REVISTA Ação Ergonômica

R. Ação Ergon., 15(2), 2021.
ISSN 2965-7318. doi: 10.4322/rae.v15n2.e202115.en

PRACTICES RELATED TO INDUSTRY 4.0 AND ITS APPLICATIONS IN THE FIELD OF ERGONOMICS: ANALYSIS OF THE APPLICATIONS OF COLLABORATIVE ROBOTS (COBOTS) AND EXOSKELETONS

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Abstract

Due to the constant change in markets and means of production today, it has become necessary to optimize technologies and systems to keep up with this demand. Thus, technology companies around the world have mobilized and started investing in new technologies, generating a new production concept that involves implementing the Internet in current services and means of production, aiming at improving communication between machines, production time, aiming at the policy of constant and intermittent improvements, the virtualization of systems, reduction in the life cycle of products and the use of sensors in machines. Since new technologies follow the above standards, this new era is called "Industry 4.0", which is believed to be the 4th industrial revolution. Along with this new trend, questions about worker health have arisen, making it plausible to reconcile Industry 4.0 technologies and Ergonomics. Thus, the objective of this study was to analyze the process of implementing technologies associated with Industry 4.0 and their applications in the field of ergonomics and to discuss whether these technologies improve the production process within companies and contribute to better working conditions in the interaction of these technologies with the work of operators, a comparison made based on a literature review. Methodological assumptions: The study was based on the concepts of cooperation of man-task-machine systems contained in ergonomics.

Keywords: Industry 4.0; Ergonomics, Human Factors; COBOTs; Exoskeletons.

1. INTRODUCTION

This article addresses the technologies associated with Industry 4.0 and their applications in the field of ergonomics and aims to identify the practices related to Industry 4.0 and their applications and contributions in the field of ergonomics (in particular in the field of Physical Ergonomics), contributing to the systematization of knowledge about these technologies and equipment. The objective is to discuss what these technologies are and

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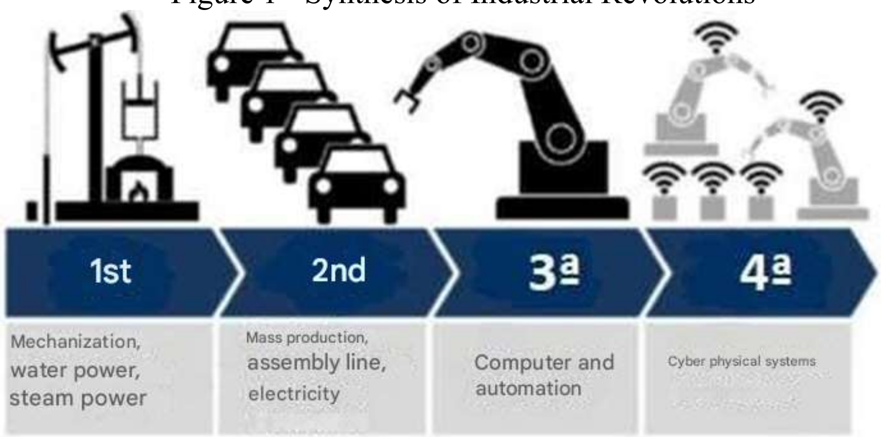
whether they are effectively improving the production process within companies and contributing to better working conditions. This is the current dilemma presented by the literature, which studies phenomena of this type related to Industry 4.0 (HERČKO; ŠTEFÁNIK, 2015; MARKOVÁ et al., 2019)

Since the first industrial revolution, the world has increasingly demanded changes and adaptations from companies, organizations, and the human being's own routine. In this case, the requirements are technological evolutions and advances in all industrial sectors, in addition to increased competitiveness, market changes, and the need for new strategies to adapt to this (MARKOVÁ et al., 2019).

It was in the midst of this environment that Industry 4.0 emerged, which is a term created by the German minister of education and research, used to refer to the 4th industrial revolution. This revolution deals with the implementation of the internet in current services and means of production, aiming at improving communication between machines, production time, aiming at the policy of constant and intermittent improvements, the virtualization of systems, reduction in the life cycle of products and the use of sensors in machines (HERČKO; ŠTEFÁNIK, 2015; MARKOVÁ et al., 2019).

The first industrial revolution was the era of mechanization of the production system, the second was the era of mass production, of production lines using electricity, the third was the era of automation and the implementation of computers and the fourth, it is believed, is the era of cybernetic physical systems. A better visualization of these eras can be seen in Figure 1 (MARKOVÁ et al., 2019; MIKULIĆ; ŠTEFANIĆ, 2018).

Figure 1 - Synthesis of Industrial Revolutions



Source: Roser, 2015

Within the technologies of this new industrial revolution, ergonomics approaches have emerged that aim to reconcile the work of the machine with the human being, in order to make their work less stressful and more productive. The stress mentioned earlier can be both physical and mental and it is at this point that industrial ergonomics integrates knowledge of physical, cognitive and organizational ergonomics. For each of these domains, there are new proposals for solutions brought by industry 4.0 and, likewise, there are studies that study their impacts within companies, both for the worker and for productivity (KADIR; BROBERG, 2020).

In physical ergonomics, the effects of work on the musculoskeletal system of workers are studied, unlike cognitive and organizational ergonomics, which study possibilities to reduce the mental stress of these workers (KADIR; BROBERG, 2020), in this sense, it should be noted that ergonomics integrates these domains and understands work overload as a result where the three domains play some role and influence each other.

That said, it should be noted that the present study focuses on technologies oriented to physical ergonomics. Among the new technologies in this area, COBOTS (collaborative robots) and Exoskeletons are, according to the literature review that will be presented in this study, the most studied and that presented problems related to their implementation within organizations (BANCES et al., 2020; DE LOOZE et al., 2016; WESSLÉN, 2018).

Thus, important questions arise, such as: what are the positive and negative impacts of the implementation of these technologies? What are the difficulties encountered and barriers to implementation and use. How are the solutions of these technologies reconciled with the work of operators? How does the cooperation process take place in order to adapt productivity and safety at work?

To answer these questions, a bibliographic review of the processes of implementation of such technologies in Brazil was carried out, whose results will be presented and discussed in this work, this initial research helped to raise information for the generation of case studies that are under development and that will later be published in new academic articles.

The relevance of the study of such technologies is due to the fact that there are gaps in the literature, mainly because it is an emerging theme, which is evidenced in the literature review presented in this article. In addition, it is important to point out that these studies can support companies in the process of choosing technologies, in the acquisition and implementation, as well as in the search for indicators that allow improving working conditions.

2. Methods

To answer the research questions presented above, a literature review was carried out that helped to formulate the research problem and identify technologies related to ergonomics in the context of Industry 4.0. The bibliographic review was carried out from the CAPES Portal Database (Coordination for the Improvement of Higher Education Personnel), which brings together journals from different areas of knowledge.

The following strings were used, through the advanced search field: Industry 4.0, Ergonomics, COBOTs, Human Factors and Exoskeletons. The searches were carried out between 06/29/2020 and 07/15/2020 and articles published between 2013 and 2020 were selected.

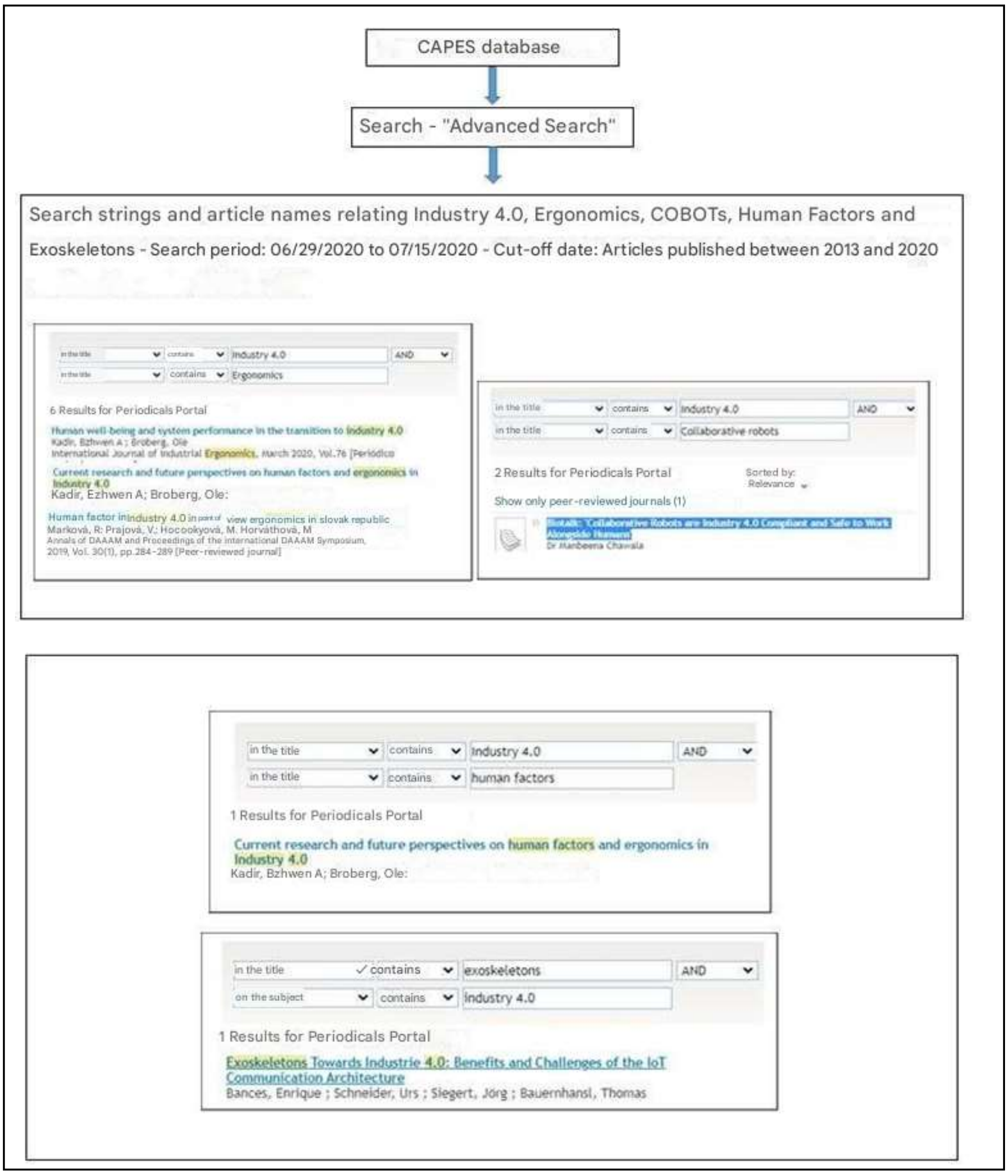
In this first moment, among 10 results found with the strings "Industry 4.0 and Ergonomics"; "Industry 4.0 and Collaborative Robots"; "Industry 4.0 and Human Factors" and "Industry 4.0 and Exoskeletons", 6 of them made the relationship between Industry 4.0, Ergonomics, COBOTs, Human Factors and Exoskeletons.

This search, in particular the literature review, helped to define as the focus of the research the technologies: Collaborative Robots and Exoskeletons, which were identified as the main technologies associated with ergonomics.

After a systematic literature review, a complementary review was carried out that brings (i) technical information about the standardization process of these technologies and also (ii) a view of how some suppliers offer their technologies. The complementary content made it possible to understand the rules related to the theme and the way these technologies are disseminated and how this can influence the expectations of companies that buy them.

Figure 2 illustrates the literature review process.

Figure 2 – Illustration of the Literature Review process



3. Findings

From the reading of the articles obtained in the systematic literature review process presented above, it was possible to establish an understanding of which and how the technologies of industry 4.0 are associated with ergonomics.

First, it was necessary to understand, through the analyzed articles, what characterizes a technology associated with Industry 4.0, in this sense, it is understood that in Industry 4.0 there are three pillars, which are: *Internet of Things and Services* (IoT and IoS), Cyber-physical systems and *Big Data*, which are connected to each other.

Internet of Things and Services is the term used to refer to advances in internet systems, which connect more products and services than the number of people on earth. In this case, it represents the impact that this new era has brought to the world, interconnecting different places in the world through different technologies that expand these possibilities of connection (COELHO, 2016).

Cyber-physical systems are those that interconnect computing, communication networks, embedded computers and physical processes, that is, they replace information systems, which were central computers, with an omnipresent computing system, which makes information available at any access location.

Big Data, which refers to the large amount of data from these new systems that has to be stored somewhere, thus generating challenges regarding the storage and interpretation of information generated by them. With this, an attempt is made to delimit a new technological era (COELHO, 2016).

Taking the discussion to the world of work, Kagermann (2013) believes that industry 4.0 will drastically change the content of work, processes, organization and environments in the factories of the future. As a consequence of this there will be an increase in the workload for all corporate members in terms of problem solving, abstraction, management complexity and physical overloads.

Thus, with the changes proposed by Industry 4.0, concerns about workers and how they will adapt to these drastic changes have also arisen. Therefore, with the rise of the new means of production, came collaborative technologies guided by wireless systems that try to work in cooperation with human beings, prioritizing the safety of the worker, his well-being and the improvement of the physical interaction of man with his work environment, that is, ergonomic factors (KAGERMANN, 2013); ESBEN H. et al., 2016).

The literature, as well as the International Association of Ergonomics and Human Factors, divides these ergonomic factors into three types, which are: Physical, Cognitive and Organizational Ergonomic Factors and in each of these areas there are new technologies, brought by Industry 4.0, which are tested to try to prove their effectiveness, both in productivity and in the health of the worker.

In this context, focusing on the domain of physical ergonomics, Kadir and Broberg (2020) demonstrate that among the various technologies being studied in this niche, there are two of them that are the main focus of research, which are collaborative robots (COBOTS) and exoskeletons (KADIR; BROBERG, 2020).

3.1. Collaborative robots (COBOTS)

When we talk about COBOTs, it is an attempt to reconcile the work of the human being with the machine in a safe way, as it comes with the purpose of serving as a tool for the worker and at the same time increasing their productivity, without generating physical or mental stress (ESBEN H. et al., 2016).

The main difference between COBOTS and conventional industrial robots is that COBOTS are supposedly safer and allow direct interaction with humans, cooperating with their tasks, while conventional industrial robots require space segregation and for safety reasons cannot share space with humans.

Figure 3 illustrates this difference.

Figure 3 – Comparison between COBOTS and Industrial Robots

Source: Image Cobots: https://elcoindustria.com.br/cobots-robos-colaborativos-linha-producao/, accessed in Sept. 2020. **Source:** Image Industrial Robots: http://reparocompensa.blogspot.com/2019/01/ranking-dos-14-maiores-fabricantes.html , accessed Sept. 2020.

3.2. Exoskeletons

Exoskeletons, on the other hand, which are suits that include a mechanical structure (composed or not of actuators), emerge as an attempt to reduce musculoskeletal changes generated by repetitive work and ergonomically unfavorable positions for the worker (BANCES et al., 2020).

According to De Looze et al. (2015) and Wesslén (2018), there are two types of exoskeletons: those that are passive and do not use any type of actuator to make movements, using only materials to support a posture, or those that are active and sustain postures with the force of actuators.

Figure 4 – Comparison between Passive and Active Exoskeleton job execution

Source: Passive Exoskeleton Image:

https://economia.estadao.com.br/noticias/geral,em-fabrica-da-fiat-operarios-e-exoskeletons,70002150839 , accessed Sept. 2020.

3.3. Results of the analysis of the normative materials on Technologies

After identifying the technologies associated with Ergonomics in the context of Industry 4.0, a complementary review was made, at first it was sought to understand the standards associated with these technologies and the regulations imposed by governments or associations of technical standards to the use of these technologies, in this context, several standards on Collaborative Robots were found, however, no standards were identified on the use of Exoskeletons.

The necessary safety measures in the design and construction of machines are derived from legal provisions. For machines sold in the European community, the machinery directive 2006/42/EC generally applies and in industrial environments in Brazilian territory, NR-12 applies. Both describe requirements for the design and construction of safe machines. In addition to these, the ISO 12100 standard helps in this process. The primary purpose of this Standard is to provide designers with a general framework and guidance for decisions during machine development to enable them to design machines that are safe for their intended use.

The concept of machinery safety considers the ability of a machine to perform its intended functions during its life cycle, where risk has been adequately reduced.

This International Standard is the basis for a set of standards that has the following structure:

- Type A standards (basic safety standards), providing basic concepts, design principles, and general characteristics that can be applied to machinery
- Type B standards (generic safety standards) deal with safety or a type of safeguard that can be used on a wide range of machines:

    - Type B1 standards address specific safety characteristics (e.g., safety distances, surface temperature, noise)
    - Type B2 standards on safeguards (e.g., bi-manual controls, interlocking devices, pressure-sensitive devices, protectors)
- Type C standards (machine safety standards) that address the detailed safety requirements for a particular machine or group of machines. Within this standard, ISO 10218-1 and ISO 10218-2 apply, and ISO 15066 complements them

In this context, the **ISO 10218-1 Robots** – Provides guidance for ensuring safety in the design and construction of the robot. Since the safety in the application of industrial robots is influenced by the design and application of the integration of the particular robot system.

ISO **10218-2 Robot Systems and Integration** - Provides guidelines for the protection of personnel during robot integration, installation, functional testing, programming, operation, maintenance, and repair.

Finally, specifically about collaborative robots, the **ISO 15066:2016 Collaborative Robot Operation** standard - provides guidance for the operation of the Collaborative Robot, which is a system that integrates the Robot and the worker in the same workspace. In such operations, the integrity of the safety-related control system is of great importance, particularly when process parameters such as speed and force are being controlled. Thus, a comprehensive risk assessment is required to evaluate not only the Robot system itself, but also the environment in which it is placed, i.e. the workplace. In Brazil, on a definitive and mandatory basis, the design and construction of machinery and equipment must follow the requirements of Regulatory Standard NR-12. This standard and its annexes define technical references, fundamental principles and protective measures to safeguard the health and physical integrity of workers and establishes minimum requirements for the prevention of accidents and occupational diseases in the design and use phases of machinery and equipment, as well as their manufacture, importation, commercialization, exhibition and assignment in any capacity. NR 12 prescribes that robotic systems that comply with the prescriptions of the ABNT ISO 10218-1, ABNT ISO 10218-2, ISO/TS 15066 and other official technical standards or, in the absence or omission of these, in the applicable international standards, are in compliance with the safety requirements provided for in this NR, thus, in Brazil, COBOTS must follow these ISO standards to comply with national legislation.

After reviewing the standards, the websites and promotional materials of some manufacturers were observed to understand how such technologies are disseminated and to compare them with the results identified in the literature.

3.4. Results of the analysis of information materials from Manufacturers and Suppliers of the Technologies

Informative materials made available by three manufacturers of each type of equipment were analyzed, and it was decided to omit the names of the companies in this article. As expected, the manufacturers highlight many benefits obtained in the use of this equipment and confirm the associations of the literature with Industry 4.0 and with aspects related to physical ergonomics.

i. COBOTs

Manufacturer A – The manufacturer describes its product as revolutionary and brings a modular and mobile approach to assembly on the factory floor, which provides a confrontation with the high complexity brought about by the increase in product variety and the continuous integration of new processes in production. These characteristics aim to increase production, quality and cost saving benefits, in addition to providing a reduction in the physical load on the worker. On the manufacturer's website there are reports of successful cases in the implementation in large companies around the world.

Manufacturer B – The manufacturer promotes its product by selling the idea of a technology that contributes to a safer work environment, operating in environments that humans cannot, such as tasks that are dangerous or monotonous to the worker, such as machine assembly, circuit board assembly, metal processing, injection molding, packaging, etc. loading and unloading, as well as testing and inspections. In addition, it provides a quieter and less stressful work environment, when compared to the environment of industrial robots. The product also has a "user-friendly" design, which, according to Manufacturer B, makes it easier for workers to accept the technology.

Manufacturer C – The manufacturer says that its X-series collaborative robots offer more options, more payload, more range, and more speed than any other COBOT series on the market. In addition, they ensure safety certification, providing COBOTs that work side by side with humans, adding value to the processes involved with the technology. Supplier C ensures that the acquisition of technologies is the solution for small and large companies, providing quick installation, easy use and high reliability.

ii. EXOSKELETONS

Manufacturer A – This manufacturer provides an industrial upper limb exoskeleton (MMSS), passive and which aims to reduce efforts in performing activities that require the shoulder, arm and back complex, seeking to optimize productivity and reduce physical load. They claim that their product is highly technological, but still

It is endowed with extreme simplicity of handling and dressing, with times of 30 seconds for its placement. Its production is entirely Brazilian, and therefore the cost and maintenance of the equipment are cheaper compared to imported products, withstanding up to 600 thousand cycles, simulating use in a 24 hour x 7 day environment, with 3 shifts for 1 year without maintenance. Among the characteristics of the equipment, its weight stands out, the reduction of force on the arms that the equipment allows, freedom of movement for shoulders and arms, there are connected versions (IoT) for monitoring the use and maintenance of equipment and monitoring user data (arm angle, hours of use per user, equipment hour meter).

It is observed that, although the manufacturer associates it with industry 4.0 technologies, this is the only characteristic that is associated with the tripod identified on the basis of 4.0 technologies.

Manufacturer B – This manufacturer provides a passive Industrial Upper Limb Exoskeleton (MMSS), which aims to make the worker the center of the production process, thus aiming at more modern, efficient and productive factories. It claims that its product preserves and enhances the worker's capabilities by reducing physical loads, such as excess load and Repetitive Strain Injuries (RSIs). This technology adjusts to different body structures, providing daily support to the worker and bringing comfort, which consequently increases the quality, efficiency and consistency of the repetitive work performed. The website of Manufacturer B provides the brochure of their product and in it they report an average reduction of 30% of muscle fatigue in the shoulder extension movement, as all effort is dissipated by the points of contact with the body and the torque boxes that transform potential energy into torque to reduce load.

Manufacturer C – This Manufacturer provides a passive Industrial Lower Limbs Exoskeleton (LLM) and claims that its product is the new chair without a chair, where the worker can perform his activities and tasks safely, reducing the stress on the lumbar spine of those who perform them. The product enables a quick, easy and flexible change between sitting, standing and walking postures, which does not create obstacles in the execution of workers' tasks. In addition, the manufacturer guarantees that the Exoskeleton allows the replacement of chairs with this versatile mechanism, allows dressing in less than 30 seconds, reduces costs due to worker leave and maintains productivity, but in a more comfortable way. The difference between this manufacturer and the others studied is that, on their website, they present a proposal for the implementation of their product within the companies that acquired it. In this way, it proposes a standard implementation process with the assistance of a specialized team, in order to understand the operation and needs of each client.

3.5. Final Thoughts on the Results

The results demonstrate that both technologies are seen, in the literature and in the information from suppliers, as contributions of industry 4.0 associated with aspects of physical ergonomics, it is perceived that there are standards for collaborative robots, however, standards related to exoskeletons and their applications have not yet been identified. Next, some discussion points and final considerations will be presented.

4. Discussion and final considerations

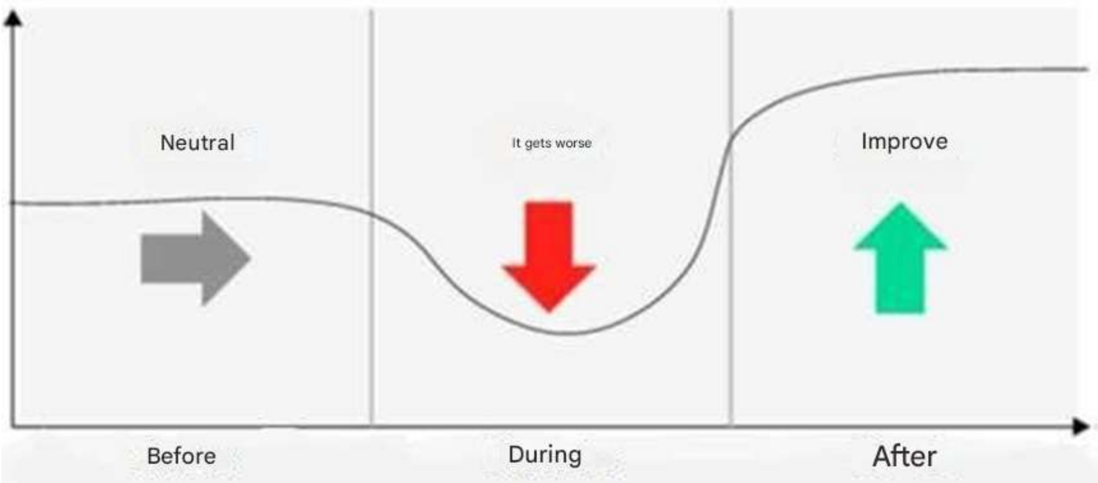
This article addressed the technologies associated with Industry 4.0 and its applications in the field of ergonomics and aimed to identify the practices related to Industry 4.0 and its applications and contributions in the field of ergonomics (in particular in the field of Physical Ergonomics), contributing to the systematization of knowledge about COBOTs and Exoskeletons, these objectives were developed and presented as results of the literature review.

In addition, it is necessary to discuss whether they are effectively improving the production process within companies and contributing to better working conditions.

In this sense, it was also verified in the literature studied that these technological evolutions, which were intended to bring ergonomic improvements, came with implementation problems, difficulties in adapting workers to the new technology, the lack of motivation for not having a standard in the implementation process, arising from the lack of studies of the new technology, and the emergence of a heavy work environment, with workers' constant concern with their jobs (KADIR; BROBERG, 2020).

According to the study by Kadir and Broberg (2020), implementation tests of these technologies were carried out in several companies of different sizes and types of production, and this implementation was divided into "Before", "During" and "After" phases. As a result, it proved difficult to implement in the "Before" and "During" periods, as not much was known about the technology (both by the company and by the employees), and the implementation protocol was not yet clear and defined, causing a lot of uncertainty within the companies. This gave rise to an inhospitable work environment that proved to be worse than the period before technology. After a certain time of studies and increased clarity about them, the beneficial factors came to light and the work environment recovered its well-being, in addition to showing that the new technologies were being beneficial in the physical character (figure 5).

Figure 5 – Perceived well-being and overall performance of the system in the periods before, during, and after the implementation of new technologies



A simple overview of how perceived well-being and overall system performance changes before, during, and after the implementation of new digital technologies
Source: Kadir & Broberg, 2020

However, although in the "After" period improvements were noted in the production process and in the well-being of employees, one should not generalize such a conclusion, because other factors such as the duration of the implementation time, costs and the best type of technology still need to be studied more deeply in order to compare benefits and harms, and therefore more focus should be placed on these processes. to shed light on a gap in the literature.

Another important discussion that emerged from this study was the classification of technologies as 4.0, for example, to what extent is a passive exoskeleton 4.0, given that very little or none of the pillars are applied in this equipment? It is verified that this association is not merely commercial and that even in academic research this situation occurs, that is, the reflection on the real framing of a technology in a context is not being effectively carried out.

The present study provided support for the understanding and systematization of knowledge about these technologies and will serve as a basis for new studies, which may involve real use cases, where companies that have applied these technologies are approached and invited to reflect on the positive and negative points of the use of these equipment, as well as the motivation for their acquisition and satisfaction.

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