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Human-Centric Assistive Technologies in Manual Picking and Assembly Tasks: A Literature Review

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Abstract
In the current industrial context, the human workforce still represents a key resource thanks to its cognitive and motor flexibility. The present work explores the role of Industry 4.0 assistive technologies in production and logistics systems from a human-centric perspective. These technologies aim to provide cognitive or physical support to operators executing manual tasks, rather than substituting them. Therefore, there is need for a comprehensive understanding of the impact of assistive technologies on the well-being and performance of operators from a human-centric perspective. In this paper, a literature review on available assistive technologies is provided. Technologies are classified based on the type of manual task (picking, assembly), type of support provided to the operator (cognitive, motor), and potential drawbacks. Outcomes emphasize the need of a thorough human-centric perspective in developing and deploying assistive technologies.

Keywords
Order Picking Tasks, Assembly Tasks, Industry 5.0, Human-centric, Assistive Technologies, Literature Review.

Introduction

Despite the implementation of I4.0 assistive technology in current industrial scenario, human workers still play a central role, mainly in picking and assembly processes (Facchini et al., 2022). In particular, thanks to their motor and cognitive flexibility, human workers still execute assembly tasks (Calzavara et al., 2020; Cavallo et al., 2022; Facchini et al., 2024), and 80–90% of order-picking operations (Loske, 2022; Zhao et al., 2019). Picking tasks involve selecting and gathering items to fulfil orders in logistics systems or feeding assembly lines with necessary components. In the latter case, items picked up are then delivered to assembly areas ensuring that the necessary components are readily available for the assembly process. Efficient picking and well-organized storage systems are vital for an efficient assembly process.

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From a human-centric point of view, picking and assembly activities affect human operators through cognitive and motor demands: cognitive or motor contents depend on the specific activity. During picking tasks, operators are required to travel through warehouses to select items: the travelling and picking actions may involve considerable force exertion and energy expenditure. At the same time, the steps of searching, detecting, and identifying items require a more cognitive effort. During assembly activities, workers are responsible for assembling components, inspecting for quality, and ensuring that the final product meets the required specifications. As in the picking, assembly tasks involve decision-making processes, such as following assembly procedures or selecting items to be assembled. Operators could make mistakes in selecting components, missing some of them, or following an improper assembly sequence. The motor demands required by assembly processes are more linked to accuracy and dexterity (Cavallo et al., 2022).

I4.0 introduced multiple technologies to increase quality, productivity, and efficiency of systems. Since these technologies were more targeted at the performance of systems, less attention was given to human-related outcomes. This aspect was observed in production and logistics systems; while these systems can benefit from implementing these technologies, less is known about the possible benefits and drawbacks related to the human workforce (Neumann et al., 2021; Sgarbossa et al., 2020). Despite the increasing level of automation and digitalization, human operators still play a crucial role in most of production and logistics systems (Grosse, 2023; Kadir et al., 2019). From a human-centric point of view, assistive technologies could provide cognitive or motor support to operators involved in picking and assembly activities. Nevertheless, despite these objectives, implementing assistive technologies to support operators could bring to drawbacks that increase psychological or physical efforts like fatigue, workload, injuries and pain, affecting well-being and performance.

Based on these observations, the primary purpose of this paper is to understand, from a human-centric perspective, how assistive technologies employed in picking and assembly activities support the human workforce (cognitive or motor support), what are the main expected results (increase performance/ensure the well-being of operators), and what could be their human-related drawbacks. Practitioners could use results from this analysis to understand both the advantages and disadvantages of implementing assistive technologies from the human-centric perspective since the full impact of technologies on humans involved in picking and assembly activities remains an open aspect to investigate. Research questions are shown in the following:

1. What kind of benefits assistive technologies provide to operators?
2. What type of support assistive technologies provide to operators to ensure the promised benefits?
3. What kind of human-related drawbacks are related to these assistive technologies?

The above-mentioned research questions formalize the main objective of the present paper. This work focuses on the human-centric vision being the operator at the centre of the proposed investigation.

The remainder of the article is organized as follows: Section 2 describes the methodology employed for the literature review. Section 3 describes the type of support that assistive technologies provide, Section 4 focuses on the human-centric benefits and drawbacks of those technologies, and Section 5 is devoted to classifying assistive technologies from a human-centric perspective. Sections 6 and 7 provide discussion and conclusion, respectively.

Methodology and Bibliometric Analysis

This section presents the approach adopted to perform the proposed review and results of the bibliometric analysis. A literature review of research papers focusing on technologies employed to support workers in production and logistics systems has been carried out. Scientific papers have been collected through an extensive search in the Scopus open-access electronic database. Inclusion criteria for the research comprise full journal and conference proceedings, English language, and peer-reviewed articles. Exclusion criteria encompass lectures, presentations, non-English language, duplicated and not peer-reviewed articles. Papers published in the last six years (2018–2023) have been considered. Keywords/search terms included in the research are "Human-centric", "Operator", "Assembly", "Warehouse", "Picking", "Industry 4.0", "Human-robot collaboration", "Collaborative robots", "Exoskeleton", "Virtual Reality", "Augmented Reality", "Pick by", "AGV", "Picking robot", "Technology". By combining these keywords, 189 papers have been identified. By reviewing the title, and the abstract of each article, a total of 118 publications were considered relevant to the review topic. After applying the inclusion and exclusion criteria, 97 papers were considered. In the present paper working scenarios where assembly tasks (e.g., manufacturing, production) and manual picking tasks (e.g., logistics, warehouse) are executed, are considered.

In this context, human-centric assistive technologies refer to technologies employed to provide a cognitive or motor support while performing assembly or manual picking tasks through an active interaction (e.g., by visual, contact, or sound) with the operator/worker. Technologies that just monitor physiological or motor parameters (e.g., oxygen consumption, heart rate variability, blood pressure, body postures), IoT, Cloud Systems, or Big Data based, are not included in this work. Following this rationale, and after full-text reading, further 48 papers were excluded, resulting in 49 papers analysed for the current literature review.

Bibliometric analysis has been carried out on selected papers. Main results are summarized in Figures 1 and 2. Human-centric assistive technologies identified in the selected papers are: Cobot, AR, VR, for assembly tasks, while AR, VR, AGV, Picking Robot, Exoskeleton, Pick-by- (Scan/Voice/Light) technologies for manual picking tasks (i.e., picking) (Fig. 1). Notably the Augmented Reality (AR) and Virtual

Reality (VR) are the most widely used technologies both in assembly and picking tasks. This observation can be highlighted also in Figure 2. By visualizing the bibliometric network obtained through the keyword co-occurrence patterns, the 'Augmented Reality' and 'Virtual Reality' keywords occupy the centre of the network with the largest number of connections, being employed in both type of tasks.

Cognitive and Motor Support of Human-Centric Assistive Technologies

Picking and assembly in production and logistics systems are effort- and time-intensive activities. Although technological advances in these systems, human workers remain the main actors involved in those activities.

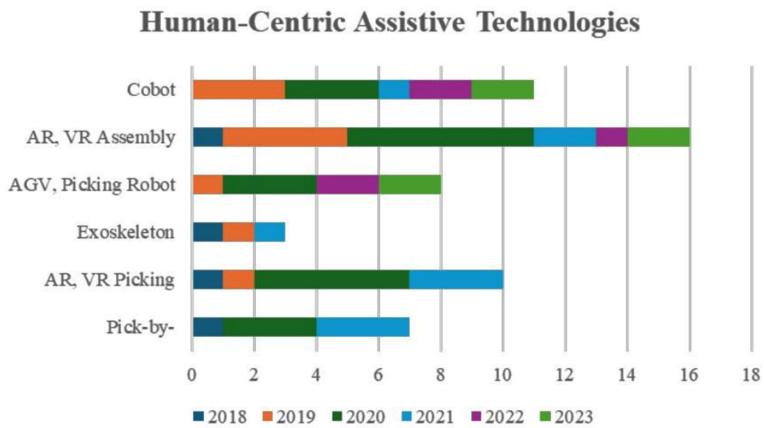

Fig. 1. Bibliometric analysis of selected articles classified by year and type of human-centric assistive technology

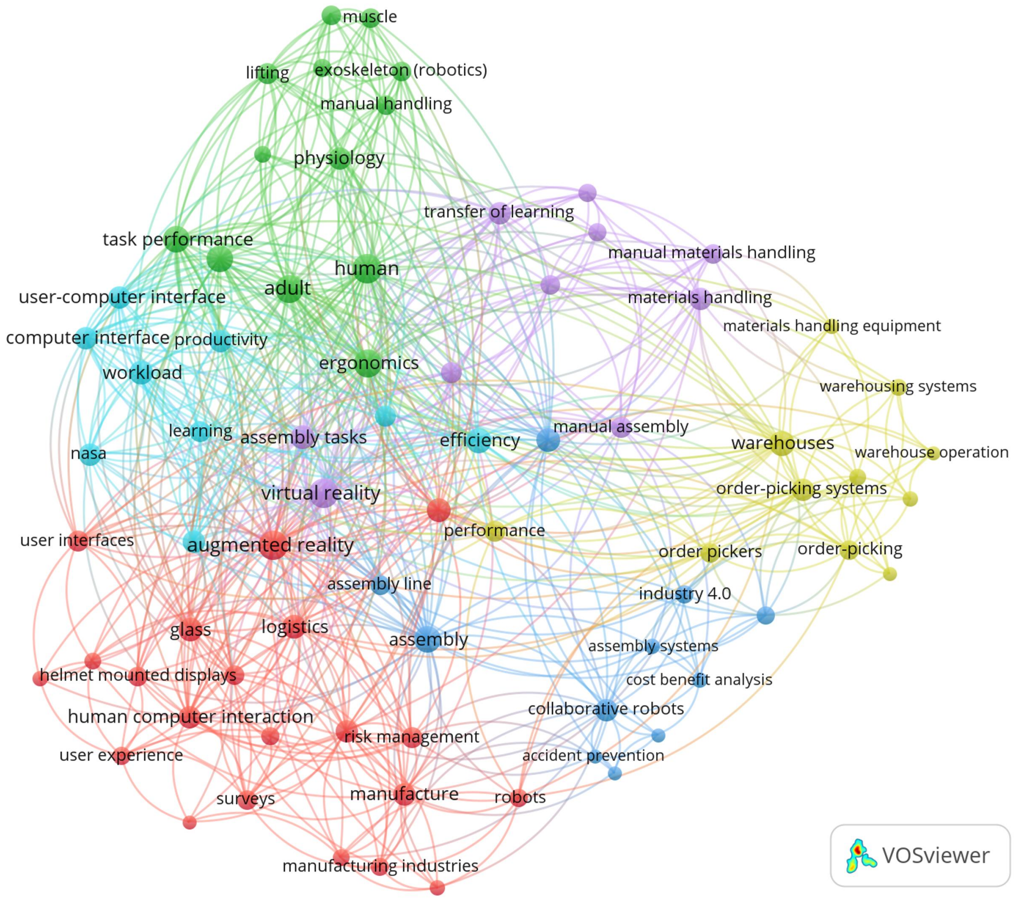

Fig. 2. Visualization of keyword co-occurrence patterns of human-centric assistive technologies

Picking Tasks

Order-picking activities include retrieving items or components from their locations to fulfil customer orders or to feed assembly lines. It is the most expensive warehouse process, accounting for 50% of operational costs (Frazelle, 2016). Therefore, to increase performance, some authors proposed to fully automate picking processes (Custodio & Machado, 2020; Jaghbeer et al., 2020). Nevertheless, since order-picking processes require flexibility, adaptability, dexterity, and fast reaction times, the possibility of designing a fully automated system with the same cognitive and motor abilities as the human workforce is very low at this stage (Vanheusden et al., 2023; Winkelhaus et al., 2021). Therefore, the implementation of technologies is still devoted to assisting and not substituting human workers in picking processes providing cognitive or motor support (Glock et al., 2021). Assistive technologies may be implemented in one or more phases that comprise the manual picking process, such as the search (detect and identify pick locations and specific items/components), the travel (between pick locations and the depot area), or the picking (action related to lift, retrieve and handle items/components from specific locations) (Tompkins et al., 2010).

Smart devices can be employed in picking tasks to assist operators in identifying items/components and verifying picks, providing cognitive support. In particular, assistive technologies like pick-by-voice, pick-by-light, pick-by-scan and pick-by-projection support human operators during the setup and search-picking phases (Dujmešić et al., 2018; Gajšek et al., 2020; Stockinger et al., 2020). Similarly, the use of Augmented Reality (AR) simplifies the visualization of items/components and the information availability and presentation mode through HUD (Heads-Up Display) and smart glasses (Bräuer & Mazarakis, 2018; Fang & An, 2020; Friemert et al., 2019; Kim et al., 2019; Murauer et al., 2018). This technology improves the surrounding environment to enhance the cognitive abilities of the operator by integrating real and virtual objects (Faccio et al., 2019). Differently from AR, Virtual Reality (VR) is more used in 'offline mode' to train workers by allowing them to navigate in 3D virtual environments simulating workplaces and movements that should be executed (Elbert et al., 2018; Friemert et al., 2018).

Other devices are employed to ease the phases of picking (handling, lifting, and retrieving items/components) and travelling, providing motor support. While exoskeletons (active and passive) help workers during the picking (Huysamen et al., 2018; Motmans et al., 2019; Zhu et al., 2021), AGVs (Automated Guided Vehicles) are more involved in the travelling and sorting phase. Where a 'picker-to-parts' strategy is adopted, sometimes AGVs are employed as mobile 'storage' systems following the worker: the mobile robot stores the items/components retrieved by the operator, and once it reaches the full capacity, it is sent to the depot, where items are automatically sorted. The employment of this mobile robot avoids the worker's travelling and sorting activity (Azadeh et al., 2019; Fager et al., 2020). Mobile robots are also employed for assembly feeding, carrying all the components needed for assembly (Battaďa et al., 2018). Therefore, some authors studied the introduction of robots for the picking (including assembly feeding) to evaluate the feasibility of human-robot collaboration rather than considering them as a substitute for human workers (Pasparakis et al., 2023).

Assembly Tasks

As well as for the picking, human operators still manually execute assembly tasks. This type of task involves both motor and cognitive demands. Human workers must first acquire knowledge about the assembly procedure through written or visual information. During the execution of assembly steps, operators are subject to physical and cognitive demands: the right components must be detected, picked, and then fastened or attached to create the final product. The process must be of high quality, while ensuring the required product specifications. As for the picking, implemented technologies aims to support human workers during manual assembly tasks. Due to the increasing complexity and diversification of assembly products, manufacturing processes are more dynamic and subject to continuous changes. The high adaptability required to those processes is still typical of human operators, whose capabilities can be enhanced by adopting assistive technologies, thus confirming the central role of workers in current production systems (Calzavara et al., 2020; Daling & Schlittmeier, 2022). Technological tools and devices like collaborative robots, AR, VR, and others can provide cognitive and motor support to operators, ensuring the high flexibility required.

Augmented Reality (AR) and Virtual Reality (VR) technologies can provide cognitive support in assembly tasks. AR technology can guide workers in following the assembly procedure, giving instructions about which, where, and how many components to pick, as well as showing them other information proper of components to be assembled through the use of smart glasses (Danielsson et al., 2020; Lai et al., 2020). On the other hand, VR technology is more employed for the study of ergonomic workplace designs through the creation of virtual environments where workers can interact with virtual elements, testing various layouts and different assembly tasks (Peruzzini et al., 2021; Wu et al., 2018). Moreover, different alternatives of workers-technologies coupling can be studied to define an optimal interaction without the need for physical models, enabling the training of workers by handling virtual objects through controllers (Kaplan et al., 2021).

Different from picking tasks, where AGVs are employed, in assembly tasks robots are mainly implemented to cooperate with workers in the same workspace. In particular, collaborative robots (cobots) actively interact with workers during the assembly task, providing assistance for the pick and place, while reducing the amount of motor actions to be performed (Cohen et al., 2019).

While AR and VR technologies are commonly used in assembly and picking tasks, other technologies are only employed in picking (i.e., the various pick-by-, exoskeletons, mobile robots) or assembly (i.e., collaborative robots). In both cases, multiple advantages and possible disadvantages/drawbacks can be identified for each assistive technology. The following section focuses on analysing the specific features of those technologies.

Benefits and Drawbacks of Human-Centric Assistive Technologies

Guaranteeing an optimal human-technology interaction is essential to get the best out of assistive technologies since their implementation is not exempted from possible drawbacks. The potentials and obstacles related to using assistive technologies are discussed in the following for picking and assembly tasks.

Picking Tasks

Using the various pick-by- techniques during the execution of picking tasks ensures lower picking times/errors and missing picks. In particular, pick-by-voice provides real-time feedback, reducing missing picks and picking times by 20-25% (Dujmešić et al., 2018). Pick-by-light technologies, made of light-emitting diodes guided (LED) placed on item bins/locations, provide light signals to identify target products. This technology is a reliable method to reduce picking errors when the number of picks is high; specifically, it can reduce the missing picks by 50% (Teo et al., 2021). Moreover, the pick-by-light technology provides lower mental fatigue and higher comfort (Gajšek et al., 2020; Stockinger et al., 2020). The employment of RFID (Radio Frequency IDentification) technology allows the operator to know the specific location and quantities of components that need to be retrieved, providing real-time error feedback (Mandar et al., 2020). The pick-by-scan comprises a portable or wearable barcode scanner: by reading barcodes placed on the item locations, it brought to fewer picking errors, while increasing productivity. Despite the multiple advantages related to the pick-by technologies, users perceived physical discomforts like ocular fatigue, headache, and eye strain. They felt their privacy was violated due to the monitoring of picking errors and missing picks (Bright & Ponis, 2021).

The use of AR smart glasses provides cognitive support to operators by lowering mental effort and mental pressure, easing the work and decreasing searching time and picking errors (Bräuer & Mazarakis, 2018; Fang & An, 2020; Glock et al., 2021; Murauer et al., 2018). At the same time, using smart glasses requires constant visual attention from operators, leading to possible drawbacks like headaches (Kreutzfeldt et al., 2019; Neumann et al., 2021). The prolonged use of AR smart glasses and their weight can also bring to physical pain (Bräuer & Mazarakis, 2018; Murauer et al., 2018). Like smart glasses, the use of AR HUD (Heads-Up Display) brings to visualize constantly graphic-based information leading to physical (device weight, eye strain) and psychological stress (Friemert et al., 2019; Kim et al., 2019). The use of VR during the execution of picking tasks, aims to train workers without using physical models. The knowledge acquired and the ergonomic postures assumed in using this system can be transferred to real-world picking systems (Elbert et al., 2018; Friemert et al., 2018). Human-centric drawbacks in the use of VR systems in order-picking tasks are mainly related to physical discomfort: operators are isolated from the real environment where hazards could occur (Lang et al., 2019), and users can be subject to eye fatigue, disorientation, and nausea (Chang et al., 2020; Manghisi et al., 2023).

Focusing on assistive technologies that provide motor support in order-picking systems, exoskeletons are the most promising devices. The use of exoskeletons can increase the endurance and strength of workers while decreasing injuries, muscle activities, physical loads and musculoskeletal disorders (MSDs) (Glock et al., 2021; Huysamen et al., 2018; Motmans et al., 2019). Active trunk exoskeletons lower the motor effort by supporting both picking and lifting phases and show a decrease in biomechanical loads by lowering the perceived trunk effort of 10% and leg (biceps femoris) activity of 5%; nevertheless, due to the higher contact pressure of the device on the thighs and trunk, only half of users recommended the device for an industrial implementation (Huysamen et al., 2018). The wide use of AGVs in order-picking systems shows improved ergonomics by decreasing physical workload and ensuring a higher operator performance (Winkelhaus et al., 2021). The AGVs can support workers during the travelling and transportation phases. By using this type of AGV, the physical effort of the worker is limited to picking items and going from one storage location to the next (Löffler et al., 2021). The coupling AGV + robotic arm has been tested in some articles like the 'Pick and Transport Robot' (PTR) proposed by Vijayakumar and Sobhani (Vijayakumar & Sobhani, 2023), and a similar solution proposed by Fager (Fager et al., 2020). These solutions, validated through real industrial case studies and laboratory experiments, enhanced productivity and well-being of workers. As for the VR systems, no significant human-centric drawbacks related to implementing AGVs to support operators in picking tasks were observed.

Assembly Tasks

AR and VR were introduced in assembly tasks to enhance the training of workers while providing cognitive support to operators. Workers who employed AR and VR systems for training showed better performance (e.g., lower task completion times and number of errors) than those using paper- or video-based training (Daling et al., 2023; Loch et al., 2019; Murcia-López & Steed, 2018; Roldán et al., 2019). Conversely, AR smart glasses showed some physical issues linked to the limited field of view and visual occlusion (Miller et al., 2020) that could hide hazards from the real world, causing safety problems (Vanneste et al., 2020). Other AR limits are related to the perceived usability and mental workload that increased in comparison to computerized procedures (Drouot et al., 2022; Wang et al., 2019). Moreover, users who tried AR smart glasses felt uncomfortable wearing them for several hours daily (Vanneste et al., 2020). Unlike VR systems employed in picking tasks, VR-based training for assembly tasks showed a higher perceived workload. This issue could be possibly related to the need to interact with virtual components rather than with physical items (Schwarz et al., 2020).

Collaborative robots (cobots) employed in assembly systems support operators by actively interacting with and assisting them in executing assembly and pick-and-place tasks. Differently from traditional robots, cobots are more flexible, enabling their applicability in different tasks while improving the productivity of the operator as well as its physical ergonomics when performing manual, and repetitive assembly tasks (Gualtieri et al., 2020a). The flexibility of cobots is also related to the speed of reprogramming or easiness of moving, features that go beyond the characteristics of traditional robots (Keshvarparast et al., 2023). Although the potentials of cobots are mainly related to enhancing productivity and ergonomics, the possibility of negative effects on the performance or well-being of the operator is still present. Since operators must physically collaborate with cobots, these interactions could lead to hazards or interferences between the two agents; therefore, physical safety is a critical aspect, and safety device meeting industrial standards must be implemented to ensure a safety interaction between the two agents (Bi et al., 2021; Gualtieri et al., 2020b). The success or failure of employing this technology depends also on psychological factors related to the human worker. The levels of trust, acceptance, and usability of operators in interacting with cobots are widely analysed in the scientific literature (Eimontaite et al., 2019; Okimoto & Niitsuma, 2020). Moreover, possible psychological drawbacks like the stress levels and anxiety are also investigated (Eimontaite et al., 2019).

This section analysed the strengths and weaknesses of human-centric assistive technologies by focusing on picking and assembly activities that are still manually executed by operators in the current industrial scenario. In the following section, a classification of technologies discussed is proposed.

Classification of Human-Centric Assistive Technologies

To respond to the research questions presented in the introduction, three classification criteria are identified. The first regards the main purpose of using technologies, i.e., to guarantee the performance or the well-being of operators. To ensure the above-mentioned main goals, cognitive or motor support (second criteria) must be provided to operators. The third criterion focuses on the human-centric perspective, highlighting the possible human-related drawbacks (psychological or physical) in using assistive technologies. In this article, the performance of the operator comprises its productivity and efficiency in executing assigned tasks.

Technologies employed to support operators in picking tasks are mainly implemented to increase the performance and well-being (Glock et al., 2021). The possible occurrence of picking-related errors can increase if elements that comprise the order picking systems are not appropriately designed: pick information format, routing strategy, facility design, storage assignment policies, and poor shelf layout are elements that fall into this instance (Kajiwara et al., 2019). Although these elements are not human factors, they affect performance and well-being.

In this context, the primary purpose of using the pick-by-, AR and VR assistive technologies is to increase the performance and efficiency of picking (lessening picking errors/times) by providing cognitive support. The possible drawbacks of using the pick-by- devices are mainly related to physical discomfort like ocular fatigue, headache and eye strain (Bright & Ponis, 2021). AR devices used for picking tasks lead to physical (device weight, eye strain) and psychological discomfort (Friemert et al., 2019; Kim et al., 2019), while VR systems can cause physical discomfort (Chang et al., 2020; Lang et al., 2019; Manghisi et al., 2023).

Exoskeletons aid workers in picking tasks where heavy items must be lifted, and repetitive movements like bending, twisting, stretching, raising or lowering must be executed.

The use of exoskeletons can increase the endurance and strength of workers while decreasing injuries, muscle activities, physical loads and the likelihood of musculoskeletal disorders (MSDs) (Glock et al., 2021; Huysamen et al., 2018; Motmans et al., 2019) making them particularly useful to ensure the well-being by acting as motor support. Nevertheless, only half of the users recommended the device for industrial implementation due to the physical discomfort caused by the higher contact pressure of the device on the thighs and trunk (Huysamen et al., 2018).

The use of mobile robots like AGVs supports workers during the travelling and transportation phases: movements performed by the worker are limited to picking items and going from one storage location to the next one, providing physical comfort and contributing to higher productivity (Löffler et al., 2021; Winkelhaus et al., 2021). Although picks are manually performed, inactivity periods of the operator are reduced thanks to more pickings and fewer travels to the depot (Winkelhaus et al., 2022). Therefore, implementing AGVs aims to increase performance and well-being by providing motor support. No significant human-centric drawbacks were observed regarding implementing AGVs to support operators in picking tasks.

Table 1 depicts the classification of human-centric assistive technologies related to picking tasks. From Table 1 two main categories can be identified. The first category comprises the various pick-by technologies, AR and VR systems. These technologies are employed to ensure performance by providing cognitive support. Exoskeletons and AGVs belong to the second category, where both well-being and performance can be ensured by providing motor support. For both categories, possible human-related drawbacks are mostly physical, while only for AGVs, no human-centric side effects have been identified.

By focusing on assembly tasks, some parallelisms could be made with picking tasks by considering AR and VR assistive technologies. Both technologies aim to increase the performance by providing cognitive support (Loch et al., 2019; Murcia-López & Steed, 2018; Roldán et al., 2019). In particular, AR devices can guide workers in following the assembly procedure, giving instructions about which, where and how many components to pick (Danielsson et al., 2020). VR technology employed in assembly systems not only enhances training of workers, with positive effects on performance (Kaplan et al., 2021), but is also used to design ergonomic workplaces for operators (Peruzzini et al., 2021; Wu et al., 2018); differently from picking tasks, the VR assistive technology is aimed also at ensuring high performance and well-being. AR systems could bring to physical drawbacks related to the limited field of view and visual occlusion (Miller et al., 2020) that could lead to safety and

Table 1
Classification of human-centric assistive technologies related to picking tasks

Assistive Technologies for Picking	Main Purpose		Support		Possible Drawbacks	
	Operator Well-Being	Operator Performance	Cognitive	Motor	Psychological	Physical
Pick-by- (Scan/Light/Voice)		•	•			•
Augmented Reality (AR)		•	•		•	•
Virtual Reality (VR)		•	•			•
Exoskeleton	•	•		•		•
AGV, Picking Robot	•	•		•		•

*Categorization of human-centric assistive technologies with the full list of articles analysed are provided in Appendix A hazard problems (Vanneste et al., 2020). VR systems employed to train operators for assembly tasks showed a higher perceived workload, leading to possible psychological drawbacks (Schwarz et al., 2020).

By focusing on motor support, cobots employed in assembly tasks actively interact with operators, assisting them in executing assembly and pick and place activities. In particular, their use can improve the performance and well-being regarding physical ergonomics (Peron et al., 2022). Some authors studied the possible reduction of awkward postures, excessive effort, and repetitive movements by implementing cobots (Realyvásquez-Vargas et al., 2019), while others focused on employing cobots to ensure that the energy expenditure required to execute the task does not exceed the physical capabilities of the operator (Dalle Mura & Dini, 2019). Nevertheless, the strengths of this assistive technology can also be its weaknesses. The physical interaction between workers and cobots could lead to hazards or interferences. The safety of operators is a critical aspect that cannot be neglected (Bi et al., 2021; Costanzo et al., 2022; Gualtieriet al., 2020b; Liao et al., 2023). For this reason, the International Organization for Standardization (ISO) defined specific guidelines for safer interactions (ISO 10218-1 and ISO 10218-2). At the same time, possible drawbacks related to the perception field (trust, acceptance and usability) (Eimontaite et al., 2019; Okimoto & Niitsuma, 2020), and psychological field (stress levels and anxiety) (Eimontaite et al., 2019) must be taken into consideration when implementing this type of assistive technology.

Table 2 depicts the classification of human-centric assistive technologies related to assembly tasks. In this case, no categories can be identified due to the limited typologies of human-centric assistive technologies considered for picking tasks. Therefore, the criteria identified (main purpose, support, possible drawbacks) did not define a clear separation between those technologies. Nevertheless, Table 2 can still be adopted to understand the main features of these technologies under a human-centric perspective, based on the classification criteria identified.

Discussion

From the above human-centric classification of assistive technologies employed in manual picking and assembly tasks, it can be noticed that most technologies provide cognitive support to enhance the performance, with possible physical drawbacks. Therefore, particular attention should be paid to the design phase of those technologies to decrease physical discomfort and side effects as much as possible. Conversely, only assistive technologies that provide motor support (Exoskeletons, AGVs, Cobots) are employed to enhance both the performance and well-being. Specifically, using cobots in assembly tasks is a very particular case since, despite their primary purposes, possible drawbacks are both of physical and psychological type.

When assessing the possible use of assistive technologies in manual picking and assembly tasks, worker diversity factors like age, gender, physical abilities, skills, and experience cannot be neglected since the possible benefits of those technologies strictly rely on the acceptability, specific needs, and preferences of operators (Katiraee et al., 2021; Mura & Dini, 2023; Neumann et al., 2021).

The level of experience indeed affects the success or failure of assistive technologies. The lack of experience, familiarity with technology, and the fear of not being skilled or upskilled enough to handle those technologies emerge when implementing mobile robots.

Physical and physiological abilities of operators can be monitored by implementing specific systems. These technologies do not properly belong to "assistive" technologies since their primary purpose is to record data about body postures or to monitor cardiovascular ac-

Table 2
Classification of human-centric assistive technologies related to assembly tasks

Assistive Technologies for Assembly	Main Purpose		Support		Possible Drawbacks	
	Operator Well-Being	Operator Performance	Cognitive	Motor	Psychological	Physical
Augmented Reality (AR)		•	•			•
Virtual Reality (VR)	•	•	•		•	
Cobot	•	•		•	•	•

*Categorization of human-centric assistive technologies with the full list of articles analysed are provided in Appendix A tivity and blood pressure (Calzavara et al., 2018; Cimini et al., 2020). IoT sensors and wearable devices monitor physiological parameters such as oxygen consumption, heart rate variability, and blood pressure. Body postures and movements performed, instead, are monitored through inertial sensors mounted on body suits or through the coupling of cameras and body suits with reflective markers attached to them. The latter is the mocap (motion capture) technology that employs specific cameras to digitalize movements performed and postures assumed (Sheng et al., 2018). Mocap systems can be easily used to evaluate traditional ergonomic indices like OCRA, NIOSH, RULA, REBA whose results can be employed to adapt workplaces and minimize the risk of musculoskeletal disorders. Therefore, monitored data could be employed to evaluate the physical and physiological impact of technologies and undertake specific actions at various levels (e.g., organizational, operational) to avoid possible injuries or excessive fatigue (Molino et al., 2020).

Individuals with particular needs, like people with cognitive impairments, must be included among workers who could benefit from implementing human-centric assistive technologies. Cognitive assistance systems are studied to evaluate their feasibility in increasing the skills and abilities of impaired workers in assembly tasks; due to particular needs of individuals, the way of organizing and showing procedures and instructions should be personalized to ensure the social inclusivity (Peltokorpi et al., 2023).

People generally respond differently when using technology. Their stress, acceptability, trust, and usability responses affect the potential benefits of those technologies. Assistive technologies must be deeply analysed and studied under a human-centric perspective, focusing particularly on the social inclusivity of aged and impaired workers.

Conclusion

Despite the progress of technology, current production and logistics systems still rely on workers: the human workforce has a pivotal role that will remain so in the following years. Human operators play a crucial role in tasks that require labour- and manual-intensive activities, such as manual picking and assembly tasks. Human-centric technologies must assist, support, and collaborate with operators rather than merely substitute them. The impact of those technologies on the performance and well-being must be adequately explored since, despite their potentials, they are not exempted from possible human-centric drawbacks, and their success strictly relies on users. Following the literature review on assistive technologies employed in assembly and picking tasks, the proposed work classifies these technologies based on three criteria: main purpose, type of support, and possible drawbacks. The novelty of this article relies on considering both the human-related outcomes of implementing these technologies, obtained by providing cognitive or motor support to operators, and human-related drawbacks. Practitioners could use the classification provided to choose among different assistive technologies under a human-centric perspective.

The proposed research can be deepened by including other human-related features like physiological, motivational, perceptual, psychosocial, and emotional factors, as well as extending the study also to non-industrial working scenarios (e.g., construction, healthcare…) . These additional features can improve the applicability of the approach, leading to further observations and reasoning on human-centric assistive technologies.

A research gap identified in this context is the lack of comprehensive studies evaluating the long-term effects of assistive technologies on operator performance and well-being. While short-term benefits have been documented, there is a need for longitudinal studies to assess the sustainability of these technologies and their impact on job satisfaction, job retention, and overall quality of work life.

Additionally, there is a need for more research on the development of inclusive systems that consider the diverse needs of the human workforce. This includes addressing the requirements of cognitive and motor-impaired workers and ensuring that assistive technologies are accessible and effective for all users.

Moreover, future research should focus on exploring innovative approaches to human-technology interaction, such as the integration of artificial intelligence and machine learning algorithms to optimize the performance of assistive technologies dynamically. The prosperity of these technologies could only be achieved if workforce diversities and social inequities are considered during the design and implementation phases.

Therefore, there is still much to be explored when considering assistive technologies and their symbiosis with the human-centric vision. By addressing the identified research gaps and shortcomings, future studies can contribute to the development of more effective and inclusive systems that enhance both operator performance and well-being in various working scenarios.

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Appendix A.

Table 3
Articles included in the literature review

Reference	Assistive Technologies	Task	Main Purpose		Support		Possible Drawbacks	
			Operator Well-Being	Operator Performance	Cognitive	Motor	Psychological	Physical
Jaghbeer et al., 2020	AGV, Picking Robot	Picking		✓		✓		
Custodio & Machado, 2020	AGV, Picking Robot	Picking	✓	✓		✓		
Glock et al., 2021	Pick-by-, AR	Picking		✓	✓		✓	✓
Dujmešić et al., 2018	Pick-by-	Picking		✓	✓			✓
Stockinger et al., 2020	Pick-by-	Picking		✓	✓			✓
Gajšek et al., 2020	Pick-by-	Picking		✓	✓			✓
Fang & An, 2020	Pick-by-, AR	Picking		✓	✓		✓	✓
Kim et al., 2019	AR	Picking		✓	✓		✓	✓
Bräuer & Mazarakis, 2018	AR	Picking	✓	✓	✓		✓	✓
Friemert et al., 2019	AR	Picking		✓	✓		✓	✓
Elbert et al., 2018	VR	Picking	✓	✓	✓			✓
Zhu et al., 2021	Exoskeleton	Picking	✓			✓		✓
Huysamen et al., 2018	Exoskeleton	Picking	✓			✓		✓
Motmans et al., 2019	Exoskeleton	Picking	✓			✓		✓
Azadeh et al., 2019	AGV, Picking Robot	Picking	✓	✓		✓		
Fager et al., 2020	AGV, Picking Robot	Picking	✓	✓		✓		
Daling & Schlittmeier, 2022	AR, VR	Assembly	✓	✓	✓			

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Reference	Assistive Technologies	Task	Main Purpose		Support		Possible Drawbacks	
			Operator Well-Being	Operator Performance	Cognitive	Motor	Psychological	Physical
Danielsson et al., 2020	AR	Assembly		✓	✓		✓	
Lai et al., 2020	AR	Assembly		✓	✓			
Peruzzini et al., 2021	VR	Assembly	✓	✓	✓		✓	
Kaplan et al., 2021	AR, VR	Assembly	✓	✓	✓		✓	
Teo et al., 2021	Pick-by-	Picking	✓	✓	✓			
Mandar et al., 2020	Pick-by-	Picking		✓	✓			✓
Bright & Ponis, 2021	AR	Picking		✓	✓		✓	
Lang et al., 2019	AR	Assembly/ Picking		✓	✓			✓
Chang et al., 2020	VR	Assembly/ Picking	✓		✓			✓
Löffler et al., 2021	AGV, Picking Robot	Picking		✓		✓		
Vijayakumar & Sobhani, 2023	AGV, Picking Robot	Picking	✓	✓		✓		
Loch et al., 2019	VR	Assembly		✓	✓		✓	
Roldán et al., 2019	Cobot, VR	Assembly	✓	✓	✓	✓	✓	✓
Murcia-López & Steed, 2018	VR	Assembly		✓	✓		✓	
Daling et al., 2023	AR, VR	Assembly		✓	✓		✓	
Miller et al., 2020	AR	Assembly	✓	✓	✓			✓
Vanneste et al., 2020	AR	Assembly	✓	✓	✓			✓
Wang et al., 2019	AR	Assembly		✓	✓		✓	
Drouot et al., 2022	AR	Assembly		✓	✓		✓	
Schwarz et al., 2020	VR	Assembly	✓	✓	✓		✓	
Gualtieri et al., 2020a	Cobot	Assembly	✓	✓		✓		✓
Keshvarparast et al., 2023	Cobot	Assembly	✓	✓		✓		✓

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Reference	Assistive Technologies	Task	Main Purpose		Support		Possible Drawbacks	
			Operator Well-Being	Operator Performance	Cognitive	Motor	Psychological	Physical
Gualtieri et al., 2020b	Cobot	Assembly	✓			✓		✓
Bi et al., 2021	Cobot	Assembly	✓			✓		✓
Eimontaite et al., 2019	Cobot	Assembly		✓		✓	✓	
Okimoto & Niitsuma, 2020	Cobot	Assembly	✓	✓		✓	✓	✓
Winkelhaus et al., 2022	AGV, Picking Robot	Picking	✓	✓		✓		✓
Peron et al., 2022	Cobot	Assembly	✓	✓		✓		✓
Realyvásquez-Vargas et al., 2019	Cobot	Assembly	✓	✓		✓		
Costanzo et al., 2022	Cobot	Assembly	✓	✓		✓		✓
Liao et al., 2023	Cobot	Assembly	✓	✓		✓		✓