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# The Comfort Zone Concept in a Human-Robot Cooperative Task

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**Abstract.** The global rise in interest towards robotics and artificial intelligence is increasing the technology acceptance among companies. This further encourages manufacturing companies to invest more in robotics on their factory floor. A robot manipulator can be sufficiently mobile and dexterous to operate alongside a human as would any other colleague. However, a human-centric viewpoint is needed in the design of the work cell to provide optimal working conditions for humans and thereby enhance employee performance. We identified a set of factors required for human comfort during cooperation with robots. These factors were divided into two main groups: mental and physical. Both mental and physical factors were based on scientific work reviews, robotics standards, and recognized human factors via a case study. These factors together are the basis for a comfort zone concept in human-robot collaboration. This concept forms design principles for developing the physical work environment of the future.

**Keywords:** Comfort Zone Concept, Human Robot Cooperation, Interaction, Collaboration, Cognition

## 1 Introduction

Currently, robots and needed safety equipment and clearance distances are taking up considerable space on factory floors. Production demands on factory floors are subject to continuous development. The diversity of product inquiries and the unpredictability of the marketplace are well recognized. These inherent changes require flexibility in the manufacturing processes, networks, factory layouts, and management systems. Moreover, local markets with low production levels must become competitive in the global marketplace and alongside mass production industries. As such, regional manufacturers must have highly customizable and personalized product lines in countries characterized by high production costs, low commitment rates, and high-quality requirements. [1]

Collaboration between humans and industrial robots is now a critical consideration due to the aging population, which, during the last decade, was six times greater than the overall population growth in Europe. In addition, there

is a demand from manufacturing companies to postpone the age of retirement [9]. Older workers typically have precious work experience that can be utilized for longer periods if these workers are provided with physical assistance on the production line as their physical abilities decline. Moreover, replacing this age group with younger generation workers requires the development of skills in these workers, which likewise takes time and money. Currently, there is shortage of experienced workers in all of Europe, and Finland has one of the severest shortages of skilled workers [10] in comparison with other European countries.

A robotic partner on the production line can physically assist a worker and be trained with the skill set required on the production line. While a human can perform more complex operations that require higher cognition, robots can do repetitive jobs, heavy material handling, and tasks requiring high physical flexibility. Furthermore, the European Union’s support for the consideration of collaboration scenarios involving human-technology interaction is highlighted in the INDUSTRIE 4.0 vision, which provides a roadmap for the so-called 4th industrial revolution [2].

The main aim of this current research is to develop a comfort zone concept (CZC) that can be used as a design guideline for designing better workplaces in the future. This paper presents a human-robot CZC that comprises a set of factors to optimize the production line environment. CZC prioritizes human comfort when working with an industrial robot.

## 2 Related Works

Here, we explore human behavior regarding interactions in the work environment. The main difference between humans and other creatures is our ability to engage in teamwork with shared intentions and objectives [26].

To achieve a desired goal, teammates must have strong commitment and determination to share learned behaviors and related cognitive abilities. During work interactions, two humans continuously observe each other to optimize the comfort of their work process. Human psychology and ergonomics contribute to these observations. Therefore, a robotic teammate and the surrounding workspace should mimic this cooperative behavior to optimize human comfort. Table 1 shows a review path of existing work related to the psychology, cognitive aspects, and human brain function with respect to cognition in human-robot Interaction (HRI) and human-robot collaboration (HRC).

An effective use of robots that considers human personality types and daily life preferences will produce a more trusting and satisfactory relationship between humans and robots [27]. Production line workers not only physically interact with the system, but their behavior is also a factor as they engage with the system during teamwork. As shown in Table 1, the main trends indicate that many studies have focused on HRI and HRC issues related to specific human cognitive needs, ergonomics, and the adoption and implementation of technology. These focuses are essential but not sufficient when considering each approach individually. Therefore, there is a gap in research regarding the concept of cre-

**Table 1.** The summary of most relevant contributions associated to this research.

Main Trends	Existing Works
Psychology	From Human Factors to Human Actors: The Role of Psychology and Human-Computer Interaction Studies in System Design [11] The psychology of emotion [12] What Is Satisfying About Satisfying Events? Testing 10 Candidate Psychological Needs [13] Goal constructs in psychology: Structure, process, and content [20]
Cognitive Aspects	Design for aging [6] Meeting of minds: the medial frontal cortex and social cognition [21] Human Factors Experiences in Context - Comparing Four Industrial Cases Using a Soft Systems Framework [22]
Cognitive Robotics/Automation	Finding Trends in Human-Automation Interaction Research in Order to Formulate a Cognitive Automation Strategy for Final Assembly [15] Knowledge-based social networking app for collaborative problem-solving in manufacturing [17]
HRI/HRC	Two Faces of HumanRobot Interaction: Field and Service Robots [14] On a human-robot collaboration in an assembly cell [16] An implemented theory of mind to improve human-robot shared plans execution [18] Human-Robot Interaction-Review and challenges on Task planning and Programming [19]

ating a zone that covers the principal human aspects required to fully support workers in manufacturing settings or an assembly line.

In the following section , we propose a general implementation roadmap for creating the CZC. In the next section, we identify the mental and physical factors related to the design model of the Comfort Zone, and the task types in which humans and robots engage. In the last section, we suggest future prospects for the development and application of the CZC.

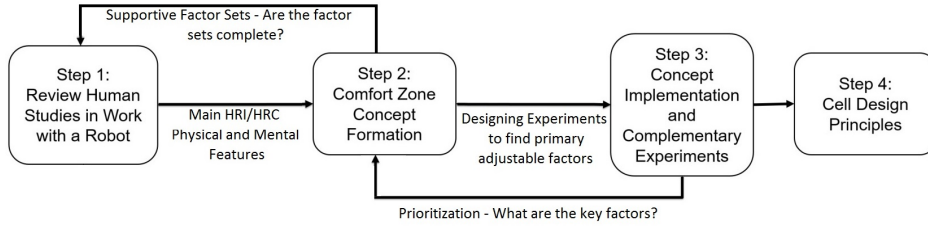
### 3 Comfort Zone Concept

Communication between interactive systems that is based on human preference requires a user model. In this study, we propose a guideline for facilitating progress from the current state-of-the-art field of industrial robotics with respect to interaction and collaboration, as well as associated human factors (in ergonomics and cognition). Our goal was to choose factors to realize an industrial robotic work cell model, for which human operator comfort is its primary design key.

#### 3.1 Research Methodology

The main aim of the research is to create definition of CZC and design guidelines based on the CZC. The methodology for the research consists of 4 steps (Fig. 1).

Step 1: Extract robotic work states and human features that make people feel most supported. For this step, we reviewed related standards (in robotics and human factors) and scientific works to identify and select the most appropriate physical and mental features. Step 2: Create a concept for an interactive or collaborative zone between a robot and human, in which the robot continues to work and the human feels supported. This zone contains the features identified in step 1.



**Fig. 1.** Main steps in comfort zone concept.

Step 3: Sensor data are integrated with the collaboration methods to establish the actual assembly steps. The data from sensors are fused with the CZC to control robot behavior in supporting the human CZC. The experimental study of human behavior is performed in this step to adjust each factor. Step 4: Create a complete workcell design with sensors in place and the human engaged in an actual manufacturing task.

The workcell includes the personalized work station adjusted according to user preferences with respect to lighting, table height, size/reach of operator, and user seating preference while working or user distance preference (personal comfort zone). In this paper, we focus on steps 1 and 2.

There are two aspects to cooperation: mental and physical (Fig. 2). When starting a task, a human worker will automatically consider how to do the work and, at the same time, have a positive or negative feeling about the job. The physical aspects involve human factors and ergonomics. Human physical factors in an environment adjacent to a robot can be categorized into three main sectors: human, environment, and task. The second aspect involves important human mental functions such as attention, memory, language comprehension, and executive control, which is also known as human cognition [3, 6, 21].

### 3.2 Factors Relating to Mental Comfort

The mental aspects of human work include human brain functions or the so-called cognitive aspects. Cognitive aspects are generally grouped into attention, memory, language comprehension, and executive functions [6] (Fig. 2). Attention involves the ability to focus on a particular process (while disregarding useless

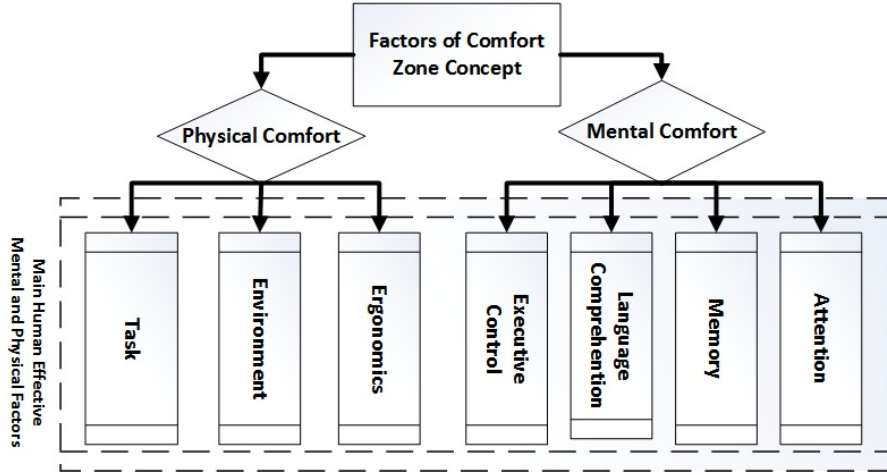
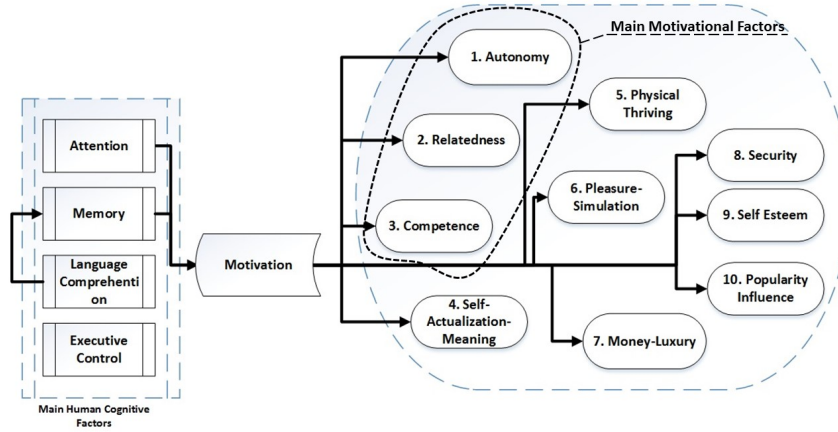


Fig. 2. Overview of CZC based on mental and physical comforts factors.

information generated by the environment) and the capacity of humans to multi-task. Memory refers to the ability of a human to mentally encode data, to store that data in the brain, and to recall the data when required. Language comprehension has a direct connection with memory and refers to the ability of the human to use perception for understanding a written or vocal message and to represent that meaning to the brain. The executive control function comprises cognitive skills correlated with the preservation and updating of cognitive and behavioral objects, the outlining and sequencing of operations, problem-solving, and the withholding of automatic replies. Studies show executive control to directly affect the aging persons life and, therefore, must be carefully considered [4, 5]. Figure 3 shows the brain's four cognitive functions.

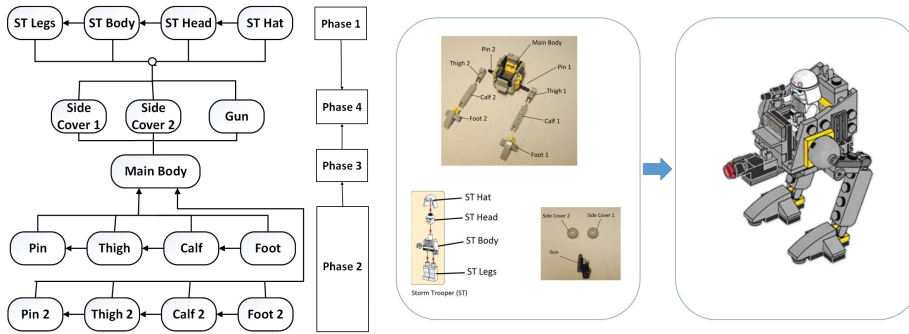
Maintaining human motivation in the workspace enables the maintenance of memory and attention and helps the individual to exhibit good performance and sustain a high-quality work level during extended working hours [28]. Motivation can be considered to be an implemented preference with respect to the task goal during the work process, whereas personal satisfaction is related to performance-related rewards [28]. Hence, a worker can be dissatisfied regarding his/her working style, task execution, or awards, but could still be deeply motivated to accomplish the task at hand, which confers ambition, good performance, and the inclination to keep working for a longer period of time.

Based on the work of [13], main motivational factors were adjusted with respect to the four main factors of autonomy, competence, relatedness, and self-esteem, the first three of which are also proposed by the self-determination theory [3]. Motivational aspects were also tested in experiments for this paper and confirm the importance of the psychological factors considered during an assembly case study with a robot (Fig. 4). Tests included interaction and collaboration tasks for human beside a collaborative robot (Universal Robot model



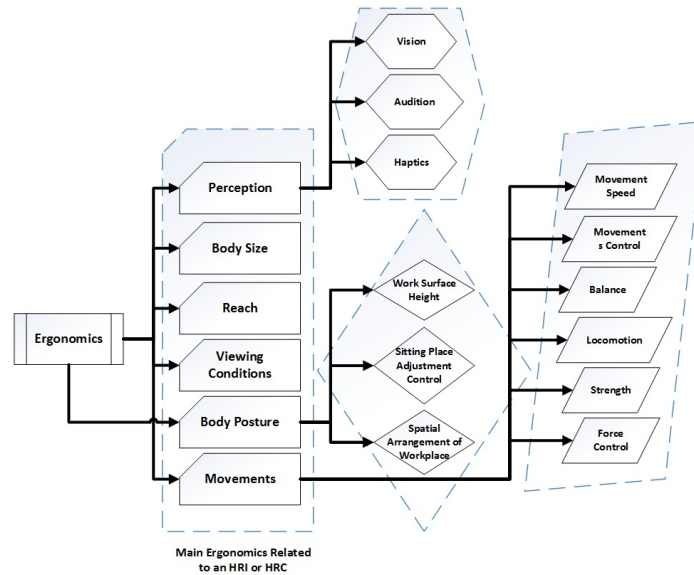
**Fig. 3.** The human mental functions are always engaged with the job at hand. The motivation to work beside the robot is critical during joint operation. By sustaining motivation, the human can retain the necessary level of attention and memory while performing a task.

UR5). In the experiments, 42 test subjects participated in Lego assembly phases that required high accuracy and a robot helped by delivering the main body and parts in the correct order to the participant. The participants then gave feedback about how they felt about their interaction or collaboration with the robot. The results showed a range of participant cognition-level engagement in the work, which demonstrated the importance of considering all cognitive factors and specifically autonomy, competence, and relatedness.



**Fig. 4.** Assembly State Decomposition Model [23] of the task performed using HRI and HRC.

Language comprehension refers to the human ability to observe texts and signs and then mentally translate them to generate meaningful phrases and an appropriate reaction. Comprehension is an essential skill set for a person employed beside a robot. However, comprehension will rely profoundly on memory. By maintaining appropriate workcell instructions, signs, and human-machine interfaces (HMI), humans can remember to use them as necessary. Therefore, supporting memory will also help humans to comprehend textual information.



**Fig. 5.** List of human ergonomic factors that are valuable in a human-robot workcell. Elements with no sub-branches are adjustable; otherwise, only the sub-braches are adjustable.

### 3.3 Factors Relating to Physical Comfort

Factors relating to physical comfort can be divided into three categories - ergonomics, environmental features, and the task type to be performed beside the robot (Fig. 2).

**Ergonomics** Ergonomics relate to the human physical features engaged during a manufacturing task next to a robot. We identified these factors by reviewing and selecting robotics standards as well as aspects identified in human factor studies [24, 7, 8]. Robots that adjust to a person's ergonomic condition or that can consider a person's limitations will help to provide more acceptable working conditions for the human during work hours. The main factors examined with

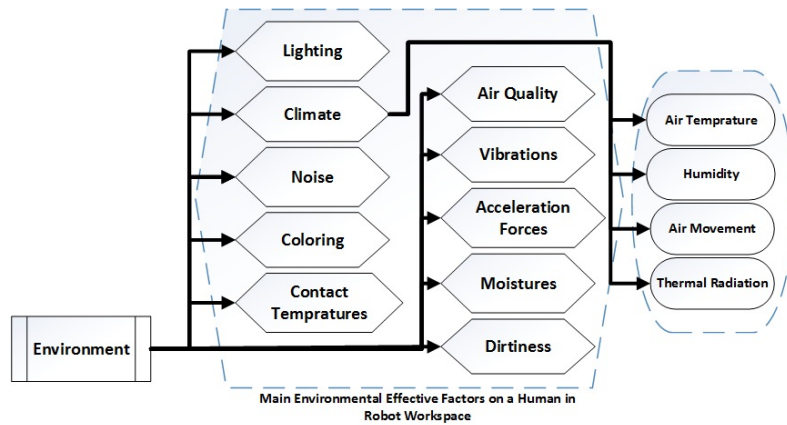


respect to the human physical state include sensory perception (vision, hearing, and haptics), bodily dimensions, reachability, viewing statuses, body posture, and movements.

Body posture can be maintained by adjusting the work height and sitting area as well as the spatial arrangement of the workcell. Human movement [6] factors include speed, movement control, balance, locomotion, strength, and force control.

**Environment** The environment includes human comfort factors related to the workspace, such as climate, noise, lighting, coloring, contact temperature, air quality, vibration, acceleration force, moisture level, and cleanliness of the workspace [24].

Climate factors [25] comprise room temperature, humidity, air flow, and thermal radiation, all of which can usually be adjusted by a central automation system. However, human climate comfort is an essential aspect when there is frequent interaction with a robotic partner.



**Fig. 6.** List of valuable environmental factors in a human-robot workcell. Elements with no sub-branches are adjustable; otherwise, only the sub-branches are adjustable.

**Task Type** Tasks performed when working next to a robot can be categorized into two types - interaction and collaboration. Interaction occurs when a robot simply passes parts to the human or takes elements away. The interaction task shown in Fig. 4 is performed by the robot moving the assembly parts and the main body into the human work area and then taking the main body away from the work area once the work is completed by the human.

Collaboration refers to instances in which the robot and human touch or operate on the same product at the same time. The human and robot have

common goals at each step in their collaboration. For example, in Fig. 4, phases 3 and 4 are performed while the robot holds and rotates the main body to facilitate the reach of the human when installing legs and auxiliary parts in the assembly.

## 4 Conclusion

The domain of this research includes the study of human performance and adaptation to industrial robots and available technologies. This work is significant for the consideration of the factors to include in design models. This study provides a guideline for creating the Comfort Zone Concept. During the investigations, identification of the most relevant factors relating to design a better cooperation between human and machine was performed. CZC refers to a set of factors that relate to a design that addresses both human mental and physical comfort in a workspace. Moreover, the autonomy, relatedness, and competence were proved during experiments to be the drivers for human motivation in HRI and HRC.

In future work, each element will be modified to optimize its value for human productivity and comfort. We note that increasing all these factors will not necessarily result in human comfort, but their adjustability is the primary goal. These adjustments should be based on individual factors and the effects of other factors. Ultimately, we expect workers to enter a human-friendly space modeled on their personal CZC.

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