stage, quality control is performed manually using paper forms, suggesting limited digitization. In the injection stage, the material is subjected to extremely high temperatures, between 400 and 500 degrees Celsius, for prolonged periods, up to 5 hours. The introduction of the sand core involves the use of a specific material (SHEL sand), essential for molding the parts. In the finishing stage, there is manual removal of burrs, characterized by sharp blades, which shows a direct physical risk. Heat treatment occurs in two types of furnaces and includes thermal shocks, with abrupt temperature variations. Finally, sandblasting involves painting the parts after the color change resulting from heating. The detailed description allows for an understanding of the technical nature of each activity. The predominance of manual processes and exposure to harsh conditions is noticeable. Furthermore, there is recurrent use of heat, pressure, and specific substances.

Table 3. Operationalization of the material storage process

Stage	Stage Name	How the process is done
First	Material Reception	The transporter delivers the 2-3 meter bars in solid form, and the receiving department records them on paper checklist forms to verify compliance with quality standards and regulations.
Second	Injection	The material is placed in the injection molding machine, heated to 400-500 °C for 4-5 hours, then injected with nitrogen under high pressure to form the cylinder head.
Third	Introduction of the sand core	Introduction to the sand core: the specific sand for this type of work, SHEL SAND. This material is used to form the cylinder head mold.
Fourth	Finishing	Removal of burrs from the cylinder head in the finishing sector. Burrs are sharp blades that must be removed.
Fifth	Heat treatment processes	Treatment of finished parts, i.e., without burrs. The process takes place in two ovens, A and B, where the parts are processed to maximize durability. After 5 hours of treatment, the treated parts are immersed in a thermal shock from 450° to 30°.
Sixth	Sandblasting	This is the painting stage, as the piece darkens and undergoes a sandblasting process over time.

Source: data collected by the authors.

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These results indicate that the work environment presents several factors that can negatively affect workers' ergonomics, particularly physical exertion, thermal exposure, and chemical risks. Manual execution of tasks, such as finishing and receiving, is associated with a higher physical and cognitive workload and a greater risk of operational errors. Prolonged exposure to high temperatures can cause fatigue, thermal stress, and reduced productivity. The use of chemical materials, such as in sand core insertion and blasting, increases the risk of contamination and requires rigorous protection measures. Furthermore, the absence of automation in critical stages can compromise both the safety and efficiency of the process. From an ergonomic perspective, this reveals an environment that requires adaptations to reduce risks and improve working conditions. The table highlights the need for interventions such as mechanization, equipment improvement, and the adoption of digital technologies. It also reinforces the importance of training and the proper use of personal protective equipment. Thus, the data directly contribute to the analysis of ergonomic factors present in the process. Finally, they demonstrate that the current operationalization presents weaknesses that can compromise occupational health.

4.3 Possible ergonomic impacts at each stage of the storage process

In the receiving stage, risks of accidents during transport and the possibility of explosions due to proximity to oxygen pipelines are identified. In injection molding, the risk of mold crushing due to the high weight of the molds is a key concern. During the introduction of the sand core, there is a risk of poisoning by harmful chemical agents. In conclusion, workers are exposed to cutting and crushing risks due to the parts' physical characteristics. In heat treatment processes, there is a risk of explosion when natural gas is used at high temperatures. In sandblasting, there is again a risk of poisoning from exposure to the chemicals used in painting. The table highlights a wide variety of occupational

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risks. These risks encompass physical, chemical, and mechanical dimensions. The detailed description provides insight into the potential severity of each impact. Furthermore, it highlights the frequency with which workers are exposed to hazardous conditions.

Table 4. Possible ergonomic impacts of the material storage process

Stage	Potential impacts	Description of the impacts
Receiving the material	Risk of accident during transport	People are working between the movement points. If the material falls, people could get hurt.
	Risk of explosion	Explosion: The oxygen pipelines run alongside the production process. If the material falls, it could cause an explosion.
Injection	Crushing injury	The molds weigh several tons. If they injure someone, the consequence could be serious.
Introduction of sand core	Risk of poisoning	During sand core manufacture, several chemical agents are used; these agents are harmful to humans. Therefore, the use of PPE (Personal Protective Equipment) is necessary.
Finishing	Risk of cuts and crushing	Because the piece has many blades, there is a great risk of the worker cutting themselves or even being crushed, since the pieces are heavy.
Heat treatment processes	Explosion	Since the parts are heated at high temperatures, natural gas is needed to heat the furnace.
Sandblasting	Intoxication	Because the part undergoes heat treatment, sandblasting is necessary. The first coat of paint is called an "intruder" (a type of coating). In this process, the worker can be poisoned by the gas.

Source: data collected by the authors.

Regarding the research objective, the data in Table 4 demonstrate that the analyzed process poses serious ergonomic limitations, compromising workers' safety and well-being. The presence of serious risks, such as explosions and crushing, indicates structural failures in safety control and work organization. The recurrence of poisoning incidents suggests that existing protection measures may be insufficient. These factors can result in workplace accidents, absences, and reduced productivity. Furthermore, continuous exposure to adverse conditions can have long-term effects on employee health. From an ergonomic perspective, this

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highlights the need for immediate interventions to mitigate risks. Measures such as improved ventilation, process review, and increased use of PPE are fundamental. The importance of more rigorous safety policies and continuous monitoring is also highlighted. Thus, the results reinforce that ergonomic aspects are critical in the analyzed context. Finally, they demonstrate that the company needs to align its processes with good industrial ergonomics practices to ensure operational sustainability.

4.4 Discussion of Results

The analysis of the results shows that the investigated storage process presents a configuration that goes beyond the classic stages described in the literature, incorporating typical industrial transformation activities, such as injection molding, heat treatment, and blasting. This finding partially converges with what is discussed by Carmo et al. (2025), Sisodia and Zaini (2025), and Oliveira et al. (2025), who highlight that modern storage processes tend to integrate with other stages of the production chain, especially in more complex industrial contexts. However, the results broaden this discussion by demonstrating that this integration can generate overlapping ergonomic risks, since the worker ceases to act only in logistical activities and begins to interact with thermal, chemical, and mechanical processes. This condition reinforces the argument of Trstenjak et al. (2025) and Plaza et al. (2025) that Industry 4.0 and 5.0 have increased the complexity of human-machine interactions, requiring more systemic ergonomic approaches. In addition, the diversity of steps identified suggests that the risks are not only varied but also cumulative throughout the production flow. This corroborates the idea that ergonomics should be analyzed holistically, as defended by Latip et al. (2025) and Islam et al. (2025). Thus, the results indicate that the company studied presents a scenario of high ergonomic complexity. This requires interventions that consider not only isolated steps, but also the production system.

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Regarding the operationalization of activities, the results show a predominance of manual processes and exposure to severe conditions, such as high temperatures, physical exertion, and the use of chemical substances. This evidence aligns with the findings of Zhao et al. (2022), Nguyen (2024), and Nasir (2025), who identify manual handling of loads as a major source of ergonomic risk in storage environments. Furthermore, activities such as manual deburring and handling heated materials are associated with inadequate postures and biomechanical overload, as discussed by Hidayat et al. (2025), Nasir et al. (2024), and Yankova-Yordanova et al. (2025). Another relevant aspect is the low level of digitalization observed in the receiving stage, which can increase cognitive load and the probability of operational errors, corroborating the arguments of Lucchese et al. (2025), Hilmi et al. (2025), and Karim et al. (2025). The literature also highlights that the combination of physical effort and mental load intensifies occupational risks. In this sense, the results indicate that the analyzed environment presents multiple sources of simultaneous ergonomic overload. This reinforces the need for interventions that integrate physical and cognitive ergonomics, thereby confirming and expanding on the findings of recent literature.

The analysis of the identified ergonomic impacts reveals serious risks, including explosions, crushing, cuts, and poisoning, distributed across all stages of the process. These findings align with the literature on the multifactorial nature of ergonomic risks in industrial environments, as highlighted by Suherman et al. (2025), Ugurtay et al. (2026), and Turgay and Özyurt (2025). Furthermore, exposure to chemical agents and extreme thermal conditions confirms the discussions of Trstenjak et al. (2025), Cosma et al. (2025), and Kamala et al. (2025) regarding the influence of environmental conditions on workplace ergonomics. The presence of poisoning and explosion risks also highlights failures in safety controls, which may be related to work organization, as argued by Bahari et al. (2025), Nilsson et al. (2025), and Nuryanto et al. (2025). Another relevant point is that these risks do not occur in isolation; they often overlap, increasing their severity. The literature indicates that combining multiple risks can amplify

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their negative effects on workers' health. In this context, the results indicate that the company has a highly critical ergonomic work environment. This requires immediate action to mitigate the identified risks, since the findings reinforce the relevance of ergonomics as a tool for managing occupational risks.

Finally, when relating the results to the research objective, it is found that the analyzed storage process presents significant ergonomic limitations that can compromise both workers' health and operational efficiency. This finding aligns with Sisodia and Zaini (2025), Carmo et al. (2025), and Oliveira et al. (2025), who highlight ergonomics as a strategic factor for organizational performance. The presence of physical, chemical, and cognitive risks throughout all stages of the process highlights the need for a systemic approach, as advocated by Nasir et al. (2025) and Trstenjak et al. (2025). Furthermore, the results suggest that inadequate ergonomic interventions can lead to increased accidents, absences, and reduced productivity. The literature also indicates that ergonomic improvements can generate significant gains in efficiency and quality. In this sense, the analyzed data indicate that the company has clear opportunities for improvement. This includes adopting technologies, redesigning processes, and strengthening safety policies. Thus, the discussion of the results shows that ergonomic aspects are central to the performance of the warehousing process. Finally, it is reinforced that ergonomics should be incorporated as a strategic element in industrial management.

5. Conclusion

This study analyzed the ergonomic implications of the organization's warehousing process operating in the Manaus Industrial Hub. The conclusion is that the analyzed warehousing process exhibits characteristics that go beyond traditional logistics functions, incorporating activities typical of industrial transformation, thereby significantly increasing its operational and ergonomic complexity. The evidence showed that the production flow comprises interdependent stages with varying levels of physical, cognitive, and

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environmental demands, exposing workers to a range of risks throughout the process. Among the main findings, the predominance of manual activities, exposure to high temperatures, the use of chemical substances, and the occurrence of mechanical risks, such as crushing and cuts, stand out. Furthermore, it was found that ergonomic risks do not occur in isolation but rather in a combined and cumulative manner, thereby potentiating their effects on occupational health. These results show that, in the analyzed context, ergonomics is not yet fully integrated into the management of the production process. Thus, it is concluded that the environment studied presents significant ergonomic weaknesses that can compromise both workers' well-being and operational efficiency. In this way, the study confirms the hypothesis that storage processes can have significant ergonomic implications. Finally, the need for structural interventions to adapt working conditions is reinforced.

Regarding the unfolding of these findings on the ergonomics of the storage process stages, each phase presents specific implications that require distinct analyses and intervention approaches. The receiving stage, for example, highlights the need to improve work organization and digitize processes to reduce cognitive load and minimize operational errors. The transformation stages, such as injection and heat treatment, require special attention to thermal risks and safety when using highly complex equipment. The finishing and sand core insertion activities stand out for involving physical and chemical risks, which require rigorous individual and collective protection measures. In turn, blasting underscores the need for adequate environmental controls to prevent poisoning. These developments indicate that ergonomics should be applied specifically at each stage, taking into account the operational particularities of that stage. Furthermore, they reinforce the importance of a systemic approach that integrates the different dimensions of work. The analysis also demonstrates that punctual interventions are insufficient given the complexity of the process. Therefore, it is necessary to adopt integrated strategies that account for physical, cognitive, and

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organizational factors. Thus, the study's findings contribute to a deeper understanding of the ergonomic implications in warehousing.

In terms of scientific contributions, this study advances by empirically demonstrating that the warehousing process, especially in industrial contexts, should not be analyzed in isolation but rather as an integral part of broader, more complex production systems. The main contribution to ergonomics lies in the evidence that occupational risks are multifactorial and interdependent, which requires more comprehensive analytical approaches. Furthermore, the study contributes to the literature by integrating concepts of physical, cognitive, and organizational ergonomics into a single analytical model applied to internal logistics. In the field of logistics, the results reinforce the need to incorporate ergonomic principles into the planning and management of warehousing processes, aiming not only at efficiency but also at safety and sustainability. Another relevant contribution is the identification of critical points in the process that can guide practical interventions in organizations. The study also broadens the understanding of the impacts of integrating logistical and productive activities on workplace ergonomics. In this way, it contributes to theoretical and applied advancement in the areas of ergonomics and operations management. Finally, the findings can serve as a basis for developing safer organizational policies and practices. This highlights the study's relevance to academia and industry.

Despite the contributions presented, the study has limitations that should be considered when interpreting the results. The main limitation is that the research was conducted in a single company, which may limit the generalization of the findings to other organizational contexts. Furthermore, the analysis relied predominantly on qualitative and descriptive data, limiting the quantitative measurement of the identified ergonomic risks. Another limitation is the absence of instrumental measurements, such as biomechanical analysis or environmental monitoring, which could enhance the risk assessment. The possibility of bias in the collected information is also highlighted, since some of the data depends on the perception of those involved. Given these limitations, it is recommended that

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future studies expand the sample to include different sectors and types of organizations. The use of quantitative methods and monitoring technologies to more precisely analyze ergonomic risks is also suggested. In addition, future investigations could explore the impact of specific ergonomic interventions on improving operational performance. Another recommendation is to further analyze the interaction between ergonomics and emerging technologies. Finally, the importance of longitudinal studies for assessing the effects of change over time is highlighted.

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