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Review

Health-Related Parameters for Evaluation Methodologies of Human Operators in Industry: A Systematic Literature Review

Nicolas Murcia [1,2], Olivier Cardin [2,*], Abdelmoula Mohafid [2] and Marie-Pascale Senkel [3]

1 Airbus Atlantic, Airbus Group, 44550 Montoir-de-Bretagne, France; nicolas.murcia@ls2n.fr
2 LS2N UMR CNRS 6004–IUT de Nantes, Nantes University, 44470 Carquefou, France; abdelmoula.mohafid@ls2n.fr
3 LEMNA EA 4272–IUT de Saint-Nazaire, Nantes University, 44600 Saint-Nazaire, France; marie-pascale.senkel@univ-nantes.fr
* Correspondence: olivier.cardin@ls2n.fr

Abstract: Human factors have always been an important part of research in industry, but more recently the idea of sustainable development has attracted considerable interest for manufacturing companies and management practitioners. Incorporating human factors into a decision system is a difficult challenge for manufacturing companies because the data related to human factors are difficult to sense and integrate into the decision-making processes. Our objectives with this review are to propose an overview of the different methods to measure human factors, of the solutions to reduce the occupational strain for workers and of the technical solutions to integrate these measures and solutions into a complex industrial decision system. The Scopus database was systematically searched for works from 2014 to 2021 that describe some aspects of human factors in industry. We categorized these works into three different classes, representing the specificity of the studied human factor. This review aims to show the main differences between the approaches of short-term fatigue, long-term physical strain and psychosocial risks. Long-term physical strain is the subject that concentrates the most research efforts, mainly with physical and simulation techniques to highlight physical constraints at work. Short-term fatigue and psychosocial constraints have become a growing concern in industry due to new technologies that increase the requirements of cognitive activities of workers. Human factors are taking an important place in the sustainable development of industry, in order to ameliorate working conditions. However, vigilance is required because health-related data creation and exploitation are sensible for the integrity and privacy of workers.

Keywords: ergonomics; industry; human factor; fatigue; long-term physical strain; psychosocial risk; occupational disease

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Citation: Murcia, N.; Cardin, O.; Mohafid, A.; Senkel, M.-P. Health-Related Parameters for Evaluation Methodologies of Human Operators in Industry: A Systematic Literature Review. *Sustainability* **2021**, *13*, 13387. https://doi.org/10.3390/su132313387

Academic Editor: Lucian-Ionel Cioca

Received: 5 November 2021
Accepted: 29 November 2021
Published: 3 December 2021

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1. Introduction

Sustainability issues, and, especially, human factors, are essential components of Industry 4.0 and, therefore, by extension, of Industry [1]. New technologies have brought a lot of opportunities in industry through automation; however, human skills, especially cognitive and decision-making skills, are key to the success of complex operations because of their cognitive and motor skills that machines cannot copy. These new technologies increase the complexity of work tasks, which make the skills of workers more valuable for the industry and more important for its performance. From a performance perspective, it is crucial to take into account the human factors in the organization and improve the working conditions to gain productivity [2,3]. This integration of human factors in the organization of industrial companies requires an important development of production processes. Recent advances in industry have allowed for improvement in the speed of production, not only with the help of the mechanization and automation of production systems, but also with developments in the organization of work, especially with Lean management. These new organizational methods have made production more flexible and customizable. However, these technological advances have also led to an intensification of workload for the operator [4]. This intensification is characterized by an increase in the production objectives as well as an increasing cognitive load for the operator, which is caused by recent developments in technologies and human-machine interfaces; with the implementation of Industry 4.0-related technologies, leading to a more sophisticated manufacturing organization that relies on intelligent physical systems and production processes [5], workers have to develop their skills and competences in order to collaborate with the machine. The recent evolutions in industry have developed and complexified these human-machine interactions, which result in a significative increase in cognitive workload for the operator, also called cognitive strain. For example, the development of Cyber Physical Production Systems (CPPS) induces a modification of the cognitive and physical workloads for the operators implied in the production process [6] as shown in Figure 1. These modifications aim to reduce the physical workload (defined as the sum of every physical action the worker has to perform) but generally result in increasing the cognitive workload. This leads to a necessary re-evaluation of the balance between physical workload and cognitive workload [7].

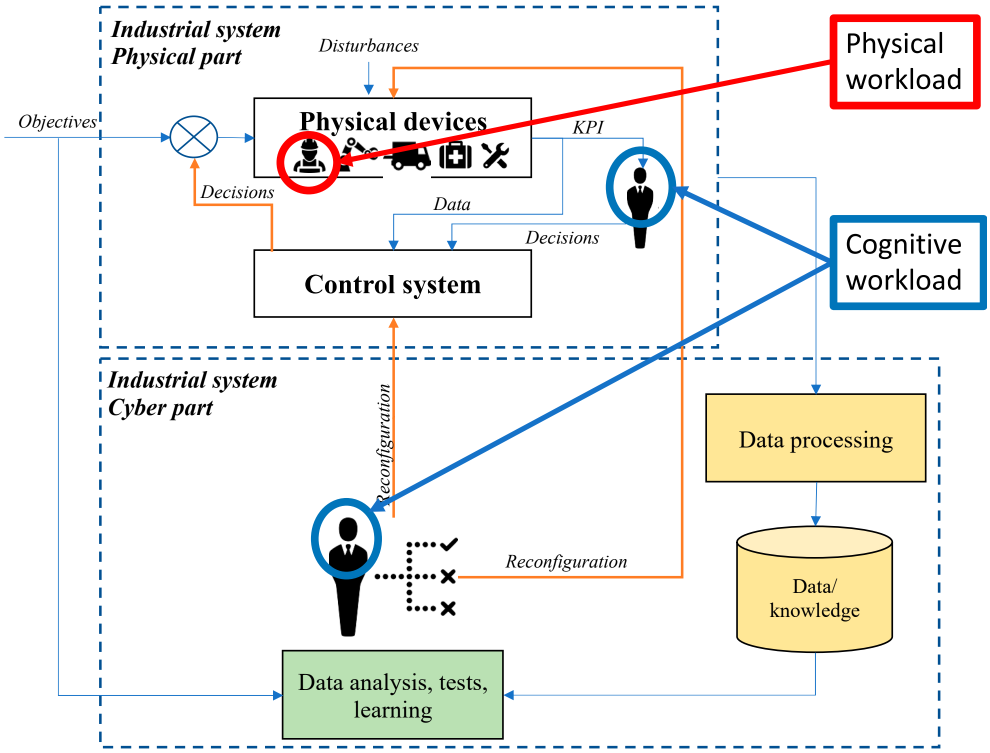

Figure 1. Physical and cognitive workload in a CPPS (adapted from [6]).

Regarding the physical aspect, Musculo-Skeletal Disorders (MSDs) are lesions or alterations of muscles, nerves, tendons and joints. MSDs have always been an important problem in industry because of the pain and restrictions they cause for humans. Numerous studies in the literature have demonstrated that they are caused by biomechanical factors, especially with prolonged exposure to awkward working postures, exerted forces, material handling and repetitive actions [8]. There are many factors increasing the risk of MSDs, but biomechanical factors have been highlighted as the most important risk factors [9,10]. Work rate, operator schedule and recuperation time are defining the exposure to biomechanical factor and, so, are also directly linked with the risks of MSDs. The Workplace Environment is also non-negligible in the development of MSDs. Extreme temperature, important vibrations [11] and loud noise are amplifying the biomechanical constraints.

Cognitive strain is directly linked to the complexity of human mental process to realize a task. The changes in Industry 4.0 induce more advanced human-machine interactions, which can be difficult to process, thus increasing the difficulty and skills required to perform working tasks. In this context, it can be significantly more difficult for the operator to realize their tasks because of the increase in cognitive workload. It is an aggravating factor in the development of MSDs because of the stress it induces for the operator. Ergonomics can be generically defined in two classes: physical ergonomics to reduce physical workload and cognitive ergonomics to reduce cognitive workload. A recent literature review showed that cognitive ergonomics is the most prolific research domain in the application field of Industry 4.0 [7].

Psychosocial constraints are becoming an emerging trend for the scientific community, regarding well-being at work. Unlike physical strain, this mental strain is more difficult to measure because it requires an understanding about how each person reacts to a given situation. Studies about well-being at work rely on questionnaires in order to obtain a subjective appreciation of the worker [12,13].

It is widely admitted that psychosocial constraints are incriminated in the development of MSDs [14]. Job satisfaction, stress engendered by deadlines and social relations with the hierarchy as well as with teammates are influencing the physical and cognitive workloads perceived by the employees. Individual sensitivity, induced by the differences in health capital between each employee, is also key in the development of industrial occupational disease.

For many years, solutions to reduce biomechanical risks factors were extensively studied and gave good results to diminish the physical workload for the operator on each workstation. However, it remains impossible to suppress every occupational disease risk factor at work. Several literature reviews already exist, usually focused on a specific aspect of the problem. For example, an ergonomics-oriented analysis was conducted in order to classify the different studies on specific domains, such as physical, cognitive or organizational ergonomics [7]. Safety issues for operators are also considered in [15,16]. Closely looking at those literature reviews, it appears that there is a lack of studies exhibiting the evaluation methods with respect to short- and long-term effects on the health of operators. However, long-term effects are key in the development of most occupational diseases. Thus, we took the decision to separate short and long-term effects in our study.

The main objective of this article is, therefore, to provide a systematic literature review (SLR) of how the physical, cognitive and psychosocial aggravating factors are measured and evaluated, leading to occupational disease in operators in industry. The SLR was performed in order to identify both the tools and methodologies available in the literature. Considering the topic, this analysis is deeply multi-disciplinary, exploring ergonomics, social sciences, health care and technologies of information as well as the communication scientific corpus, and, therefore, provides an actual added value to a practitioner intending to examine this issue on their own industrial system. The purpose is to answer the following research questions that guided our research.

- What are the tools and methodologies used to evaluate the health parameters considered for evaluation of the working conditions of the operators in industry?
- Which methods are proposed to mitigate the impact of the working conditions on operators and their health?
- How are these methods integrated into an industrial environment?

To answer this last question, we categorized every article according to the health objective targeted. The first category is relative to short-term fatigue, cognitive and physical; the second category is constituted by long-term physical strain due to professional activities; and the third one is focused on the psychosocial risks for the operator in Industry 4.0. These categories were selected to differentiate which part of the occupational risks the articles study.

Section 2 introduces the methodology used to make the systematic literature review. The results are presented according to three main health parameters categories: short-term fatigue, long-term physical strain and psychosocial risks. Section 3 shows an overview of the articles studied in this literature review. This section is split into three subsections and presents the result of the SLR. The main focus is to highlight the different technologies used to consider human factors in industry and the objective of considering these human factors. The first subsection explains the different methods used to measure the short-term fatigue of an operator and how manufacturing organizations are using these data as decision variables. The second subsection presents technologies and methods used in order to reduce long-term physical strain. As for the third subsection, it provides an overview about the psychosocial risks and the impacts they have on the well-being of an employee at work: flexibility, safety, work comfort, motivation and satisfaction [17]. Conclusively, in Section 4, we propose a discussion about the specificities of each health parameter, how they are measured and what the solutions are to reduce their impacts on occupational disease risk. This discussion also details the conditions in order to integrate health-related parameters in industry organizational decisions. Future perspectives and ethical questions are, finally, proposed in the last section.

2. Material and Methods

In this article, qualitative research has been made through a systematic literature review, based on PRISMA guidelines. PRISMA provides a standard peer-accepted methodology that uses a guideline checklist, which was followed in this article [18]. The objective of this systematic literature review is to identify the knowledge and current existing technologies in industry used to measure health-related data as well as how to consider this data within decision systems.

2.1. Data Sources and Search Strategies

We systematically searched the Scopus electronic database. Only peer-reviewed articles written in English were declared eligible. Table 1 presents the keywords used for the research. They are structured into two classes with Industry 4.0-related terms searched together with human factor-related ones. These keywords were chosen by aggregating the keywords of other related reviews, and our own keywords were added based on past experiences. The combination of keywords meant that no pertinent results could be found before 2014. Although studies related to the field of industry exist in the literature before this date, it was considered here that the technological and organizational evolution observed and foreseen in Industry 4.0 limits the validity of these studies in this new context. Therefore, the study presented here only shows publications between the years 2014 and 2021.

Table 1. Keywords for the systematic literature review.

Industry 4.0/CPPS	Human Factors and Ergonomics
Industry 4.0 Industry of the future Cyber-Physical Production System Industrial Cyber-Physical System Smart factory Smart operator	Human factor Ergonomics Well-Being Human-in-the-loop Health monitoring Workplace organization Job design Task design Musculoskeletal disorders Operator fatigue Mental strain

2.2. Eligibility Criteria

Figure 2 details the methodology of the systematic literature review. The selection of articles to review was conducted in three steps. First, we had to exclude results that are editorial material (e.g., call for special sessions in conferences) in order to only include peer-reviewed journal articles and conference articles. Next, we filtered articles based on their abstracts. Rayyan QCRI (http://rayyan.qcri.org, accessed on 27 November 2021) has been used in order to simplify this screening work, by tagging the articles. For example, a lot of results were addressing issues related to machine health-management and prognosis.

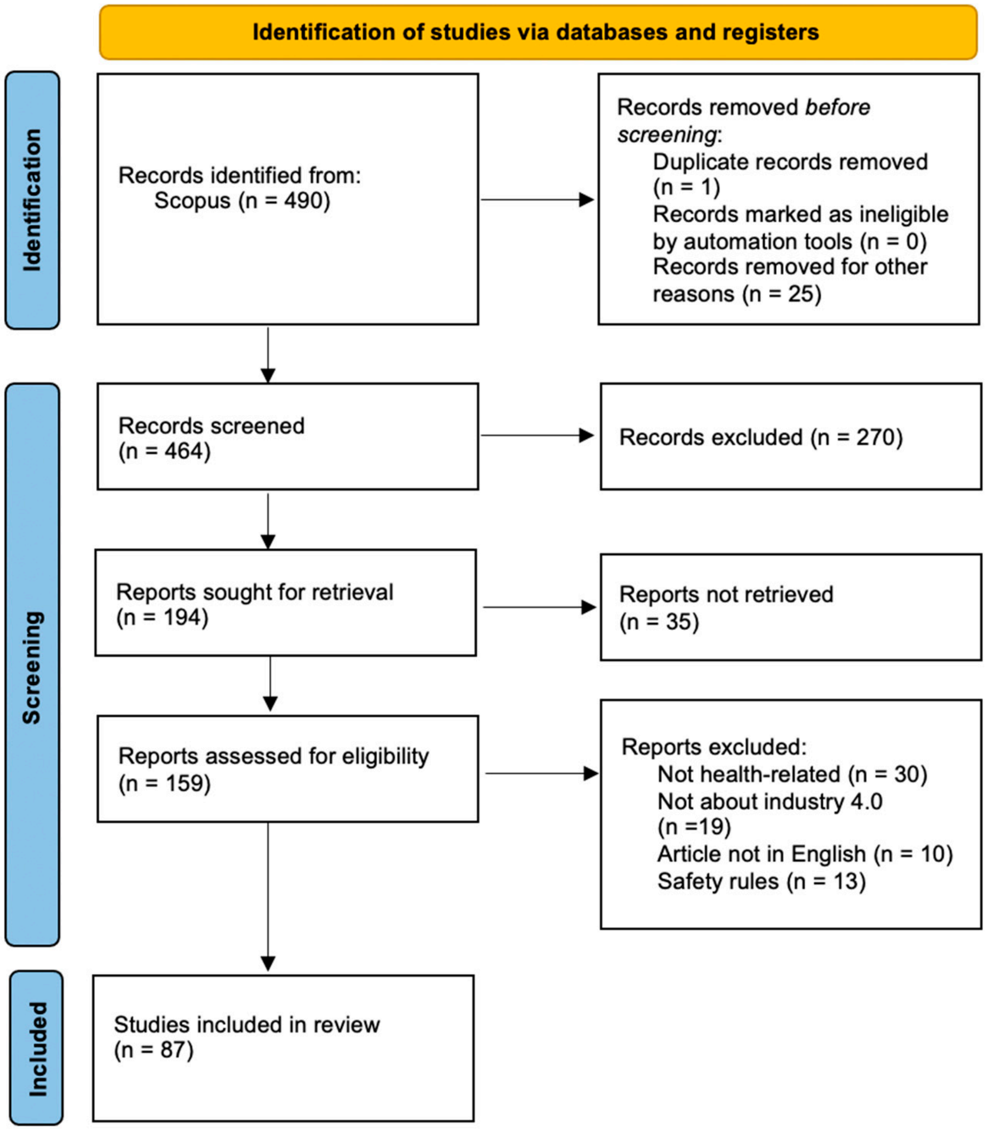

Figure 2. Report of the systematic literature review, derived from PRISMA model.

The last step was to examine the remaining articles with full-text screening, in order to determine their inclusion in our study. We rejected articles that were not in relation with health parameters or with industry and articles that were only focused on safety at work.

2.3. Details of Included Studies

The search based on the inclusion criteria, which are the keywords in Table 1, found a total of 490 articles between 2014 and 2021. After the application of the exclusion criteria presented before, we narrowed this number to a total of 87 articles relevant to the present systematic review of the literature. This review is constituted by 28 conference proceedings associated with 21 conferences (Figure 3) and 59 journal articles that come from 32 different journals (Figure 4), mostly targeting an industrial audience.

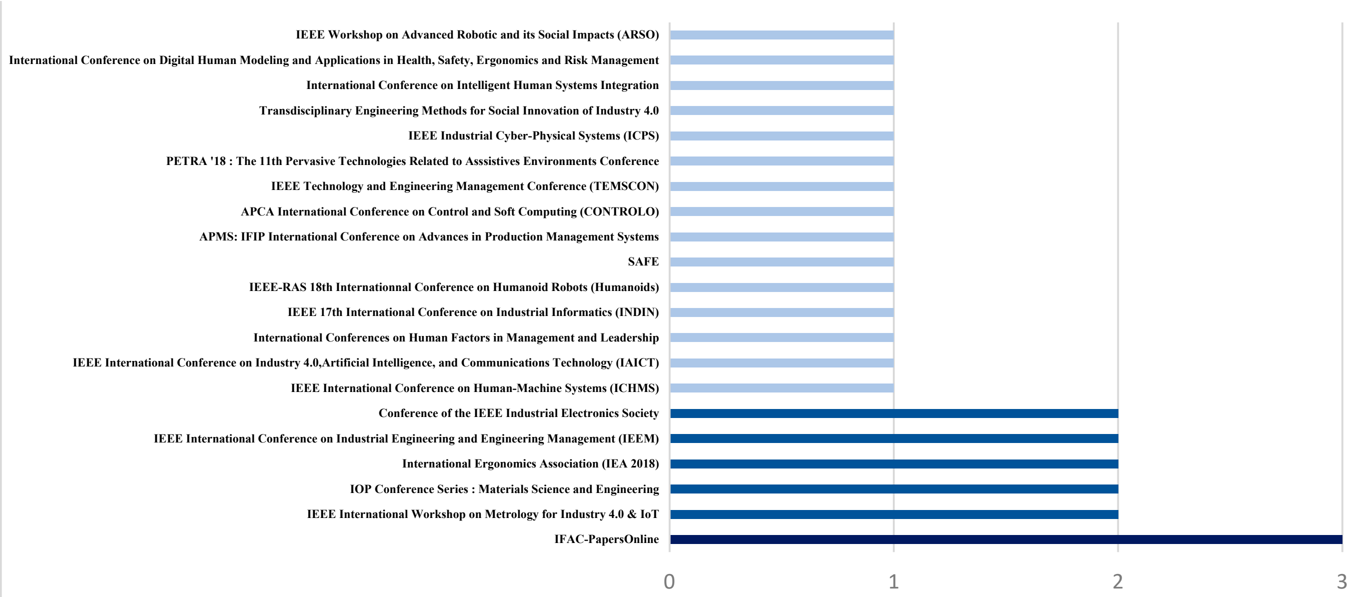

Figure 3. Conference proceedings included in the SLR.

Figure 4. Journal articles included in the SLR.

The literature review was conducted at the beginning of 2021; we found a relevant increase in the number of articles published over the years, with the majority published in 2019 and 2020, as depicted in Figure 5. After gathering the articles incorporated in the SLR, we classified them according to the health parameters they were focusing on.

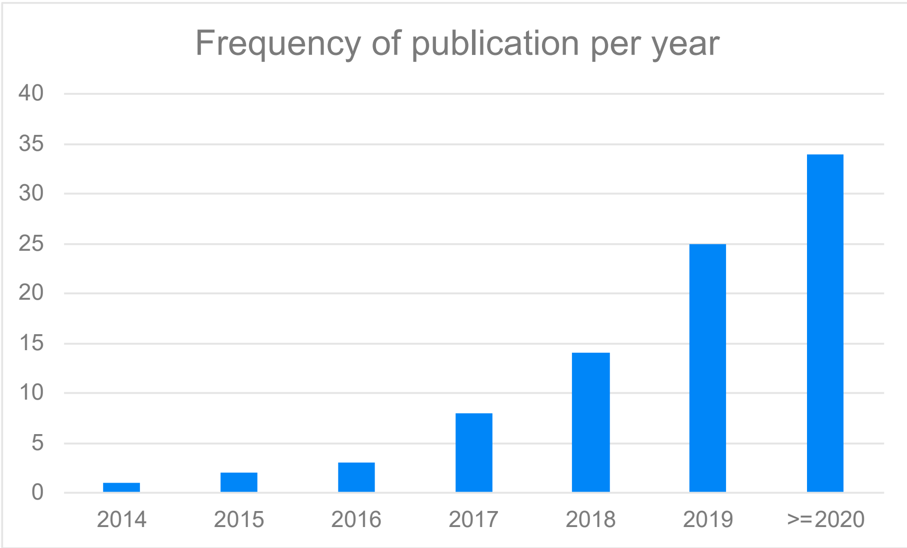

Figure 5. Frequency of publication per year.

3. Results

In this section we present the results of the systematic literature review, structured around the three main impacts on the condition of operators: short-term fatigue, long-term physical strain and psychosocial risks. We notice that some articles may belong to different categories. The distribution of the articles is shown in Table 2, exhibiting a relative balance in the amount of works between the categories.

Table 2. Classification of selected articles based on their health objectives.

Short-term Fatigue	Short-term fatigue measurement	[16,19–33]
	Reduction of fatigue	[7,15,24,34–43]
	Integration of human short-term fatigue in an industrial decision system	[2,44–55]
Long-term physical strain	Long-term physical strain risks measurement	[11,16,23,28,56–73]
	Reduction of long-term physical risks	[7,15,27,34,37,38,74–83]
	Integration of long-term physical risks in decision system	[2,45–47,50,84–89]
Psychosocial constraints	Psychosocial parameters measurement	[16,28,37,39,90–96]
	Integration of psychosocial risks in decision system	[2,13,37,45–47,50,53,97–104]

This section introduces a specific analysis of each class of health objective.

3.1. Short-Term Fatigue

The term "fatigue" was extensively studied in the literature. In this work, we consider the definition given by [105], stating that "Fatigue is a suboptimal psychophysiological condition caused by exertion". This definition covers all the aspects of fatigue. Considering the short-term consequences of fatigue in an industrial context, we define short-term fatigue as the loss of performance due to the efforts required for the worker to execute all their daily actions to fulfill industrial operations. This fatigue is often physical, with the energy expenditure the operator is developing in order to realize their work tasks, and it often increases with the cognitive load the operator has to deal with. The fatigue of workers has gradually become an important concern for the Industry, to improve their performance and because of the growing importance of the societal impact of human factors for manufacturing companies [7]. This first paragraph is providing an overview about how this fatigue can be measured, what the solutions are to reduce the impact of fatigue for the operator and how fatigue is taken into account in the organization.

3.1.1. Short-Term Fatigue Measurement

The first question that appeared is the measurement of the fatigue. In order to take decisions based on short-term fatigue, it is required to correctly, and with precision, understand the accumulation of the physical workload and cognitive strain for the worker. There is also a key interest to understand what the impact is of this fatigue on the human body and how it impacts the performance and well-being of the worker.

Wearable sensors are examples of physical methods used in order to measure the efforts that the operator has to deploy in order to realize a task. Pistolesi et al. [19] has shown that with the help of barometers, accelerometers and magnetometers it is possible to obtain key information about the risk of back injury for workers that lift loads. This approach of using wearable sensors is helping health specialists reinforce subjective observational methods for ergonomics, which are checklists evaluating the difficulty to realize a task and the possible strenuous situations. It has determined a key approach, leading to a revision of International Standards for human ergonomics [20] because of the enhancement of the accuracy of the measures. The use of these new methods is necessary because of the evolution of the workplace, especially with new technologies being used to enhance the human body. Another fully wearable solution has been developed by Conforti et al. [21], in order to determine the precise force exerted on the lower limbs up to the L5/S1 joint on the body, during a manual handling task. Heartbeat is also an indicator used in the understanding of the difficulty of a task and on the fatigue the operator may experience [26,29]. A more practical solution is to use a smartphone- or smartwatch-integrated accelerometer, which monitors the movement of the body in order to obtain information about energy expenditure during an effort [22,32]. These different studies show that physical sensors are a good solution in order to grasp how the human body responds when doing industrial tasks as well as identifying risks for the operator, knowing that computer simulation is also used in some cases [23]. Physical workload is the main cause of fatigue for the human, however with the growing of new technologies in industry, there is an intensification of cognitive fatigue for operators. This cognitive load has mostly developed due to the complexification of work tasks and the human-machine interface [25]. Unlike physical strain, this cognitive fatigue cannot be directly measured. However, this cognitive load has a direct impact on the perception and concentration of the operator of the workload [31]. This cognitive aspect of work life also increases the risk of work accidents and may decrease the performance of the operator [28].

3.1.2. Reduction of Fatigue

Competitivity in the manufacturing industry has induced many evolutions over the last twenty years. Productivity, the tracking of operations and products and the security of data have been major objectives for the workplace; however, more recently work safety and human factors have become crucial subjects in order to improve the image of companies and also to improve the performance of workers by ameliorating the quality of life at work and worker well-being, by reducing the energy expenditure for operators. Technological solutions have been developed over the years, which are contributing to the objective of sustainability in the Industry 4.0 paradigm [35].

Increasing cognitive workload has been observed with the development of intelligent manufacturing systems [7]. As a logical response, an important part of ergonomics in the beginning of the Industry 4.0 era is directed at the development of practical human-machine collaboration. Gualteri et al. [15] proposed a systematic literature review of industrial collaborative robotics, which highlighted two principal research axis: safety and ergonomics. Ergonomics in collaborative robotics is then decomposed in two sub-clusters, physical ergonomics and cognitive/organizational ergonomics, the same way as in CPPS (Figure 1). In particular, Antao et al. [39] take into consideration human fatigue in the human-robot collaboration to improve the quality of this collaboration. Fatigue can also be an objective to minimize in mathematical optimization. For example, Weckenbourg and Spengler [36] used an assembly line-optimization algorithm, with the addition of collaborative robots under ergonomics constraints. Battini et al. [24] have made a list of the different assembly line and sequencing mathematical problems under the constraints of human factors. Biomechanical factors are the principal factors of short-term fatigue; another solution developed to reduce this strain was to conceive exoskeleton systems. The objective of exoskeletons is to relieve the muscular activity of the worker and to assist them during their working operations. In particular, Grazi et al. [34] have developed a passive upper-limb-support exoskeleton in order to reduce the muscular activity of the user and their heart rate.

3.1.3. Integration of Human Short-Term Fatigue into an Industrial Decision System

Safety and human factors have gained importance through the years as decision variables in industry, in order to achieve sustainability. The development of new technologies and CPPS have enabled the important potential of the automation of tasks; however, human-in-the-loop tasks are still indispensable because some tasks cannot be automated [48,52]. Within the CPPS paradigm, human operators require more technological performance in order to perform manufacturing tasks [51]. With a conceptual model, Suarez-Fernandez et al. [45] aim to identify the degree of incorporation of human factors into the different areas of digital and technological transformation of Industry 4.0. Paredes-Astudillo et al. [44] presented a human fatigue-aware cyber-physical Production system. This system aims to dynamically change the schedule of operations to the worker, according to their measured cognitive fatigue level. Stern and Becker [47] have shown with their experiments that the design of the human-machine interface has a significative impact on performance and work perception in cyber-physical production systems. This collaborative human-machine interface needs to be optimized in order to reduce the difficulty of cognitive tasks. An important aspect of this human-machine cooperation is the adaptability of the CPPS with the data fed back to the system. Reis et al. [53] focus on a CPPS, which enables self-adaptation in industrial equipment in order to support the human operator under a high level of stress and fatigue.

The research around short-term fatigue in industry is constituted by three different subjects: fatigue assessment, methods to reduce fatigue at work and how to integrate operator fatigue into the decision system. Short-term fatigue is a great indicator of the performance and perception of the workload for the operator, but most occupational diseases at work are due to long-term physical strain. In the next subsection, we will analyze how long-term physical strain is measured.

3.2. Long-Term Physical Strain

Also based on the definition of fatigue provided by [105], we define long-term physical strain as the loss of performance due to the accumulation of efforts and constraints applied to the worker on a daily basis. Long-term effects of physical strain in industrial occupational work are an important problem for society. Specifically, MSDs cause pain and incapacitate the worker from doing habitual activities. These physical diseases are created because of important workloads, repetition of physically difficult tasks or strenuous postures at work.

Long-term physical strain, unlike fatigue, is considered impossible to numerically evaluate because the risk of developing occupational diseases depends on hundreds of parameters over many years.

3.2.1. Long-Term Physical Strain Risks Measurement

Historically, physical ergonomics focuses on the prevention of injuries and musculoskeletal disorders at the workplace. The increased incidence of MSDs in industry led to the development of numerous physical risk assessment methods. These risk assessment methods can be divided into three categories, namely observation-based measures, self-evaluation questionnaires or measurement methods [9]. Risk assessment with measurement methods can be physical, with the usage of sensors and tools to monitor variables relative to work exposure. The objective of physical ergonomics is also to reduce risks for the worker by creating a safer workplace through design improvements of the workstation or creating technical solutions to reduce physical strain for the worker. Physical measures are not the only technical tools used in order to obtain precise information on the human body during industrial tasks. In the Industry 4.0 context, a lot of research has started focusing on the virtual environment, in order to obtain information about the realization of industrial tasks. Motion capture, in particular, is trending in industrial applications and is a technology that can solve problems that require precise sensor solutions. This technology mostly consists of inertial measurement units and visual cameras, which can be used to support solutions relating to human factors and for human safety [56]. An application of the motion capture technology is the simulation of manufacturing task, with a mixed or augmented reality system, in order to assess the parameters of the ergonomics of a workstation [59,62,66,68,70]. The objective of this simulation, and the creation of a human digital twin [57,64], is to make a virtual ergonomic assessment of the occupational physical constraints. The main contributions of the mixed reality system used to assess the ergonomics risks on the operator are the possibility to compute precise data about the realization of the work task and to avoid the subjectivity of the ergonomic assessment with the help of a health specialist. For instance, Caporaso et al. [71] focus on the human shoulder joint in industrial tasks and analyze the biomechanical effort of the shoulder during physical activity.

3.2.2. Reduction of Long-Term Physical Risks

In order to reduce the long-term physical strain, the principal idea offered by ergonomics is to reduce the constraints on the human body by adapting the workstation design to match the regulations defined by health specialists. A user-centered approach for workplace design can be used in order to reduce long-term physical strain for the operator [77]. The process of optimizing workplace design, before the construction of the workstation, is possible because of the virtual ergonomic assessment; it becomes possible to predict the work process and to verify human operator posture beforehand. Within the simulation of the digital twin of a human operator doing manufacturing tasks, it is also possible to realize an ergonomic assessment of the constraints, following ergonomic observation methods [7]. Papetti et al. [75] indicate that human-centered design for improving the workplace has shown that efficient ergonomic assessment needs multiple perspective measurement methods, and that ergonomics risks are constituted of a combination of physiological parameters measurement, expert based methods and self-report techniques.

Long-term physical risks are aggravated with repetitive movements. In order to break these repetitive tasks, an idea developed by operation research is to create job rotation between workers. The most popular objective of the job-rotation problems in operation research is to balance the workload, measured by ergonomic assessment methods for the worker [106]. These optimization ideas were developed in order to help work organization integrate long-term physical risks into decision systems.

The learning process of a task has a direct impact on the productivity of the worker because it affects the actions required to perform a task, thus being key for performance in industry [82,83]. This learning process is important for the worker because a well-executed movement reduces physical strain during task execution.

3.2.3. Integration of Long-Term Physical Risks in Decision System

The next challenge is to take into consideration these ergonomics measures and solutions into the decision, aiming to reduce long-term physical risks for human operators. Gualtieri et al. [84] present an evaluation of a robot-human collaboration in an assembly line with ergonomics considerations. For this study, an algorithm was developed to analyze the performance of the collaboration in terms of ergonomics, safety, production efficiency and economics. Perruzini et al. [85] proposed an exploration of the different tools used to assess ergonomics and performance at work as well as feedback on the feasibility of the operator 4.0 interface. However, these tools need to be adaptative in order to respond to the cognitive needs of the worker, for example, to assist the ageing workforce with new machine interfaces [89]. The emotional response of workers, the applicability of the method and the needs of large empirical data are the limitations highlighted in the study. To simplify the integration of human error in the decision system, Angeloupou et al. [86] computed a simulation model using performance indicator such as: Experience, Stress, Safety or cognitive complexity of a task. These new management trends in Industry 4.0 are aiming to strengthen the human-machine collaboration; however, this collaboration bring possible occupational risks for the human [87].

3.3. Psychosocial Risks

Psychosocial constraints at work are an important risk factor in the development of occupational diseases at work [12]. The idea of this paragraph is to list the different methods to evaluate the different psychosocial parameters and their impacts on the well-being and physical risks of the worker. The second is to understand how psychosocial constraints are integrated into industrial organizational and decisional systems.

3.3.1. Psychosocial Parameters Measurement

There are six identified factors in the development of psychosocial risks [4]: intensity and quantity of work, emotional strain, lack of independence, social relations, value conflicts and insecure work situation. These psychosocial risks factors are impacting the perception of the workload for the human and are often associated with stress and possible burnouts. Psychosocial parameters are harder to measure than fatigue and ergonomics assessments because they rely on a questionnaire answered by the worker and are influenced by the possible biases of the subjectivity of the person. Many questionnaires are used in order to measure these psychosocial parameters [92]; the most used is by Karasek, which aims to measure stress [107]. Schulte et al. [16] have shown, through a literature review about potential hazards at work, that the most anticipated risks are physical, chemical and biological risks. Scafà et al. [98] have shown, in an industrial use case, a strong relation between well-being at work and perceived workload for the operator. This effect has a strong long-term beneficial impact for companies because of the increase in productivity and decrease in absenteeism. Emergency operations in industry heavily rely on self-control, which is heavily impacted by psychosocial parameters [28].

3.3.2. Integration of Psychosocial Risks in the Decision System

The integration of psychosocial parameters in the organization process is harder because the data are less reliable and the performance indicator may be biased. With the advances of Industry 4.0, work is evolving and the increased interaction with technology has an impact on the well-being of workers [99]. Emotional strain, lack of independence, social relations and the insecurity of the work situation are questioned during this evolution of the workplace in industry. Feedback from workers is needed in order to evaluate psychosocial risks on the workshop floor because there is no objective measure to determine well-being. The implication of workers in the designing process reduces the insecurity risks linked with the integration of new technologies because workers have a better understanding of the human-machine collaboration and have an impact on the development of their tools [90,93]. The integration of human-in-the-loop simulation inside the process control of CPPS objectives is to provide assistance systems in order to benefit from human competencies and capacities, while simultaneously respecting human limits [101]. Climate and ties to the workplace are menaced by the psychosocial factors, which greatly impact the sense of stress and the sense of threat for the worker [13].

3.4. Synthesis on Health-Related Parameters Measurement in the Literature

After reviewing the various measurement methodologies used for assessing the health-related parameters for human operators in industry, Table 3 introduces a classification of these works according to the methodology they are using and the health objectives they are addressing.

Table 3. Synthesis of health parameters, measurement methodologies and health objectives.

References	Measurement Methodologies				Health Objectives		
	Observation	Questionnaires	Measurement	Simulation	Short-Term Fatigue	Long-Term Strain	Psychosocial Risks
[19]			X		X		
[20]			X		X		
[21]			X		X		
[22]			X		X		
[23]				X	X	X	
[24]				X	X		
[25]	X				X		
[26]	X		X		X		
[28]	X				X	X	X
[29]			X		X		
[30]	X	X			X		
[31]	X				X		
[32]			X	X	X		
[33]			X		X		
[56]			X	X		X	
[57]				X		X	
[58]				X		X	
[56]			X	X		X	
[59]				X		X	
[60]	X	X				X	
[11]		X				X	
[61]				X		X	
[62]			X	X		X	
[63]				X		X	
[64]				X		X	
[65]				X		X	
[66]				X		X	
[67]				X		X	
[68]			X			X	
[69]				X		X	
[70]	X		X			X	
[71]			X	X		X	
[72]				X		X	
[73]			X	X		X	

Table 3. *Cont.*

References	Measurement Methodologies				Health Objectives		
	Observation	Questionnaires	Measurement	Simulation	Short-Term Fatigue	Long-Term Strain	Psychosocial Risks
[39]	X						X
[90]		X					X
[91]		X					X
[92]		X					X
[93]	X	X					X
[94]	X						X
[95]	X						X
[96]		X					X

A cell marked with an X indicates the measurement methodologies or health objectives expressed in each reference.

Referring to our study in [108] and from the analysis of the measurement methodologies presented before, it appears that these methodologies can be classified into four different categories: observation methods, where the impact of the workload on the operator is assessed by a human observer; questionnaires, designed to obtain non-measurable data from the feeling of the operators; direct measurements, for example, wearable effort sensors; and simulation models, for example, through virtual reality or physical models.

This classification exhibits the interest of using sensors and direct measurement for short-term fatigue. Sometimes coupled with simulation models, these very precise data allow an assessment of the mechanical efforts felt by operators. Surprisingly, very few works confront these models to the actual health of the operators, for example, via some questionnaires.

Due to time constraints and the difficulty of reproducing long-term physical strains in the laboratory, studies related to this objective usually rely on simulation techniques. Again, there is a lack of model validation that can be observed from a global point of view, and the actual effects on the operators are generally not assessed.

Finally, as expected, psychosocial risks are usually assessed by using questionnaires and observation methods. This result was expected due to the lack of availability of measurement methodologies and corresponding devices. However, it also has to be noted that simulation models are not available either. Among others, this is due to the lack of models describing the evolution of such risks in the literature.

4. Discussion

The results from the systematic literature review confirm that the health-related issues in industry have been gaining interest in research communities over the last few years. The global scope of questions is addressed in a balanced way, and while many solutions are already provided, a lot of research questions still remain.

Short-term fatigue measurement has already been a key research question in professional sport, and the tools used to measure energy expenditure can be suitable to the industrial workplace. This understanding of the human fatigue facilitates its measurement and the integration in industrial systems. Digitalization of these processes, with the virtual reproduction of a task, is a new step developed to predict and to reduce the physical-straining situation in the workplace. The motion capture technology used to virtualize a task relies on high precision sensors that evaluate the position and force exerted on the joints and muscles of the worker. This use of body sensors may create a measuring bias, as the worker may adapt their movements because they are being monitored and wearing equipment with sensors.

Physical fatigue has been well documented over the past decades, but cognitive strain is a relatively new problem within the workplace. Decision taking and reaction time can be measured, thus creating an indicator on operator performance; but, the biggest part of understanding cognitive constraints requires a subjective analysis of the worker. Cognitive ergonomics have become part of designing workplaces, in order to facilitate the operations of workers in a complex workplace.

Long-term strain and the development of occupational musculoskeletal disorders are an important societal and financial problem for industry because of the medical allowances for workers with occupational diseases as well as the costs to recruit and train new workers. Progress on the understanding of these long-term work-related physical risks have been made with the help of evaluation methods, which are either observational, based on a self-evaluation questionnaire or dependent on tools to measure the physical expenditure of the worker. However, this large range of methods makes it difficult to uniformize the measure of a physical constraint. For example, in 2010 Takala et al. [109] had already identified 30 observational methods used to measure long-term physical strain. This huge diversity of measurement methods eases the finding of a good fitting solution for the evaluation of physical constraints, as it can consider the integration of different workplace specificities. However, this large choice also affects the uniformity of a measure, when, for example, the same task is measured at two different physical strain levels. The comparison of the eight main observational methods used to evaluation physical constraints shows that the results produced with these methods may differ considerably [110]. Empirically, industry companies tend to contribute more in developing solutions for long-term physical strain risks such as posture, repetition of tasks and force exerted because these risks represent the major risk of developing occupational diseases. The integration of these long-term risks in the industry organization remains complex because it is nearly impossible to track occupational disease risk for a specific worker over forty years and the risk factors of MSD are too numerous to all be studied in working conditions.

This measurement problem also tends to appear with the measurement of psychosocial constraints because these constraints are mainly measured with questionnaires directed to workers. For example, the Karasek questionnaire [107] is the most frequently used in order to measure stress at work, but it is not often adapted for industrial work life because this questionnaire is not designed to show an evolution of the health parameters of workers; thus, new questionnaires have been created by psychologists and health specialists in order to answer specific problems identified by industrial companies. The psychosocial risks are tougher to address because they rely more specifically on the perception of the worker than the objective situation at the workplace. This review shows that prevention and understanding of the psychosocial risks is key for companies to create a sustainable workplace to enhance the well-being of workers, which improves both worker productivity and company image.

This review also highlights the reality that in recent years manufacturing companies have tended to invest more into research about the well-being of workers and collaborations with scientists in order to understand the physical, cognitive and psychological risks for the production worker. Many solutions are being developed with the objective to reduce these identified risks and to integrate human factors into decision systems. However, most such studies have a theoretical approach to human factors and well-being in industry as well as a lack of empirical evidence to support either the measurement, the reduction or the integration of human factors. It is very likely that the integration of these different solutions on site remains complicated because it represents important expenses for the companies with a slow return on investment. Physical assistance is often prioritized because physical strain represents, for most companies, the key parameter in occupational musculoskeletal disorders.

The complexity behind these measures is that they rely on an important subjectivity: different measurement methods, the individual sensibility of workers and out-of-work elements. The difficulties for the organization are to take into account these measures and to integrate them into the manufacturing process. To simplify this process, we can question the possibility of defining notation standards to make the physical, cognitive and psychosocial risk evaluations by the workplace more comparable.

Results are also showing that including production operators in the development and ramp-up of new technologies or new production means is mandatory to obtain great user satisfaction and better performance. The acceptance of new technologies is an addressed problem that may occur during Industry 4.0. Workers can perceive the introduction of intelligent systems as a threat to their role in industry, and this fear of replacement is a stress factor and a psychosocial risk that can affect well-being if it is not properly addressed. This operator consideration within industry reduces the impact of the human-machine competition and leads to a better understanding of the collaboration.

With the integration of health parameters in decision systems, we can address the problem of personal data privacy and the ethical aspect of using the personal data of workers in order to improve performance and reduce physical risks. In order to reinforce the consideration of human factors within the organization, workers agree to give access to personal information about health and psychosocial parameters that are often bound to their personal lives outside of the workplace. This information is sensitive because it may discriminate against workers in the workplace at decisive moments of their careers. Recruitments and promotions may be influenced by these private data, creating stress for workers about their physical states. This problem needs to be addressed when creating tools for organizations based on the private data of workers.

5. Conclusions

Sustainable development has been an important subject over the last decade in modern industry; thus, integrating human factors into the design and organization of the workplace has become a key subject, with the objectives being improving well-being at work and reducing the risk of workers developing occupational diseases. This importance is highlighted by the significant increase in the number of publications on the subject during the last seven years.

Considering the first research question addressed in this review, a large set of tools and methodologies used to evaluate the health parameters considered for the industry were identified and presented. They consist of sensor device implementation, health questionnaires, ergonomic observations and simulation. The large diversity of tools and methods can be explained by the specificities of each usage. Consequently, this diversity complicates the comparison of working conditions between different industrial situations.

Considering the second research question, the mitigation of the impact of the workload on the condition of operators is targeted by a diminution of the workload itself (both physical and cognitive). In practice, these two measures can be applied: either changing the typology of operations asked to the operator in order to modify their physical or cognitive impacts; or assisting the execution of the operations with the use of technical devices or robots.

Finally, considering the third research question, the implementation of those solutions in an industrial context can be seen as relatively heterogeneous. If assisting solutions, often based on ergonomics studies, are generally efficient and well adopted, organizational solutions such as job rotation are usually a lot more challenging.

Short-term fatigue and long-term strain have been differentiated to understand the different approaches; the first one is mostly based on efforts by the worker while the other one relies on the repetitiveness of the industrial tasks. Solutions to identify and to reduce psychosocial risks in industry have also been screened because of their importance in the development of occupational disease and their role in the well-being of the worker at the workplace.

This review facilitated the identification of three primordial steps: analysis of the situation and highlighting of the operational risk; research and proposal of a solution to reduce this risk; then, implementation and integration into the organizational loop.

In the future, we can expect more research studies on occupational disease caused by industrial working activities. Societal evolutions are pushing the importance of safety at work and human well-being; this dynamic is helping research about human factors at work, which may explain the rapid increase in articles published on this subject. These societal evolutions are key in the research of the development of human factors because they bring an overview of what can be done to help assist workers. An evaluation of the risk of occupational disease from previous work-based tasks by workers could be key to supporting companies in the integration of technological methods to reduce physical and psychosocial risks at work.

Author Contributions: Conceptualization, N.M. and O.C.; methodology, N.M., O.C., A.M. and M.-P.S.; validation, O.C., A.M. and M.-P.S.; formal analysis, N.M.; resources, N.M. and O.C.; data curation, N.M.; writing—original draft preparation, N.M.; writing—review and editing, N.M., O.C., A.M. and M.-P.S.; visualization, N.M., O.C., A.M. and M.-P.S.; supervision, O.C.; project administration, O.C.; funding acquisition, N.M. and O.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was financed by Airbus Group and ANRT in the framework of a CIFRE thesis.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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