



# Investigating Ergonomics in the Context of Human-Robot Collaboration as a Sociotechnical System

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**Abstract.** In this publication, we investigate how the term ergonomics could be defined for human-robot collaboration (HRC) as a sociotechnical system (STS). Thus, we compare different definitions of ergonomics and human factors and conclude on a definition suggested for adoption. Moreover, we compile a list of human factors relevant to that context. We conducted this investigation, because HRC is mainly viewed from a technical viewpoint, although the implications of human involvement should not be underestimated. However, ergonomic evaluation of HRC is based on old methods. The main purpose of this publication is therefore to contribute to a foundation for new ergonomic evaluation methods.

**Keywords:** Human factors · Human-Robot Collaboration  
Sociotechnical Systems

## 1 Introduction

This publication focuses on regarding all relevant aspects of human factors and ergonomics in the context of Human-Robot Collaboration (HRC) as a sociotechnical system (STS). It is meant as groundwork to establish novel ergonomic evaluation methods for collaborative robots designed for assembly and production systems. This in turn will lead to new approaches in the development of collaborative robots.

HRC as an alternative to full automation and human labor in assembly and production systems seems a promising way to combine the strengths of human and robot, mainly increasing the ergonomics and efficiency of the human activity. However, HRC has been subject to research for over 20 years now, while the market share of HRC robots is still marginal. Besides safety issues, task allocation and ergonomic evaluation are the main challenges.

Until now, research focused on the technical issues, i.e. safety and task allocation while mainly disregarding ergonomic aspects. This makes groundwork like this publication necessary to follow a methodical approach to improve ergonomics in assembly and production systems using HRC.

Regarding ergonomic evaluation, the problems are old methods coming from the evaluation of human labor that are ill adapted to HRC [1]. To enable the development of new methods, a complete and precise definition of ergonomics in the context of HRC must be found. The interpretation of HRC as a STS acts as a boundary for this investigation.

This is meaningful, because the field of ergonomics and human factors has a very broad scope that can be broken down into multiple subtopics. This makes the definition of ergonomics and human factors depending on the regarded context. Therefore, adopting existing definitions without investigating the fitness to the context is not an improvement over the present situation.

While this publication is not presenting a new method or any new data, it lays a very important foundation for future work and should be presented by itself to make the reasoning behind the decision on a definition comprehensible.

After describing the method used to gather relevant data, we present the chosen definitions from related research topics, as well as global and common definitions in the main part of this publication. Following up, we discuss the findings while taking the implications of HRC as a STS into account.

Summing up, this publication tries to answer the following research question:

*Regarding Human-Robot Collaboration as a sociotechnical system, how can ergonomics be defined and what aspects of ergonomics have to be considered to enable the ergonomic evaluation of collaborative robots?*

## 2 Method

Building upon the research question, the main task of this publication is twofold: find a suitable definition of the terms human factors and ergonomics and compile a list of aspects that can be used in future publications to define metrics of new methods for ergonomic evaluation.

The investigation of literature is limited by regarding those terms only in the context of HRC as a STS. Therefore, corresponding definitions that have been chosen are presented in the following.

For HRC, we use the definition as a kind of human-robot collaboration from Bütepage and Kragic [2]. They define HRC as an interaction with these properties:

1. Human and robot exchange information
2. Both share a representation of the task
3. Both share the same goal
4. The subtasks performed by both partners are interdependent
5. HRC leads to mutual learning and adaptation, requires mutual trust

As definition of STS, we used the one from Whitworth: “Social-technical systems arise when cognitive and social interaction is mediated by information technology rather than the natural world.” [3].

Mariani [4] builds on this definition and describes the following characteristics as essential to STS:

1. Some properties of STS can only be evaluated after deployment, not at design time
2. STS are mostly non-deterministic, i.e. they produce different outputs from the same input
3. At design time it is not possible to predict all ways in which humans may interact with STS
4. Awareness is described as fundamental in STS
5. Adaptation of humans to systems is not exclusive; they may also adapt the systems to them.

To find a definition, we took general definitions of human factors and ergonomics from dictionaries, books on these topics and organizations focusing on human factors and ergonomics. In addition, we searched journals and conferences for entries regarding the definitions they used.

The compilation of a list of ergonomic aspects used the same sources, however the focus is more on current research than on books.

The main search terms were *human, robot, collaboration, sociotechnical, ergonomics, human factors*. The search engines used to find publications were Scopus, Google Scholar, ScienceDirect and Web of Science.

For both tasks, the abovementioned properties of HRC and STS are used to concentrate all findings into one definition and one list of human factors.

### 3 Results

In the first subsection of this chapter, we state all regarded definitions of ergonomics and human factors, whereas the second lists all sources used to compile a list of human factors important for HRC as a STS.

#### 3.1 Definitions of Ergonomics and Human Factors

The first definitions identified as important are the definitions of both terms from the Cambridge Dictionary. They define ergonomics as:

“the scientific study of people and their working conditions, especially done in order to improve effectiveness” [5] and human factors engineering as:

“the act of studying how people use systems or equipment in order to design, develop, and create technology that is safer, more effective, etc.” [6]. It should also be noted that ergonomics is stated under the *see also* section of the human factors engineering definition.

More specific are the definitions of international organizations of ergonomics and human factors.

The International Ergonomics Association (IEA) has the following text under the section *Definition*:

“Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance.

Practitioners of ergonomics and ergonomists contribute to the design and evaluation of tasks, jobs, products, environments and systems in order to make them compatible with the needs, abilities and limitations of people.

Ergonomics helps harmonize things that interact with people in terms of people’s needs, abilities and limitations.” [7].

The Human Factors and Ergonomics Society [8] uses two definitions on their website “What Is Human Factors/Ergonomics?”. While one is the definition of the IEA stated above, the other is from the Computer Ergonomics for Elementary School Students (CergoS):

“Ergonomics and human factors use knowledge of human abilities and limitations to design systems, organizations, jobs, machines, tools, and consumer products for safe, efficient, and comfortable human use.” [9].

The definition from the IEA has also been adopted in research publications, with Dul, Bruder et al. being a prominent example. [10].

### 3.2 Sources for a List of Relevant Human Factors

The first source for human factors is the IEA, which was already quoted for their definition of ergonomics in the section before. They divide ergonomics into three main domains: physical ergonomics, cognitive ergonomics and organizational ergonomics. Although the terms contained in Table 1 are called topics by the IEA, we interpret them as individual or grouped human factors.

**Table 1.** Human Factors taken from the IEA website [7]. Entries marked with \* were excluded for reasons stated in the discussion (Sect. 4).

Physical ergonomics	Cognitive ergonomics	Organizational ergonomics
Working postures	Mental workload	Communication
Materials handling	Decision-making	Crew resource management
Repetitive movements	Skilled performance	Work design
Work related musculoskeletal disorders	* Human-computer interaction	Design of working times
Workplace layout	Human reliability	Teamwork
Safety	Work stress	Participatory design
Health	Training	* Community ergonomics
		Cooperative work
		* New work paradigms
		* Virtual organizations
		* Telework
		* Quality management

Hancock et al. [11] compiled a list of human factors to conduct correlational studies regarding trust in human-robot interaction. They split the factors into three categories, human-related, robot-related and environmental factors.

**Table 2.** Human factors from Hancock et al. [11]. Entries marked with \* were excluded for reasons stated in the discussion (Sect. 4).

Human-related	Robot-related	Environmental
Attentional capacity	Behavior	* In-group membership
Expertise	Dependability	* Culture
Competency	Reliability of robot	Communication
Operator workload	Predictability	* Shared mental models
Prior experiences	Level of automation	Task type
Situation awareness	Failure rates	Task complexity
Demographics	False alarms	Multi-tasking requirement
Personality traits	Transparency	Physical environment
Attitudes towards robots	Proximity	
Comfort with robots	Robot personality	
Self-confidence	Adaptability	
Propensity to trust	Robot type	
	Anthropomorphism	

Ogorodnikova considered human strengths and weaknesses in HRC in her publication [12]. The human factors she mentions can be grouped into three categories: information processing, human error and physical ergonomics. While human error by itself could be regarded as a single human factor, it is listed here as a category with its different forms to represent the significance it has in her publication.

**Table 3.** Human factors from Ogorodnikova [12].

Information processing	Human error	Physical ergonomics
Decision-making time	Slip	Magnitude of load
Decision accuracy	Lapse	Mutual allocation
Mental workload	Mistake	Dimensions
Vigilance	Violation	Safe methods of operation
Awareness		Kinematics
		Anthropometrics
		Robot anatomy
		Contact forces

Maurice et al. [1] present an approach to reduce musculoskeletal disorders by using collaborative robots. The focus is the ergonomic evaluation of HRC. A main result of the publication is a list of ergonomic indicators used for the evaluation. While these are exclusively biomechanical, we view them as relevant because of their in-depth description.

**Table 4.** Human factors from Maurice et al. [1]. Entries marked with \* were excluded for reasons stated in the discussion (Sect. 4).

Constraint oriented indicators	Goal oriented indicators
Joint normalized position	Balance stability margin
Joint normalized torque	Dynamic balance
Joint velocity	Velocity transmission ratio
Joint acceleration	Force transmission ratio
Joint power	Head dexterity
	Kinetic energy

## 4 Discussion

In this section, the results of the literature research presented in Sect. 3 are discussed. The section shares the same structure as Sect. 3 for clarity reasons.

### 4.1 Discussion of Definitions of Ergonomics and Human Factors

While the definitions from the Cambridge dictionary are very general, they are a good way to cross-check definitions from a scientific background against definitions meant for the general linguistic usage. The key points of the definition of ergonomics is the focus on people and their environment and the focus on effectiveness. Compared to the human factors engineering definition, people and effectiveness are used as well, however the focus lies more on the interaction partner than the environment. Even in the Cambridge Dictionary, both terms are marked as related, since ergonomics is remarked below the human factors engineering definition.

The main aspects of the CergoS definition are the focus on human abilities and limitations, the design of different types of systems and safe, efficient and comfortable human use. However, these three focus points are also mentioned by the IEA. Human abilities and limitations is mentioned in the last sentence. The focus on systems is mentioned in the first sentence, although it varies slightly by including the human into the regarded system. The IEA definition wants to optimize human well-being, which can arguably be interpreted to include safe, efficient and comfortable human use of systems.

The IEA definition therefore includes all key points of the CergoS definition and is also widely disseminated and featured in the research domain as well.

Compared to the Cambridge Dictionary definitions, the IEA definition also includes their key points. The focus on people is obvious in both definitions. Whereas Cambridge mentions the environment directly, it can be argued that the IEA includes the human environment into the system as well, if it already includes the human and the other system components.

Therefore, we suggest to adopt the verbal definition of ergonomics and human factors of the IEA in the context of HRC as a STS as well.

## 4.2 Discussion of Sources for a List of Relevant Human Factors

Since it would go beyond the scope of this publication to investigate every single factor in detail with this number of factors, only the excluded factors are discussed in the context of HRC as a STS, as defined in Sect. 2.

Starting with the IEA list of human factors (see Table 1), all factors from the physical ergonomics category were included.

In the cognitive ergonomics category, the human-computer interaction (HCI) was excluded because it would be misleading, since HCI is a research topic by itself, and its focus points are represented by other human factors, if at all relevant.

Regarding organizational ergonomics, a lot of the stated factors are focused on bigger groups of humans and therefore irrelevant for HRC. If HRC should be regarded at a bigger scale, featuring multiple robots and humans, those factors can be added retroactively. The excluded factors of this category consist of community ergonomics, new work paradigms, virtual organizations, telework and quality management, all sharing the same reasoning for exclusion as stated in this paragraph.

With regard to the factors collected by Hancock et al. (see Table 2), the first two categories, human-related and robot-related, were deemed relevant completed. Naturally, robot and human are the most important aspects in HRC and we deemed none of the factors redundant. In the environmental category, in-group membership, culture and shared mental models were excluded. In-group membership was excluded because it is a very general term for something that is already covered by various other human factors, including communication, teamwork, work design and crew resource management. Culture was excluded for the similar reasons. It is a very general term, and possible implications for HRC are very complex to establish, so in our view, it would be wrong to include it in a baseline human factors list. The same reasoning applies to shared mental models.

Since Ogorodnikova (see Table 3) shares the scope of HRC for her human factors compilation and none of the factors were deemed redundant, no factor was excluded from the three categories. Her work was included because of the relevant factors regarding human error, the factors focusing on information processing missing from other publications and also the mention of contact forces between robot and human.

The ergonomic indicators identified by Maurice, Padois et al. (see Table 4) are intended as parameters for the ergonomic evaluation of HRCs and therefore fit for inclusion into our list of human factors. While they may be very specific by solely focusing on biomechanical measurements of the human, it makes sense to take them into account.

## 4.3 Compiled List of Relevant Human Factors

In Table 5, the list of all remaining human factors is presented. It has been restructured for better readability. As principal categories, we adopted those of the IEA. Since the physical factors have the most factors by far, they were divided into the subcategories General, Robot-related and Biomechanics. *Operator workload* and *Situation awareness* were removed since they are already represented by *Mental workload* and *Awareness*. *Decision-making* was also removed because *Decision-making time* and *Decision-making accuracy* were already listed.

**Table 5.** Compiled list of relevant human factors.

Physical ergonomics		
General	Robot-related	Biomechanics
Physical environment	Robot type	Dimensions
Working Postures	Robot anatomy	Kinematics
Materials handling	Robot behavior	Kinetic energy
Repetitive movements	Robot dependability	Magnitude of load
Work related musculoskeletal disorders	Robot reliability	Anthropometrics
Safety	Robot predictability	Contact forces
Health	Robot proximity	Joint normalized position
	Robot personality	Joint normalized torque
	Robot adaptability	Joint velocity
	Level of automation	Joint acceleration
	Failure rates	Joint power
	False alarms	Balance stability margin
	Transparency of action	Dynamic balance
	Anthropomorphism	Velocity transmission ratio
		Force transmission ratio
		Head dexterity
Cognitive ergonomics		
Mental workload	Competency	Propensity to trust
Skilled performance	Prior experiences	Decision-making time
Human reliability	Demographics	Decision accuracy
Work stress	Personality traits	Vigilance
Training	Attitude towards robots	Awareness
Attentional capacity	Comfort with robots	Human error
Expertise	Self-confidence	
Organizational ergonomics		
Workplace layout	Design of working times	Task complexity
Communication	Team work	Multi-tasking requirement
Crew resource management	Participatory design	Mutual allocation
Work design	Task type	Safe methods of operation

## 5 Conclusion and Future Work

Interpreting HRC as a STS, we chose definitions for both terms as foundation for a literature review on definitions for the terms ergonomics and human factors, as well as different human factors. The goal of the review was to suggest one definition and a list of human factors with relevance to HRC as a STS. Afterwards, we presented definitions and factors gathered during the review. We discussed differences between those definitions, resulting in the suggestion to use the definition of the IEA. Subsequently, the human factors of the different source were discussed, with the reasoning behind the exclusion of factors in the focus. In the last chapter, the compiled list of human factors is presented.

This investigation is intended to contribute to a foundation for the ergonomic evaluation of HRC by suggesting definitions for the essential terms of HRC and a basic list of human factors.

The next step is to find definitions of metrics derived from the human factors list, in order to create a new way to calculate ergonomic scores. Due to the very different natures of the stated factors, we believe this to be a major challenge. While some may represent physical quantities and are therefore calculable, other require empirical methods to develop metrics.

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