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Exploring the Effects of Industry 4.0/5.0 on Human Factors: A Preliminary Systematic Literature Review

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Abstract: Industry 5.0, built on the foundation of Industry 4.0, aims to integrate human capabilities and principles for a sustainable and human-centric industrial paradigm. This article proposes a systematic literature review to explore the empirical effects of Industry 4.0/5.0 (I4.0/5.0) technologies on human factors, emphasizing the often overlooked physical, psychological, and cognitive dimensions. The methodology, adhering to PRISMA guidelines, involved a Scopus search spanning from 2005-2023, ultimately resulting in a selection of 15 articles. The preliminary results depict the studied I4.0/5.0 technologies and their impact on workers' physical, psychological, and cognitive aspects. Some (I4.0/5.0) technologies received significant attention, such as human-robot communication and human-robot interaction, while others remain understudied. The limited number of papers makes it difficult to compare and generalize the empirical results reported. In this regard, we propose avenues for refining this systematic literature review in future research endeavors.

Keywords: Industry 5.0, Human factors, Cognitive factors, Psychological factors, Physical factors

1. INTRODUCTION

Industry 5.0 (European Commission *et al.*, 2021) is deeply rooted in the foundation of Industry 4.0, emphasizing the fusion of human capabilities and principles to foster a sustainable, resilient, and human-centered industrial paradigm. It focuses on aligning technology with human behaviors and needs while also integrating ethical and societal aspects into the creation and deployment of technology. This new industrial concept has led several researchers to study the impact of Industry 4.0/5.0 technologies on process and operational performance. However, the impact of these technologies on human factors is understudied, with many researchers focusing solely on the technical dimensions of I4.0/I5.0 technology (Grosse et al., 2023; Neumann et al., 2021; Reiman et al., 2021)

Human factors encompass the physical, psychological, and cognitive conditions (Longo, Nicoletti and Padovano, 2019; de Winter and Hancock, 2021). According to Longo et al.'s taxonomy, the physical state refers to an individual's physical well-being, motor health, and ability to perceive stimuli from the external environment. It emphasizes the importance of physical abilities in influencing human performance, particularly in manual occupations where mastery of physical skills is critical. The psychological state includes conscious and unconscious inherent personality traits associated with emotions and feelings that influence human cognition and behavior. The cognitive state represents the cognitive abilities that enable the worker to act and experience the workplace, including acquiring knowledge and understanding through thoughts, experiences, and senses. Attention and mental workload are central concerns in a human's cognitive state as industrial workers must encounter and process a substantial and increasing amount of information (Longo, Nicoletti and Padovano, 2019). These factors significantly influence company performance due to their direct impact on worker effectiveness and efficiency in the workplace (Reiman et al., 2021). Additionally, there is evidence that human factors play a mediating role in the relationship between I4.0/I5.0 technology implementation and operational performance (Virmani and Ravindra Salve, 2023).

The primary goal of this systematic review is to enhance our understanding of the interplay between Industry 4.0/5.0 technologies and human factors. By doing so, we aim to gain a deeper insight into how these elements influence one another, thereby contributing to a more comprehensive view of their interaction within the industrial landscape. To achieve this goal, we have systematically reviewed the literature to uncover scientific studies reporting empirical findings on the impact of I4.0/5.0 practices or technologies on human factors. The remainder of the article is organized as follows: Section 2 presents the methodology used, i.e., the systematic review protocol. The preliminary results and discussions are presented in Section 3. In section 4, the conclusions and future work are discussed.

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2. METHODOLOGY

A systematic literature review protocol was developed in accordance with PRISMA-P guidelines to identify and evaluate scientific studies reporting empirical results measuring the impact of I4.0/5.0 technologies on human factors (Shamseer et al., 2015). The flowchart of Figure 1 depicts the information flow through the different phases of the review and shows the number of records identified, included, and excluded, and the reasons for exclusions. The query was conducted within the Scopus database and was first applied to titles, abstracts, and keywords of peer-reviewed English scientific articles from 2005 to 2023. The query included a list of keywords related to Longo et al.'s human factors taxonomy: the "physical", "psychological" and "cognitive" spheres, as well as their various attributes (attention, communication, knowledge, memory, reasoning, health, motion, perception, motions, relationships, and self-management). The query includes keywords related to the industrial context: Industry 4.0 and Industry 5.0. To identify empirical data from the targeted articles, we explicitly selected articles that used quantitative methodology (survey, experimentation, laboratory study, simulation, Delphi) or qualitative methods with quantitative data (case study, use case, prototyping). To study the impact of I4.0/5.0 technologies on humans, the query focuses on the following keywords: worker, human, operator, supervisor, manager, and employee. To ensure replication, the query is posted on this site[1].

A first screening of the abstracts (547) was performed to identify irrelevant concepts to the research objectives. For example, all papers dealing with *cognitive, physical, and psychological* elements and *their facets* that did not refer to human factors (e.g., cognitive IoT, physical engineering, knowledge graph, semantic reasoning, secure communication, health management, simulation modeling, etc.) were excluded. This resulted in a total of 307 exclusions.

A second screening phase was then conducted based on the remaining 240 papers. Two reviewers independently screened the abstracts to verify that the article reported a quantitative impact of I4.0/5.0 technologies on human factors. In case of disagreement between the two reviewers, a third reviewer made the final decision. The screening phase returned 36 articles. The two reviewers then independently screened full articles to verify that they addressed human factors at the expected level of detail, that the methodology was clearly stated, and that the reported results were consistent with the stated aim of this systematic literature review. Fifteen articles were shortlisted and evaluated based on the reported results (antecedent variables, outcomes, nature of the reported effects, and statistical validity of each study). Preliminary results are presented in the following section.

3. PRELIMINARY RESULTS

3.1 Results description

All findings are outlined in the table provided in Appendix A. For the 15 selected articles, we have delineated the I4.0/5.0 technologies that constituted the focus of each study. Of these, seven articles focused on Human-Robot Interaction (HRI) and/or Human-Robot Communication (HRC), while only one focused on Virtual Reality (VR), one on Artificial Intelligence (AI), one on Augmented Reality (AR), one on Decision Aid Systems, and one on Digital Instructions. In addition, four articles analyzed the intersection between HRI/HRC and AI, AR, VR, and decision support systems.

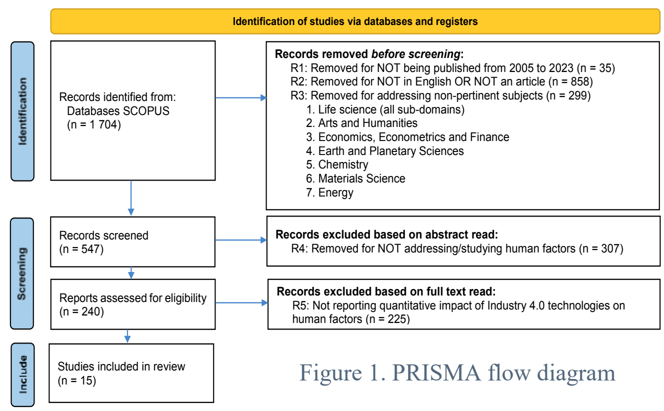

Figure 1. PRISMA flow diagram

For each of the 15 articles, the research methodology and data collection processes were thoroughly extracted. Each of the selected articles included a field or laboratory experiment. Data collection methods consisted of various approaches, such as questionnaires, physiological data, or a combination. Some studies employed experience video analysis, facial expression analysis, and unstructured interviews. The most employed questionnaires in the reviewed articles are the NASA Task Load Index (TLX), System Usability Score (SUS), Robot Scale (NARS), Robot Anxiety Scale (RAS), and Godspeed Questionnaire. Physiological data primarily covers Electrodermal Activity (EDA), Electrocardiogram (ECG), and heart rate variability (HRV).

Lastly, human factors variables were carefully identified for each article, and the impact of using I4.0/5.0 technologies on these variables was examined (see Appendix A).

The review of the selected articles has provided empirical evidence regarding the impact of adopting I4.0/5.0 technologies on human factors. In Appendix B, figures succinctly present a synthesis of positive and negative effects alongside those not statistically substantiated. It is important to highlight that the current study did not reveal any overlap between studied effects. Furthermore, the studies are often conducted in a manner that makes it challenging to reproduce the experiments due to ambiguous protocols or difficult to generalize due to specific protocols or participant characteristics.

[1]https://sites.google.com/view/scopusqueryincom24?usp=sharing

Mental workload, usability, acceptance, and effort are the most studied effects that displayed an improvement while using I4.0/5.0 technology. Trust and Anxiety are the most studied variables that deteriorated while using the technology. As this systematic literature review aims to establish a benchmark for the human factors studied to enhance the design of 5.0 systems, the focus has been on identifying the specific human factors under investigation. Figure 2 illustrates the mapping of various human factors identified based on Longo's taxonomy. We found that the cognitive sphere is understudied compared to the others.

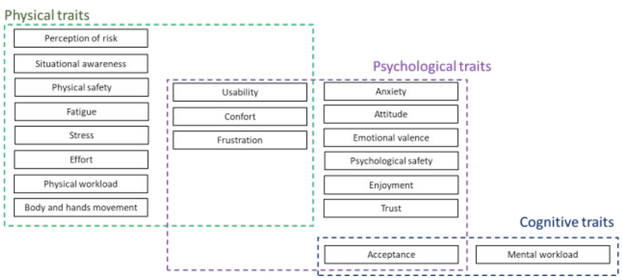

Figure 2. Human effect categorization based on Longo et al. taxonomy

3.2 Results Discussion

The number of articles addressing quantitative methods for assessing the impact of Industry 4.0 technologies on human factors is low. Additionally, very few hypotheses have been clearly articulated, raising doubts about the quality of the selected works and the rigor of the experimental approaches. As a result, the 15 selected articles have investigated distinct hypotheses and focused on different cognitive, psychological, and physical factors, rendering direct comparisons unfeasible. In conclusion, this systematic literature review cannot currently yield conclusive results.

One initial limitation stems from the query used, which does not explicitly integrate 4.0 technologies and practices in a nominative manner. Additionally, the query relies solely on the Scopus database, unlike other engineering-oriented ones such as Engineering Village or IEEE Xplore. Another limitation lies in the selection of taxonomy. The human factors taxonomy proposed by Longo et al. is tailored for industrial accidents, emphasizing the relationship between human factors and workers' response performance during emergencies. It may be less effective for broader manufacturing contexts (e.g., routine operations), where ongoing operations demand steady performance and attention to long-term worker well-being. This specificity potentially restricts the taxonomy's broader application in scenarios beyond emergencies, highlighting a need for a more versatile framework to address the diverse aspects of manufacturing work. This need becomes more apparent when examining the psychological dimension of the taxonomy, in which psychological factors are treated as static traits that may impact emergency response performance. The static view in Longo et al.'s taxonomy overlooks how these psychological aspects can change over time, influenced by technology design, workplace conditions, and management practices, among others. For example, worker motivation is seen as a worker's inherent ability to motivate themselves, ignoring the dynamic nature of motivation that can fluctuate due to various external factors (Passalacqua et al., 2020). As such, a human factors taxonomy for general manufacturing should include psychological traits (e.g., personality) and psychological states (e.g., stress levels, motivation), recognizing that the latter are susceptible to change over time (Neumann et al., 2021; Passalacqua, et al., 2024). Psychological traits and states can be grouped under the concept of psychosocial factors, emphasizing the interaction between a worker's social environment (e.g., technology design, organizational culture) and their psychological states (Neumann et al., 2021; Passalacqua, Cabour, et al., 2024). This perspective acknowledges the fluidity of psychological states influenced by external conditions and the importance of designing work environments that support positive psychosocial dynamics (Grosse et al., 2023).

4. CONCLUSIONS

This article is one of the first to provide a comprehensive description of the results of quantitative studies on the impact of technology on human factors. Other literature reviews exist on similar topics. For example, (Valette, Bril El-Haouzi and Demesure, 2023) focused on the place of humans in CPS or IOT industrial systems and (Sotirios Panagou and Fruggiero, 2024) depicted the relationship between human-robot interactions through design features and its impact on operators. The current review aimed to cover all I4.0/5.0 technologies and exhaustively describe how all three human factors' spheres are affected. The presented results show that there are few quantitative studies. At this research stage, limitations have been identified in selecting specific query terms and the databases searched. One possible course of action would be to expand the query to include a list of I4.0/5.0 technologies to be studied and to explore other databases, such as IEEE Xplore and Engineering Village, to obtain additional articles to strengthen the presented results. The second course of action will be to review the human taxonomy used to grasp better all the facets of human factors presented in current articles. Ultimately, our goal is to refine the systematic review protocol and undertake the review process again to produce more robust and comprehensive results.

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Appendix A. Returned articles analysis

Article	Research design	Data collection method	Participants	Research object and context	Outcome variables
(Islam and Lughmani, 2023)	Case study	Survey (5-point Likert scale)	18 participants	Human-Robot Collaboration with Artificial Intelligence (HRC+AI) based on anxiety evaluation factor (decision making for task planning)	Perceived physical and psychological safety Comfort Legibility (situational awareness between robot and operator)
(Marino *et al.*, 2021)	Case study	Questionnaires Nasa-RTLX (Raw Task Load Index) and System Usability Score (SUS)	16 participants	Augmented Reality (AR) for error detection in industrial inspection processes	Usability Perceived mental workload
(Gervasi *et al.*, 2024)	Case study	Physiological information: EDA and heart rate data + Unstructured feedback	12 participants	Human-Robot Collaboration (HRC) in decision making process with assembly tasks	Stress Cognitive load Fatigue
(Moya *et al.*, 2023)	Case study	Questionnaires (NASA TLX and SUS)	6 participants	Augmented Reality-Human-Robot Collaboration (AR-HRC): inspection and verification for assembly tasks	Mental and Physical workload Acceptance / Usability / Safety
(Bortolini *et al.*, 2020)	Industrial case study	Spaghetti diagram	10 participants	Decision Aid system for task assembly	Body movements Right hand movements
(Dammacco *et al.*, 2022)	Case study	Questionnaire	20 participants	Virtual Reality (VR) for engineering/design phase of complex manufacturing system	Workload / Usability User feedback
(Pacaux-Lemoine *et al.*, 2017)	Case study	Questionnaires NASA-TLX	1 participant	Human-robot interaction (HRI)-Decision Aid system: Human-centered design approach for decision assistance system to manage HRI	Global workload (mental/physical/temporal/effort/ frustration/performance)
(Gualtieri *et al.*, 2022)	Laboratory case study	Survey	14 participants	Human-robot interaction and collaboration (HRI-HRC) in assembly tasks with a set of specific design guidelines integrating cognitive requirements	Participants' acceptance Perceived enjoyment and cognitive workload / Usability Reported stress levels / Frustration
(Caiazzo *et al.*, 2023)	Case study	NASA TLX questionnaires and real-time objective measurements EEG	9 university students	Human-robot interaction and collaboration (HRI-HRC) in assembly tasks	Physical and mental workload (as indicators of stress/engagement or relaxation during the tests) Temporal and mental demand / Effort / Frustration
(Kuts *et al.*, 2022)	Use case	NASA-TLX+ The Godspeed questionnaire	40 participants	Virtual Reality with Human-Robot Collaboration (VR+HRC) during Industrial Robots Manipulation	Stress level Anxiety Mental and physical demand Perception of effort
(Simon *et al.*, 2023)	Case study	Questionnaire with Likert scale and different range	53 engineering students	Human-Robot Collaboration (HRC): Human decision making following the request of a Cobot	Human Compliance with the robot Trust in the robot Perception of risk Subjective mental workload
(Eimontaite *et al.*, 2019)	Case study	Robots Scale (NARS) + The Robot Anxiety Scale (RAS +Facial expression analysis	90 participants (3 groups of 30)	Human-Robot Collaboration (HRC) in manufacturing task	Anxiety Negative attitude Emotional valence
(Peltokorpi *et al.*, 2023)	Case study	Video analysis and ongoing remarks	24 subjects with disabilities	Digital instruction for assembly tasks	Cognitive load Learning
(Saßmannshausen *et al.*, 2021)	Case study	Online survey	130 respondents	Artificial Intelligence (AI) characteristics (perceived ability and perceived comprehensibility)	Trust
(Gervasi *et al.*, 2022)	Laboratory case study	Questionnaires + Physiological signals	42 participants	Human-Robot Collaboration (HRC) with assembly task	Interaction quality (trust and help) Interaction quality (safety) Affective state (pressure and anxiety)

Appendix B. I4.0 technologies impacts on human factor