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Article

Analysis and comparison of exoskeleton prototypes to carry out activities under normal conditions in industrial companies to reduce risks

Análisis y comparación de prototipos de exoesqueletospara realizar actividades en condiciones normales en las empresas industriales para reducir riesgos

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Abstract

The use of exoskeleton prototypes in industrial companies has emerged as a technology strategy that helps reduce workplace accidents and improve productivity OEE. This qualitative research focuses on explaining observations, using data collected from various academic sources between 2018 and 2022, selecting 47 relevant articles that address the use of exoskeletons in industrial environments. Three main objectives are presented using exoskeletons: 1) Reduction of accidents, 2) Analyze the most suitable exoskeleton prototype for industrial activities, and 3) Compare the effectiveness with respect to the activities. Some studies were discarded and most articles were found to support the effectiveness of exoskeletons in reducing ergonomic risks and workplace accidents. The functionality and effectiveness of several exoskeleton prototypes is compared under normal working conditions and is highlighted as a tool to improve safety and productivity in the industrial field.

Analysis and comparison of exoskeleton prototypes To carry out activities under normal conditions in industrial companies to reduce risks		
Objectives	**Methodology**	**Contribution**
1) Reduction of accidents, which influence productivity, 2) Analyze the most suitable exoskeleton prototype for different industrial activities, and 3) Compare the effectiveness of these with respect to carrying out the activities without them	This qualitative research focuses on analyzing and explaining observations, using data collected from various academic sources between 2018 and 2022, selecting 47 relevant articles that address the use of exoskeletons in industrial environments	This study highlights the potential of exoskeletons as a tool to improve safety and productivity in the industrial field

Research, Exoskeletons, Risks

Resumen

El uso de prototipos de exoesqueletos en empresas industriales ha surgido como una estrategia de tecnología, apoya a reducir accidentes laborales y mejorar la OEE de productividad. Esta investigación cualitativa se enfoca en explicar observaciones, empleando datos recopilados de diversas fuentes académicas entre 2018 y 2022, seleccionando 47 artículos relevantes que abordan el uso de exoesqueletos en entornos industriales. Se presentan tres objetivos principales utilizando los exoesqueletos: 1) Reducción de accidentes, 2) Analizar prototipo de exoesqueleto más adecuado para actividades industriales, y 3) Comparar la efectividad con respecto a las actividades. Se descartaron algunos estudios y se encontró que la mayoría de los artículos respaldaban la efectividad de los exoesqueletos en la reducción de riesgos ergonómicos y accidentes laborales. Se compara la funcionalidad y efectividad de varios prototipos de exoesqueletos en condiciones normales de trabajo y se resalta como herramienta para mejorar la seguridad y productividad en el ámbito industrial.

Análisis y comparación de prototipos de exoesqueletos Para realizar actividades en condiciones normales en las empresas industriales para reducir riesgos		
Objetivos	**Metodología**	**Contribución**
1) Reducción de accidentes, que influyen en la productividad, 2) Analizar el prototipo de exoesqueleto más adecuado para diferentes actividades industriales, y 3) Comparar la efectividad de estos con respecto a realizar las actividades sin ellos.	Esta investigación cualitativa se enfoca en analizar y explicar observaciones, empleando datos recopilados de diversas fuentes académicas entre 2018 y 2022, seleccionando 47 artículos relevantes que abordan el uso de exoesqueletos en entornos industriales.	Este estudio resalta el potencial de los exoesqueletos como herramienta para mejorar la seguridad y productividad en el ámbito industrial

Investigación, Exoesqueletos, Riesgos

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Introduction

Within industrial organizations, occupational accidents occur with great frequency nowadays (Byun & Jung, 2021), being a vital issue that impacts the whole world and although policies aimed at improving occupational health and safety are implemented, the reality is that occupational accident and mortality rates continue to increase. According to the International Labour Organization (ILO), 2.78 million workers are reported to die from work-related accidents or diseases in 2020.

During the period from 2018 to 2022, around 12 thousand work-related accidents occurred in Peru according to data recorded by the Ministry of Labour and Employment Promotion (MTPE) and the General Office of Statistics and Information and Communication Technologies (OGETIC), Figure 1 shows in more detail the data published for that period (*Estadísticas Accidentes de Trabajo | Ministerio de Trabajo y Promoción del Empleo*, n. d.). Despite the confinement due to the covid19 pandemic, occupational accident rate data remained high.

Box 1

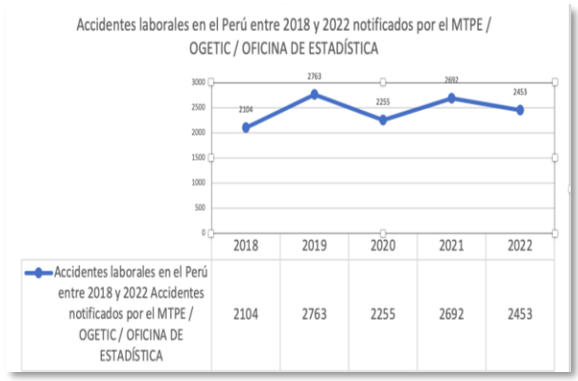

Figure 1

Accident rate data in Peru between 2018 and 2022

Own elaboration, 2024

Occupational accidents in Peru, according to the Regulations of Law No. 29783, Law on Safety and Health at Work, are defined as "those sudden events that occur due to or on the occasion of work, and which cause injury or death to the worker. These accidents may occur during the performance of the worker's normal duties, on the way to or from work, or during the performance of work-related activities.

The law establishes that it is the employer's responsibility to implement safety and prevention measures to avoid occupational accidents, as well as to provide the necessary medical care in case they occur" (Salinas, 2003). Occupational disease, according to law 29783, is defined as any disease that is the direct result of exposure to risk factors inherent to the work activity. These risk factors may include physical, chemical, biological, ergonomic or psychosocial agents present in the work environment. The law states that it is the employer's responsibility to identify and control occupational hazards that may cause illness, as well as to provide the necessary medical care in the event that a worker develops a work-related illness.

Occupational accidents are a problem of concern to all enterprises; however, despite existing safety standards and risk plans, the data provided annually by the ILO does not show a decrease in data related to occupational accidents. The fact that workers have supplementary risk work insurance (SCTR) or private insurance from the company does not guarantee that their lives can be saved or that accidents can be eliminated. Accidents at work not only leave their mark on human lives, but also lead to administrative costs, loss of time and unproductiveness in companies.

Technologies and innovation are presented as a good alternative to improve the quality of life of workers during the working day, as well as to protect their lives and reduce the accident rate and/or the lethal consequences of accidents in case they occur. From the above, it can be deduced that technologies used in the right way can contribute to minimising or reducing accident rates during the working day.

There are several mechanisms that contribute to improving the protection of industrial workers during their working day, and one that has gained special interest in recent times is the exoskeleton prototype.

Prototype exoskeletons are prostheses that function as a mechanism external to the body, which adapt to the body, helping the worker to carry out certain types of activities, with the aim of preventing the appearance of diseases in their muscles or skeleton (Miranda, 2021).

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The use of exoskeleton prototypes has seen a boom in developed countries, constituting an innovative way for companies to reduce mortality and accident rates during the working day, achieving great results in this regard and increasing the economy and profitability of companies without neglecting the life, health and safety of their employees.

Exoskeletons help the effective mobilisation of the body members and are a good option to implement in industrial companies in order to reduce accidents during the working day, as well as problems related to ergonomics, thus contributing to the reduction of mortality rates, occupational diseases and accident rates, thus providing a proposed solution to the problem described.

In this research work, the qualitative research method is applied, it is oriented to analyse problems and try to explain observations, being a reflexive, systematic, critical and verifiable procedure with real sources.

For the development of this work, we used data collected from the period 2018-2022 from various indexed scientific journals such as Scielo Peru, Redalyc, EBSCO, Proquest, Scopus, Uisek, Riecs and the repository of the Cesar Vallejo University, in order to obtain reliable data. Articles not included in indexed journals, without bibliographic information, more than 5 years old and not related to the reduction of accidents through the use of exoskeleton prototypes in industrial companies were rejected.

The study was based specifically on industrial companies that applied exoskeleton prototypes to reduce ergonomic risks and occupational accidents, obtaining a total of 57 articles of significant relevance, considering the following specific objectives:

1. To determine how the reduction of accidents influences the improvement of productivity in industrial companies.

2. To identify the most appropriate exoskeleton prototype according to the activities in industrial companies.

3. To compare the effectiveness and functionality of the exoskeleton prototype in comparison to performing activities under normal conditions in industrial enterprises.

Design

Review of studies and background information on the subject

From this search and selection of data, the articles were filtered and analysed rigorously in two stages: in the first stage, the title of the articles was taken into account in relation to the general topic, selecting a total of 57 articles and in the second stage, a group of 47 articles were selected from the total number of articles found (see appendix 1) as these had the greatest impact and relevance according to their citations and relationship with the topic. The focus of this article is quantitative and both the industrial companies and the population were determined. In the first stage, a thorough inspection of the 57 articles found in the searches was carried out, and 10 articles were discarded in these stages, mainly because their focus was oriented towards the use of exoskeletons as a means of rehabilitation and not to the reduction of occupational accidents in industrial workers.

The discarded articles are listed below:

- Exoskeleton and End-Effector Robots for Upper and Lower Limbs Rehabilitation: Narrative Review (Molteni et al., 2018).
- Exoskeletal Assisted Rehabilitation After Spinal Cord Injury (Gorgey et al., 2019)
- Exoskeletons: state of the art, design challenges and future directions (Agarwal & Deshpande, 2019)
- Current Evidence for Use of Robotic Exoskeletons in Rehabilitation (Jayaraman et al., 2020)
- Exoskeletons in Nursing and Healthcare: A Bionic Future (O'Connor, 2021)
- Lower-Limb Medical and Rehabilitation Exoskeletons: A Review of the Current Designs (Plaza et al., 2021)
- A framework for clinical utilization of robotic exoskeletons in rehabilitation (Hohl et al., 2022)

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- A systematic review of technological advancements in signal sensing, actuation, control and training methods in robotic exoskeletons for rehabilitation (Mathew et al., 2023)
- Opportunities and challenges in the development of exoskeletons for locomotor assistance (Siviy et al., 2023)
- The-state-of-the-art of soft robotics to assist mobility: a review of physiotherapist and patient identified limitations of current lower-limb exoskeletons and the potential soft-robotic solutions (Morris et al., 2023)

From the first stage, 47 articles were finally left that generate percentage data on how exoskeleton prototypes can reduce accidents in industrial companies.

Table 1 shows the number of articles used in the work for each year of the selected study period.

Box 2

Table 1

Tab Summary of publications by year

Year	Total number of items	Percentage
2018	6	13%
2019	8	17%
2020	16	34%
2021	15	32%
2022	2	4%

Own compilation,2024

The bar chart in figure 2 complements the above information. The highest percentage of articles collected was in 2020, where the following year, the highest percentage of articles were published.

In the bar chart in figure 2 we can complement the previous information, the highest percentage of articles collected was in the year 2020 where 16 articles were published, equivalent to 34%, followed by the year 2021 with 15 articles published with a percentage of 32%, occupying 66% of the total in these years alone, in contrast to the year 2022 where only 2 publications were found with a percentage of 4%.

Box 3

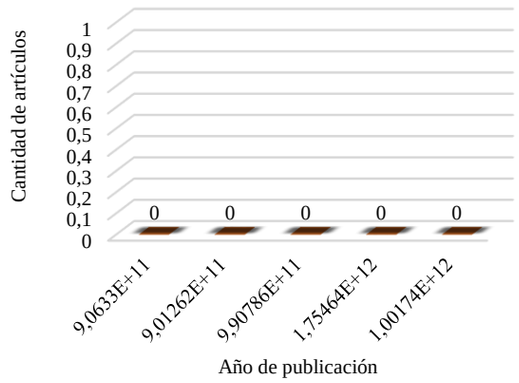

Figure 2

Number of publications per year

Own compilation, 2024

In order to analyse the number of articles according to their country of publication, table 2 can be observed and the pie chart in figure 3 shows the ratio of the percentage of publications by country of publicationSpain is the country with the highest number of published articles, with 13 publications, equivalent to 28% of the total, followed by Peru with a total of 8 published articles, equivalent to 17% of the total, and finally Venezuela, Argentina, Bolivia and Italy with only one published article each, equivalent to 2% of the total, and Venezuela, Argentina, Bolivia and Italy with only one published article, equivalent to 2% of the total article published each, equivalent to 2% of the total.

Box 4

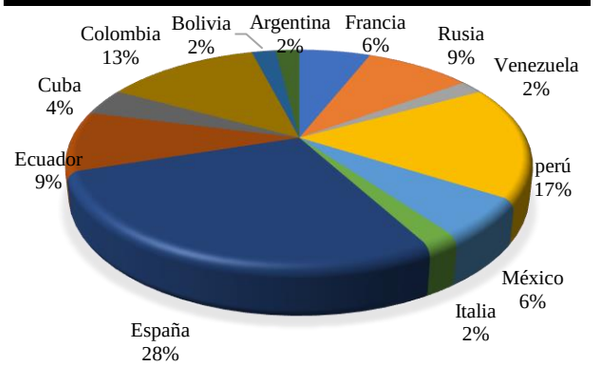

Figure 3

Percentage of published articles by country, collection, 2024

The source of information with the highest number of articles found is Dialnet with 13%, Redalyc, Science Index and the institutional repository of the UPN with 10%, for more information see figure 4.

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Box 5

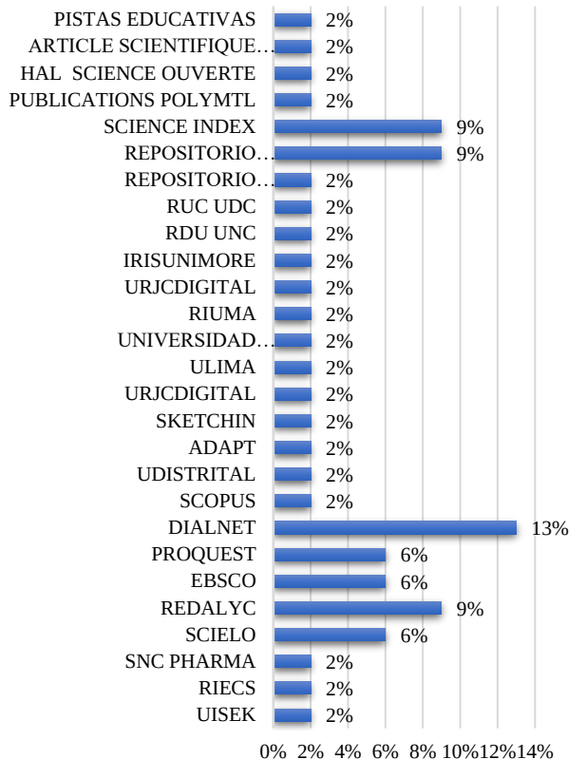

Figure 5

Percentage of articles according to their source of information

Prepared by authors, 2024

The in-depth analysis of the 47 articles made it possible to identify how many of them met the objectives set out in this research.

Rationale

Based on the evidence we have collected, we did not find a sufficiently verifiable basis for demonstrating the advantage of using more appropriate exoskeleton prototypes in terms of risk reduction activities in industrial enterprises.

General Objective

To present prototypes of exoskeletons more appropriate to the activities in industrial enterprises.

Specific objectives

1. To analyse the most appropriate exoskeleton prototypes according to the activities to reduce risks and improve the productivity of industrial companies.
2. To identify the most appropriate exoskeleton prototypes according to the activities to reduce risks and improve the productivity of industrial companies.
3. To compare the effectiveness and functionality of the exoskeleton prototype in performing activities under normal conditions in industrial companies to reduce accidents within industrial companies.

In Table (1) different prototypes are analysed, comparing the effectiveness and functionality to perform activities in normal conditions in industrial companies to reduce accidents within industrial companies.

Methodology

From the point of view of its application it is qualitative research, since by means of the collection and analysis of relevant data a thorough inspection of the 57 articles found in the searches was carried out, being discarded in these stages 10 articles, sufficiently verifiable base that demonstrates the advantage of using prototypes of exoskeleton more appropriate in function to the activities in the industrial companies to reduce risks.

Box 6

Figure 6

Collection and Analysis Methodology

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Box 7

Table 2

Summary of the analysis of the use of exoskeletons as a function of the activities in industrial companies

N°	AUTOR(ES)	TITLE,Year of publication,COUNTRY	Ventajas	Disadvantages
1	Doris Amanda Puebla Farías	BENEFITS AND LIMITATIONS OF THE USE OF OCCUPATIONAL EXOSKELET FOR THE PREVENTION OF MUSCULOSKELETAL DISORDERS: A SYSTEMATIC EXPLORATORY REVIEW,2020,Ecuad	• Reduction of physical demands during specific tasks - Reduction of muscle fatigue - Increase in work performance - Reduction of physical loads on the lumbar spine - Reduction of pain in the lumbar region - Reduction of the risk of disc injuries - Significant reduction in the physical load on the lower limbs - Prevention of musculoskeletal disorders.	• Possible adverse effects such as hyperextension of the knees - Increased metabolic costs during certain activities - Increased activity of antagonist musculature - Need for further research to assess short and long term consequences in real work settings - Limitations in current studies that may not fully reflect effects over full working days - Increased antagonist muscle activity associated with increased metabolic costs.
2	Laura Gema Fernández Álvarez , Susana Núñez Nagy and Roberto Cano de la Cuerda	Portable exoskeletons in people with spinal cord injury. Systematic review,2020,Spain	The advantages of wearable exoskeletons for people with spinal cord injury include their ability to facilitate standing and walking, as well as their use in rehabilitation. In addition, most of these devices have been found to focus on the hip and knee joints, making them useful for improving mobility in these areas.	On the other hand, some limitations of portable exoskeletons are the need for a complementary support product, which may imply an additional cost for users. Furthermore, although 20 portable exoskeletons have been identified in the study, it is important to consider that each device has its own specific features and benefits, so choosing the most suitable one for each person with spinal cord injury may require an individualised assessment.
3	Héctor Mandomingo Mediavilla, Pilar Fernández González, Francisco Molina Rueda	Usability and acceptability of wearable exoskeletons for gait training in spinal cord injured subjects: systematic review,2018,Spain.	The advantages of using wearable exoskeletons for gait training in spinal cord injured subjects include: - They allow users to walk without the need to be continuously connected to a power source; - They generate acceptance and satisfaction among spinal cord injured patients; - No major adverse effects were described in the studies reviewed; - Participants reported an improved perception of their quality of life; - Improvements in gait parameters such as speed and endurance were observed.	The disadvantages or limitations identified in the studies included in the systematic review are: - The studies have methodological limitations, such as lack of control groups and blinding of the evaluators; - There are few studies available in the literature, which makes the data obtained less robust. - Adverse effects reported were mild, such as skin discomfort and pressure sensation in the contact areas of the wearable exoskeletons - Further research with long-term follow-up is needed to assess possible long-term adverse effects and the safety of continued use of the exoskeletons - Usability in non-laboratory environments still requires improvement.
4	Yeyson Alejandro Becerra Mora	A review of roboric platforms for the construction sector,2020,Colombia	The advantages of using robots in the construction and mining industry include: - Improved efficiency and productivity: Robots can perform repetitive tasks faster and more accurately than human workers, which can increase efficiency and productivity at construction and mining sites - Improved safety: By using robots for hazardous tasks or in hostile environments, the risk of injury or workplace accidents for workers is reduced. - Accuracy and quality: Robots can perform tasks with millimeter accuracy, which can result in higher quality in the execution of construction and mining projects - Long-term cost reduction: Despite the initial investment in robotic technology, in the long term it can result in significant savings due to improved efficiency and productivity - Ability to work in harsh environments: Robots can operate in extreme conditions or hazardous environments where humans might have difficulty working - Ability to work in harsh environments: Robots can operate in extreme conditions or hazardous environments where humans might have difficulty working.	On the other hand, some potential disadvantages of using robots in the construction and mining industry could include: - High initial cost: Robot technology can be expensive to acquire and implement, which may be a barrier for some companies - Need for specialised training: Trained personnel are required to operate and maintain robots, which may involve additional costs and training time - Potential loss of jobs: The automation of certain tasks may result in a reduction in jobs for human workers, which may have social and economic implications - Limitations in versatility: Although robots are efficient at specific tasks, they may be more costly to operate and maintain. - Potential job losses: The automation of certain tasks may result in the reduction of jobs for human workers, which may have social and economic implications - Limitations in versatility: Although robots are efficient at specific tasks, they may have limitations in terms of adaptability to changes in the environment or in the tasks to be performed.
5	Mauricio Plaza Torres , Fredy Bernal Castillo	System for the measurement and prediction of movement intention,2019,Cuba	The advantages identified in the paper on the use of bioelectrical signals to predict the movement intention of people are the following: - They allow predicting the user's movement intention before the movement is initiated, which considerably reduces the delay in starting and stopping the movement; - They facilitate the identification of movement-related patterns through signal processing and the use of artificial intelligence; - They enable the implementation of control systems for exoskeletons and orthoses to assist people with disabilities or muscle weakness; - The use of multi-layer artificial neural networks for the identification of patterns in the electro-skeleton and orthoses to assist people with disabilities or muscle weakness. - They enable the implementation of control systems for exoskeletons and orthoses to assist people with disabilities or muscle weakness - The use of multi-layer artificial neural networks for pattern identification in electrophysiological signals has proven to be effective and fast once the corresponding training has been performed.	On the other hand, the main disadvantage identified in the paper is the need for manual or reaction control of currently used devices and exoskeletons. This limitation means that the devices do not assist the initiation of movement, which makes them less practical to operate.
6	Leonardo Brioche Vázquez, Mauricio Torres Quezada, Daily Milanés Hermosilla	Robotic exoskeleton for the rehabilitation of the upper limb of the hemiplegic patient,2020,Cuba	The advantages of the exoskeleton for the rehabilitation of the upper limb in hemiplegic patients are the following: - It allows controlled and precise movements thanks to the built-in actuators and sensors; - It offers the possibility of capturing the patient's electrical muscle activity or the intentionality of the movement through electromyographic signals or electroencephalography. - Can be used in a wide range of applications, from patient rehabilitation to the replacement of vital functions - Provides a customisable and adjustable design for each patient, considering their anthropometric and kinetic characteristics - Allows specific therapeutic movements with a controlled rotational speed.	The disadvantages of the exoskeleton for upper limb rehabilitation in hemiplegic patients are as follows: - It requires a complex mechanical and structural design which can be costly; - The implementation of actuators and sensors can increase the complexity of the system and its maintenance; - Although it is mentioned that the resistance applied to the patient's movement is controlled, there is a risk of injury if not applied correctly; - The need for an electronic control system and specialised software may require additional learning by physiotherapists. - Although it is mentioned that the resistance applied to the patient's movement is controlled, there is a risk of injury if not applied correctly - The need for an electronic control system and specialised software may require additional learning by physiotherapists - There may be limitations in the patient's mobility and freedom of movement during exoskeleton therapy - There may be limitations in the patient's mobility and freedom of movement during exoskeleton therapy.
7	Woge Oscar Gonzalez Ortiz Gabriela Gavino,	STRESS ANALYSIS AND DEVELOPMENT OF A MATLAB GUIDE APPLIED TO AN EXOSKELET STRUCTURE THROUGH THE VON MISES CRITERION,2022,Mexico	Advantages of exoskeletons according to the paper: - Exoskeletons can benefit people with spinal injuries and other mobility problems by providing lightweight, rigid and safe equipment - The use of carbon fibre as a material to build the structural components of exoskeletons provides the necessary rigidity and lightness to withstand the demands required in orthopaedic equipment - Finite Element simulation allows to evaluate possible flaws in the design of exoskeletons and to make adjustments to improve their structural performance - The application developed with MATLAB simplifies the process of simulation and analysis of the exoskeletons. - The Finite Element simulation allows to evaluate possible flaws in the design of the exoskeletons and make adjustments to improve their structural performance - The application developed with MATLAB simplifies the process of simulation and analysis of the exoskeletons, allowing to identify critical areas that require reinforcement.	Disadvantages of exoskeletons according to the document: - No specific disadvantages of exoskeletons are mentioned in the document provided - Evaluation of exoskeletons through simulations may depend on the accuracy of input data and component modelling - Implementation of exoskeletons may require a detailed design and analysis process to ensure their effectiveness and safety - No specific limitations in terms of disadvantages related to exoskeletons are mentioned in the document read - No specific limitations in terms of disadvantages related to exoskeletons are mentioned in the document read - No specific limitations in terms of disadvantages related to exoskeletons are mentioned in the document read.
8	López Méndez Santiago; Martínez Tejada Hader Vladimir; Valencia García Marco Fidel.	Development of an armored upper limb exoskeleton ,2020,Colombia	Advantages: - Exoskeletons can enhance the physical capabilities of users and help them bear loads they could not handle on their own - Exoskeletons can restore proper limb function, assist basic movements and simplify effort-intensive tasks. - Exoskeletons can provide ballistic protection for personal safety purposes, through the use of advanced materials such as aluminium and carbon nanotubes - Exoskeletons can be controlled by electronic systems that can adjust the force and position of the system, and integrate different adaptive control strategies and impedance.	Disadvantages: - Exoskeletons can be heavy, complex and expensive, limiting their portability and accessibility - Exoskeletons may have a limited or different range of motion (ROM) than human limbs, which may cause discomfort or interference between parts. - Exoskeletons may require a large amount of electrical power to operate, involving the use of batteries or external power supplies - Exoskeletons may present safety risks or harm to the user or the environment, if an adequate control system is not in place or if a system failure occurs.
9	Joga Dharma Setiawan; Adyanto Mochammad; Nugroho Sri; Ismail Rifky; Purbayanto, Tedi	Fuzzy Logic Control for a Soft Exoskeleton Glove Using a Motor-Tendon Actuator,2021,Colombia	Advantages: - Assistance to people with disabilities: Exoskeletons can provide assistance to people with hand disabilities, allowing them to perform everyday activities with greater ease and autonomy - Flexibility and comfort: Exoskeletons made of soft materials, such as the one developed in the study, offer greater flexibility and comfort compared to rigid exoskeletons. This makes them more comfortable to wear for extended periods - Cost-effectiveness: The use of low-cost materials, such as RTV silicone rubber, can make exoskeletons more accessible to a wider range of people, especially in resource-limited environments - Precise control: The implementation of fuzzy logic control allows for more precise control of exoskeleton movements, which can improve their functionality and utility for the user - Potential for rehabilitation: Exoskeletons can not only assist in daily activities, but also have the potential to be used in rehabilitation programmes to improve hand strength and function.	Disadvantages: - Design and manufacturing complexity: The design and manufacture of exoskeletons, especially those incorporating advanced control systems such as fuzzy logic, can be complex and require specialised expertise - Performance limitations: While exoskeletons can provide assistance, they may have limitations in terms of the amount of force they can apply and the movements they can perform, which can affect their usefulness in certain scenarios - Power requirements: Powered exoskeletons often require a power source, such as batteries, which can limit their autonomy and require frequent recharging. - Individualised adaptation: For best results, exoskeletons generally need to be adapted to the individual needs and characteristics of each user, which may require additional time and resources - Potential ergonomic issues: Although exoskeletons are designed to provide assistance, they may cause fatigue or discomfort if they are not properly fitted or if they do not adequately adapt to the user's anatomy.
10	Jorge Daniel Rodríguez Jayakumar Ashwin; García Javier Bermejo; Sánchez Francisco Romero; Sánchez Francisco Javier Alonso.	DESIGN OF AN INVERSE DYNAMICS MODEL OF A LOWER-LIMB ASSISTANCE EXOSUIT, 2021,España	Advantages: - High wearability: Exoskeletons based on cable-driven actuators with anchor points on the segments to be actuated stand out for their high wearability. This means that they are more comfortable to wear and have less impact on the user's mobility compared to traditional exoskeletons - Low weight and reduced cost: These exoskeletons are lighter and less expensive compared to other assistive walking technologies, making them more accessible to a larger number of people who could benefit from them. - Increased user comfort: By using cables to transmit force from the actuators to the anchor points, these exoskeletons offer increased user comfort by dispensing with the rigid structures present in traditional exoskeletons - Design optimization: The inverse dynamics model proposed in the paper allows for optimization of various aspects of exoskeleton design, such as the location of anchor points, the exact number of actuators and the arrangement of cables. This helps to design exoskeletons that are better suited to the needs and characteristics of the users.	Disadvantages: - Limitations in performance: Although exoskeletons can provide assistance during walking, they may have limitations in terms of the amount of force they can provide and the movements they can facilitate. This may limit their usefulness in certain scenarios and for certain users. - Design and manufacturing complexity: The design and manufacture of cable-driven actuator-based exoskeletons can be complex and require specialised expertise. This can increase costs and development times for these devices. - Need for individualised adaptation: For best results, exoskeletons generally need to be adapted to the individual needs and characteristics of each user. This may require additional time and resources for customised assessments and adjustments.
11	DHL Supply Chain Iberia	DHL incorporates exoskeletons at the Mercedes-Benz factory in Vitoria,2020,Spain	Benefits: - Injury prevention: Exoskeletons help reduce pressure on bones, muscles and joints, which can reduce the risk of injuries related to repetitive physical activities or heavy lifting - Physical strain relief: Workers can experience a significant reduction in physical workload due to the support provided by exoskeletons, which can improve their comfort and well-being during work tasks. - Improved productivity: By reducing fatigue and the risk of injury, exoskeletons can help maintain workers' health and performance over time, potentially contributing to increased productivity in the workplace. Innovation and safety: The adoption of exoskeletons reflects an innovative approach to addressing ergonomic challenges in industrial settings, demonstrating companies' commitment to the health and safety of their employees through the implementation of advanced technologies.	Disadvantages: - Cost: Procurement and implementation of exoskeletons can be costly, which can be a challenge for some companies, especially those with limited budgets. - Training and adaptation: Additional training may be required for workers to adjust to and use exoskeletons correctly. In addition, it may take time to adapt to new technology and optimize its use in the work environment. - Limitations of use: Exoskeletons may not be suitable for all tasks or work environments, and may have limitations in terms of mobility or freedom of movement, which could affect the effectiveness of their use in certain situations. - Ongoing evaluation: As exoskeletons are implemented, it is important to conduct ongoing evaluation of their effectiveness and their impact on worker productivity and health to ensure that the desired results are being achieved.
12	Mauro Callejas Cuervo; Manuel A. Vélez Guerrero; Wilson Javier Pérez Holguín	BIOPARAMETER MEASUREMENT SYSTEM ARCHITECTURE INTEGRATING INERTIAL-MAGNETIC AND ELECTROMYOGRAPHIC SIGNALS,2018,Colombia	- Injury prevention: Exoskeletons help to reduce pressure on bones, muscles and joints, which makes them especially useful in preventing potential injuries, such as those caused by muscular overexertion or repetitive movements. - Relief of physical strain: They allow manual load handling tasks involving significant and repeated physical strain to be performed with less effort on the part of workers. In the automotive industry, it has been shown that they can provide individual relief of up to 20% in operators handling heavy tools. - Improved ergonomics: They contribute to improve ergonomics in more physically demanding workplaces, which can increase the comfort and health of workers. - Applicability in various industries: Exoskeletons can be applied in different industrial sectors where there are physically demanding tasks, such as manufacturing, construction, logistics, among others.	- Cost: Procurement of exoskeletons can be costly, which may limit their implementation in some companies, especially those with limited financial resources. - Need for fitting and adjustment: Exoskeletons require fitting and adjustment testing to ensure their effectiveness and comfort for workers, which can take additional time and resources - Technical complexity: The design and implementation of exoskeletons can be technically complex and require expertise in areas such as biomechanics and engineering, which can make their development and maintenance difficult - Interference with mobility: In some cases, exoskeletons can interfere with the natural mobility of workers, which could negatively affect their job performance and safety.
45	КУЛАГИНА А.Н., ПОНОМАРЕВ А.С.	EXOSKELETON,2018,RUSIA	- Improved quality of life: The article suggests that the use of exoskeletons can improve the quality of life of people with disabilities by enabling them to perform daily activities more independently and comfortably - Applications in military and social areas: It highlights the versatility of exoskeletons, which have proven to be useful in both military applications and everyday life - Rehabilitation potential: It mentions that exoskeletons can help in the rehabilitation process by enabling people with disabilities to regain lost motor functions.	- Cost: Not specifically mentioned in the summary, but one of the common drawbacks of exoskeletons is their high cost, which may limit their accessibility for some people or institutions - Technical limitations: Depending on the design and technology used, exoskeletons may have limitations in terms of mobility, comfort or ability to adapt to different users and scenarios - Potential adaptation problems: Some people may experience difficulties in adapting to the use of exoskeletons, either physically or psychologically - Potential adaptation problems: Some people may experience difficulties in adapting to the use of exoskeletons, either physically or psychologically - Potential adaptation problems: Some people may experience difficulties in adapting to the use of exoskeletons, either physically or psychologically.
46	БОРИСОВ А.В., ВОЛКОВА Ю.Е., КОЛЮБИНА Л.В., МАСЛОВА К.С.	PASSIVE-ACTIVE EXOSKELETON WITH LINKS OF VARIABLE LENGTH AND SPRING ELEMENTS OF TWO TYPES,2020,RUSIA	Advantages: - Reduced load on the joints: The proposed exoskeleton aims to reduce the load on the joints by providing support and absorbing some of the user's weight - Improved strength and endurance: By incorporating spring elements, the exoskeleton can help increase the user's strength and endurance by providing assistance during movement. - Energy recovery: The design includes springs that allow energy recovery during movement, which could increase user efficiency and extend the time of use of the exoskeleton - Adaptability and comfort: The ability to adjust the length of the links and the presence of springs could increase the adaptability of the exoskeleton to different users and activities, thus improving comfort and user experience.	Disadvantages: - Complexity and manufacturing costs: Implementing an exoskeleton with passive-active features and spring elements can be technically challenging and costly, which could limit its availability and accessibility - Potential need for customised adjustments: Due to the variable nature of the links and spring configuration, customised adjustments may be necessary to adapt the exoskeleton to the specific needs and characteristics of each user. - Maintenance requirements: Mechanical components, such as springs, may require periodic maintenance to ensure optimal functioning, which could result in additional costs and downtime for the user.

Continuation of table 2…

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N°	Functionality	Effectiveness according to company conditions and how it impacts on reducing occupational risks.	SOURCE OF INFORMATION	Link
1	According to the article, the proposed exoskeletons have functionalities such as reducing physical demands in work tasks such as lifting, carrying and bending. .	The effectiveness of exoskeletons in reducing occupational hazards varies depending on the conditions of the company and the exoskeleton model used. Benefits such as reduced muscle fatigue and physical demands have been observed in work environments, but more research is needed to assess the short- and long-term impacts in real work environments.	UISEK	https://repositorio.uisek.edu.ec/bitstream/123456789/3978/2/ARTICULO%20EXOESQUELETOS%20INDUSTRIALES%20AMANDA%20PUEBLA.pdf
2	According to the article, the proposed wearable exoskeletons are mainly used for rehabilitation purposes in people with spinal cord injury, focusing on the hip and knee joints.	Regarding effectiveness in reducing occupational risks, the article does not specifically address this issue.	RIECS	https://dialnet.unirioja.es/servlet/articulo?codigo=7468522
3	According to the article, the proposed wearable exoskeletons for gait training in people with spinal cord injury have proven to be tolerable and acceptable, with mild and infrequent adverse effects, such as skin discomfort or pressure on the contact areas.	In terms of effectiveness in reducing occupational risks, it is mentioned that these devices generate hardly any significant adverse effects and have been well received by patients, which could have a positive impact on rehabilitation and improved functionality of the lower limb in spinal cord injured subjects.	SNC PHARMA	https://sncpharma.com/wp-content/uploads/2018/03/Usabilidad-y-aceptabilidad-de-los-exoesqueletos-portables-para-el-entrenamiento-de-la-marcha-en-
4	the exoskeletons proposed in the article offer specific functionalities designed to improve working conditions in the construction sector. Here is a summary of each: - HAL (Hybrid Assistive Limb) from Cyberdyne: Ø Functionality: Helps increase the user's strength and reduces the stress applied to the back from heavy lifting Ø Effectiveness: This exoskeleton can significantly reduce muscle fatigue and the risk of injury associated with handling heavy loads in construction. Its effectiveness will depend on proper fitting and training in its use by workers - Lockheed Martin's Fortis: Ø Functionality: Relieves user loading and reduces muscle fatigue through biomechanics, increasing user strength and endurance Ø Effectiveness: Like HAL, Fortis can reduce fatigue and the risk of musculoskeletal injuries in workers performing physically demanding tasks in construction. Its effectiveness will also depend on proper implementation and training.	Both exoskeletons have the potential to positively impact on occupational risk reduction by reducing the physical burden on workers, which may result in a lower incidence of musculoskeletal injuries and chronic fatigue. In addition, by improving the ergonomics and physical capacity of workers, these exoskeletons can contribute to a safer and more productive work environment in the construction industry. However, their effectiveness may vary depending on factors such as the specific application, the design of the exoskeleton, staff training and proper integration into the company's work processes.	SCIELO	http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S0123-921X2020000100115
5	The main functionality of the proposed exoskeletons is to help solve ergonomic problems in tasks such as repetitive work and rehabilitation. These devices are designed to maintain or improve the user's quality of life by enabling new movements or reducing fatigue at the end of a working day.	In terms of effectiveness, the study shows that the design and implementation of the system to obtain, process and identify electrophysiological signals has been able to predict the movement intention of the lower limbs with success rates of over 86.66%. This suggests that the proposed exoskeletons could be highly effective in assisting workers to perform specific movements, which can have a significant impact on reducing occupational risks associated with fatigue and repetitive strain.	SCIELO	http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S0864-03002019000200277&lang=pt
6	Functionality of the proposed robotic exoskeleton: Ø The developed robotic exoskeleton is designed for the rehabilitation of the upper limb in hemiplegic patients, providing a support system and controlled movement to facilitate the recovery of mobility and muscle strength in affected patients. Here are some features of its functionality: Ø Selection of actuators and rotation mechanisms: The exoskeleton incorporates force actuators and mechanisms for arm rotation and forearm pronation and supination, designed to provide controlled and precise movements that mimic the physiological movements of the upper limb. Ø Mechanical armature and ergonomic design: The structure of the exoskeleton is designed to adapt to the dimensions and anthropometric characteristics of the patients, ensuring balanced weight distribution and ergonomics suitable for use during rehabilitation sessions. Ø Control and safety system: The exoskeleton is equipped with simple and safe control systems, allowing interaction and supervision by the physiotherapist. In addition, it has integrated safety measures, such as travel limiters and emergency buttons, to ensure patient safety during rehabilitation sessions.	Ø Improvement of mobility and muscle strength: The exoskeleton provides controlled and precise movements that help hemiplegic patients to regain mobility and muscle strength in the affected upper limb, which contributes to improve the patient's functionality and autonomy in daily life activities. This contributes to improving the patient's functionality and autonomy in activities of daily living. Ø Facilitation of physiotherapeutic therapy: The exoskeleton facilitates the application of physiotherapeutic therapies by providing controlled movements and adjustable resistance during rehabilitation sessions. This helps to optimise the physiotherapist's time and resources, as well as ensuring accurate and safe delivery of therapies. Ø Progression monitoring and evaluation: The exoskeleton is designed to enable monitoring and evaluation of patient progression during rehabilitation sessions. This provides valuable information on the effectiveness of the therapy and allows the treatment to be adjusted according to the individual needs of each patient.	REDALYC	https://www.redalyc.org/journal/2251/225165187003/
7	Based on the information provided in the article, the proposed exoskeletons appear to have several potential functionalities and benefits: Physical support and assistance: exoskeletons can provide additional support to users, especially those with spinal injuries or other mobility problems. This can help them perform physical tasks that might otherwise be difficult or painful. Improved safety: By improving ergonomics and providing additional support during the performance of physical tasks, exoskeletons could help reduce the risk of musculoskeletal injuries and other occupational hazards associated with repetitive movements or heavy lifting.	In terms of the effectiveness of the proposed exoskeletons in company conditions and their impact on reducing occupational hazards, here are some points to consider: Ergonomic assessment: It would be important to conduct a detailed ergonomic assessment of the specific work tasks and activities in the company to determine how exoskeletons could be effectively integrated to improve safety and reduce the risk of injury. Assessment of costs and benefits: In addition, the costs associated with the implementation of exoskeletons in terms of procurement, maintenance and training should be considered, as well as the expected benefits in terms of reduced occupational injuries and increased productivity.	EBSCOHOST	https://eds.p.ebscohost.com/eds/detail/detail?vid=0&sid=88e6d35e-a057-409c-8c40-35314d49f066%40redis&bdata=Jmxhbmc9ZXMmc2l0ZT1lZHMtbGl2ZQ%3d%3d#db=edsgao&AN=edsgcl.699258373
8	Functionality of the proposed exoskeletons: Ø Physical support: Exoskeletons are designed to provide additional support to workers during the performance of tasks involving repetitive movements or heavy lifting. This helps to reduce muscle fatigue and the risk of work-related injuries. Ø Personal protection: In addition to providing physical support, exoskeletons are equipped with armour that protects the user from possible impact or injury while performing work tasks. This helps to ensure the safety and well-being of the worker in the workplace.	Ø Reduced musculoskeletal injuries: By providing physical support and protection, exoskeletons help reduce the workload on the body's muscles and joints, which can reduce the risk of musculoskeletal injuries such as strains, sprains and sprains. Ø Improved safety: The combination of physical support and personal protection offered by exoskeletons helps to increase workplace safety by reducing the likelihood of accidents and injuries. This contributes to a safer and more secure working environment for workers. Ø Increased productivity: By reducing fatigue and the risk of injury, exoskeletons can contribute to improved productivity in the workplace by enabling workers to perform their tasks more efficiently and safely. This can result in decreased downtime due to injury and increased efficiency in performing work tasks.	PROQUEST	https://www.proquest.com/docview/2338410285/FD36C650A21F4020PQ/17accountid=37408
9	The exoskeletons proposed in the article have as their main functionality to provide mechanical assistance to the hands, specifically for people with hand disabilities or hand impairment. These exoskeletons are designed to assist in the flexion and extension movement of the fingers, which facilitates the performance of daily activities that require the use of the hands.	In terms of effectiveness, these exoskeletons could have a significant impact on reducing occupational risks in environments where repetitive and strenuous use of the hands is required, such as in manufacturing, construction or agriculture. By providing mechanical support to the hands, these exoskeletons can help prevent musculoskeletal injuries such as muscle fatigue, carpal tunnel syndrome and other work-related conditions. In a company, the implementation of these exoskeletons could improve worker health and safety, reduce absenteeism due to injury, and improve productivity by allowing workers to perform tasks more efficiently and comfortably. In addition, by reducing the risk of workplace injury, the company could also experience significant cost savings associated with medical treatment and workers' compensation. In summary, the proposed exoskeletons can not only improve workers' quality of life, but also have a positive impact on the company's profitability and sustainability.	PROQUEST	https://www.proquest.com/docview/2593129795/FD36C650A21F4020PQ/2?accountid=37408
10	The main functionality of the exoskeletons proposed in the article is gait assistance, especially designed for people with disabilities or mobility difficulties. These exoskeletons use an inverse dynamic model to calculate the traction forces on the cables and the torque demanded from the actuators, thus providing support and improving mobility during walking.	In terms of their effectiveness in business conditions and their impact on reducing occupational risks, we can consider the following: Ø Effectiveness in business conditions: Wearable exoskeletons can be effective in work environments where workers perform tasks that require repetitive movements or heavy lifting. By providing gait assistance and reducing the load on joints, these devices can improve worker comfort and health, which can lead to increased productivity and job satisfaction. Ø Impact on reducing occupational risks: Exoskeletons can help reduce occupational risks associated with musculoskeletal injuries and physical activity-related fatigue. By providing support and assistance during walking, these devices can help prevent joint and muscle injuries, especially in workers performing physically demanding tasks. This can result in a decrease in workplace accidents, sick leave and costs associated with medical care and workers' compensation.	PROQUEST	https://www.proquest.com/docview/2605660386/FD3C650A21F4020PQ/3?accountid=37408
11	The main functionality of the proposed exoskeletons is to improve ergonomics in the most physically demanding workplaces at the Mercedes-Benz factory in Vitoria. These devices are designed to provide support during manual load handling tasks, such as sequence preparation or activities in the empty container folding area, which involve significant and repeated physical effort for workers. Exoskeletons reduce stress on bones, muscles and joints, which helps prevent potential musculoskeletal injuries and repetitive motion fatigue.	In terms of effectiveness, exoskeletons are expected to be highly effective in company conditions, especially in reducing occupational risks associated with overexertion and musculoskeletal injuries. Tests in the automotive industry have shown individual relief levels of up to 20% in operators handling heavy tools. By providing support and reducing the physical strain required by workers during physically demanding tasks, exoskeletons are expected to contribute to improving working conditions and reducing the number of accidents and medical leaves related to musculoskeletal injuries and repetitive motion fatigue.	DIALNET	https://dialnet.unirioja.es/servlet/articulo?codigo=7591454
12	Based on the article, the main functionality of the proposed exoskeletons is to assist in the rehabilitation of people with physical limitations, especially those affected by cerebrovascular accidents (CVA) or injuries that affect mobility. These exoskeletons are designed to provide support and assistance in body movements, especially in the upper and lower extremities, with the aim of improving motor function and facilitating patients' recovery.	In terms of effectiveness, as described in the article, exoskeletons have proven to be a useful tool in the rehabilitation process. By integrating motion capture technologies, such as motion processing units (MPUs) and electromyography (EMG), along with digital processing algorithms, these devices can provide accurate information on patient performance during rehabilitation. This allows healthcare professionals to monitor patient progress, adjust treatments as needed and provide real-time feedback. From a business perspective, the implementation of exoskeletons in work environments can have a significant impact on reducing occupational risks. By providing physical support and reducing the burden on the human body during physically demanding tasks, exoskeletons can help prevent work-related injuries such as musculoskeletal injuries and chronic fatigue. In addition, by improving workers' ability to perform physical tasks, exoskeletons can increase productivity and efficiency in the workplace.	REDALYC	https://www.redalyc.org/journal/678/67866319010
45	The functionality of exoskeletons includes: Ø Rehabilitation support: Exoskeletons provide physical support for people with disabilities, helping them to perform movements and tasks that would otherwise be difficult or impossible to perform. Ø Improved mobility: They enable people to regain or improve their ability to walk, stand, sit and perform other daily activities. Ø Stabilisation and postural correction: Exoskeletons can correct posture and provide joint stability, which is especially useful for people with balance problems or muscle weakness. Ø Reduction of physical load: In work environments, exoskeletons can help reduce the physical load on workers by providing support for heavy lifting or repetitive tasks.	In terms of the effectiveness of exoskeletons in business conditions and their impact on reducing occupational risks, the following points can be highlighted: Ø Increased safety: By reducing the physical burden on workers, exoskeletons can help prevent musculoskeletal injuries and fatigue, contributing to a safer work environment. Ø Improved productivity: By facilitating physically demanding tasks, exoskeletons can increase worker efficiency and productivity by reducing downtime due to injury or fatigue. Ø Reduced costs: By preventing workplace injuries and reducing the need for sick leave, exoskeletons can help companies save on medical costs and workers' compensation. Ø Adaptability and customisation: Exoskeletons can be designed to adapt to different work environments and specific worker needs, making them effective in a variety of industries and working conditions.	SCIENCE INDEX	https://www.elibrary.ru/item.asp?id=35121986
46	Functionality of the proposed exoskeletons: Ø Variable length links: These allow better adaptation to the user's anatomy and movements, providing a more precise fit and greater capacity for movement. Ø Two types of spring elements: Tension-compression and torsion springs help maintain link length and recover energy during movement, reducing muscle fatigue and load on the joints. Ø Energy recovery: The ability of the springs to recover energy during the user's movement increases the efficiency of the exoskeleton and reduces fatigue, allowing prolonged use and improving the user's endurance.	Effectiveness under company conditions and reduction of occupational risks: Ø Improves work ergonomics: By providing additional support and improving the user's biomechanics, the exoskeleton helps reduce the load on the joints during work tasks that require repetitive movements or lifting. Ø Increases safety and prevents injuries: By reducing the load on joints, the exoskeleton can help prevent work-related musculoskeletal injuries, such as back, shoulder or knee injuries. Ø Improves productivity and efficiency: By reducing muscle fatigue and increasing user endurance, the exoskeleton can help improve productivity by allowing workers to perform physical tasks more efficiently and for longer periods of time. Ø Facilitates rehabilitation: In environments where rehabilitation or recovery from work-related injuries is required, the use of the exoskeleton can aid in the recovery process by providing support and relief from the load on affected joints.	SCIENCE INDEX	https://www.elibrary.ru/item.asp?id=43912827

Tr s a comprehensive examination of the information gathered and studies reviewed in this paper, table (2) presents a summary of the articles on occupational exoskeletons, which present a wide range of benefits as well as limitations that need to be considered. These devices are noted for their ability to reduce physical demands in work tasks such as lifting, carrying and bending, resulting in reduced occupational hazards, muscle fatigue and physical demands in work environments. In addition, exoskeletons are a valuable support tool for people with spinal cord injuries, facilitating standing, walking and actively participating in rehabilitation processes. However, it is important to note that their implementation entails additional considerations, such as additional cost for users and the need for individualised assessment to determine the most appropriate option. Personalised fitting and adjustment are essential to ensure the effectiveness and comfort of these devices, which can require considerable time and resources.

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On the other hand, the technical complexity involved in the design and maintenance of exoskeletons can pose challenges, especially in terms of interference with workers' natural mobility and the need for expertise in areas such as biomechanics and engineering. Despite these considerations, exoskeletons show great potential in a variety of areas, from patient rehabilitation to improving ergonomics and occupational safety in industrial settings. Their ability to provide physical support, reduce body burden and prevent work-related injuries offers significant benefits for both workers and companies, which can translate into significant improvements in quality of life, productivity and long-term profitability. In summary, exoskeletons represent a promising innovation with the potential to positively transform both the workplace and the health and rehabilitation field.

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