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# Framework of a Neuroergonomic Assessment in Human-Robot Collaboration

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Human-robot Collaboration (HRC) is a relevant research field dealing with socio-technical and economic issues to consider in manufacturing industries. A Human-robot team, where the partners are human and robot, committed to reach a common goal through a collaboration, is the highest grade of interaction according to the different modes of integration of the robot in the manufacturing workplaces. In this regard, collaborative robots, or cobots, have enthusiastically found application in manufacturing assembly activities. However, the implementation of the cobot in the manufacturing workplace might be challenging as it requires a changeover of the environment, and it might be critically decided according to the task defined. Despite these drawbacks, the benefits highlighted by previous research works seem positively impact on the physical and mental health of the operator working alongside these machines. This research paper shows the impact of cobots on operators and the surrounding work environment from a neuroergonomic point of view. The article proposes a comparative analysis in a laboratory workstation set up for manufacturing assembly tasks, in which the operator accomplish an assembly task with and without the robot assistance. The presence of the robot is the element of comparison in the experimental design of the assembly task. The paper presents a comparative evaluation of the mental workload of the operator performing the task with and without the machine. The collection and analysis of physiological data, through electroencephalogram (EEG) devices, extend the possibility to set an ergonomic evaluation of the cognitive state of the operator during the HRC application.

*Keywords*: Human-Robot Collaboration; Neuroergonomics; Collaborative Robotics; Mental Workload; I4.0; EEG.

## 1. Introduction

Sustainability is one of the pivotal aspects of Industry 4.0, or I4.0. Sustainable companies consider environmental, social, and economic aspects to guarantee a higher level of productivity, quality, and efficiency of the company. In this regard, sustainable products are the result of processes in which environmental impacts are reduced and safety and ergonomics principles are respected for the welfare of employees (Braccini and Margherita, 2018).

Organizational Health and Safety (OHS), wellbeing and satisfaction are the core of sustainability processes in manufacturing to improve safety, physical and mental health of operators (International Ergonomics Association)

Therefore, manufacturing companies should consider the human element as a relevant resource and a valuable part by improving work conditions and developing human-centred production systems. A possible and concrete solution to improve the social sustainability without neglecting the production efficiency is represented by human-robot collaboration (HRI), as demonstrated by the increasing scientific literature on such a topic (Zhong et al., 2017, Gualtieri et al., 2019).

HRC is the utmost application of collaborative interaction between human and robot in the industrial workplaces. It guarantees either a proper assistance or interaction of the machine co-working with the operator in those activities that are stressful, repetitive, and complex, in which the physical and mental workload might be exacerbated. The success of HRC is in part due to the ground-breaking application of collaborative robots or co-bots. These devices are more intuitive than their ancestors and allow a closer interaction with the operator, in a fenceless environment (Faccio et al., 2019).

Furthermore, the implementation of cobots in manufacturing workplaces defines different typologies of collaboration with the human mate. Different modes of cobot implementation are objects of study: Speed-rated Monitored Stop, Hand-Guiding, Speed and Separation Monitoring, and Power and Force Limiting (Wang et al., 2017).

With the application of cobots, the human role has been changed by the disruption of automation technology in the real-world manufacturing scenarios. Assembly tasks are more and more monitored by the agent to possible system failures. In this regard, ergonomic assessment is of paramount importance for an HRC activity (Johansson et al., 2018; Gualtieri et al., 2019).

Neuroergonomics, as the application of neuroscience to ergonomics, allows a deeper acknowledgement of the operator's mental workload (MWL) (Parasuraman and Rizzo, 2006; Ayaz and Dehais, 2019).

The analysis of MWL is defined through indirect and direct observational methods. These last methods are possible through unobtrusive and portable devices such as EEG that paves the way to a new methodology of objective ergonomic assessment, monitoring, and evaluation of parameters in the field of HRC (Katmah et al., 2021; Salehzadeh et al., 2022).

The paper highlights the application of EEG devices in a comparative analysis of a manual assembly task in a laboratory environment between two cases in which the operator works with and without the robot.

## 2. Literature Review

Cobots have seen a drastic deployment in those repetitive, tedious manual assembly tasks in industrial scenarios (International Federation of Robotics).

Due to their ease to be programmed, no-sharp edges and sensibility through the adoption of visual sensors, the adoption of these innovative machines replaced the conventional robots in industries, allowing to accomplish tasks in fenceless environments. The application of these machines allowed robotic designers to set advanced HRC interaction to allow the system to properly communicate with the operator during a task (Faccio et al., 2019).

Authors designed a symbiotic interaction between the human and robot in a fenceless workplace for those critical tasks where both the agents, robot and human, work in proximity (Wang et al., 2019).

Hoffman defined the concept of collaborative fluency, in which the two parts cooperate synchronously as teammates in the shared workplace (Hoffman, 2019).

Wang stated that shared activities come to enhance the level of flexibility and scalability of tasks in the workplace by the collaborative aid of the human and the robot (Wang 2019).

Furthermore, the deployment of cobots requires careful safety aspects in the design phase to avoid unexpected collisions. (ISO 10218-1/2; ISO/TS 15066, 2016).

The proper level of automation is of concern in the HRC. A poor automated collaboration makes the task more flexible, cost effective, and let the operator act and think without any constraints (high decision making). However, the operator might be dissatisfied in those repetitive and tedious tasks. On the other hand, a full-automized system does not let the operator be impactful in the process, with less decision making. The lack of situation awareness of the operator working

alongside these systems increases the degree of psychological stress (Liu et al., 2021).
To deal with this last issue, Ergonomic principles are adopted to let the operator be more involved. In the case of the HRC, ergonomic principles are applied so as the operator is in harmony with the other systems involved in the workplace, such as the robot, sensors and other equipment or devices used during the execution of a task.
Different factors might affect operator (Scafà et al., 2019).
Among these, operator's mental workload (MWL) affected by the presence of the robot is the subject of study of this research paper.
According to Teplan (2002), workload may be conceived as the cost of mental or cognitive energy spent by the operator to achieve a determined level of performance. Furthermore, workload is the level of effort experienced by the operator when performing a task. Different factors influence operator workload, either internal or external. Internal factors are related to the current state of the operator during the task, both mental and physical capability. On the other hand, external factors include the level of difficulty of the task, the time available, as well as environmental factors such as temperature and lighting. Therefore, in the design phase, workload must be levelled for the success of the task performance (Infantolino et al., 2014).
The focus on the operator's mental state and behaviour has progressed towards the analysis of physiological or neurological responses. Such analyses provide an opportunity for timely communicate the workload information to the operator (Felice et al., 2016).
Different physiological measures are evaluated for the analysis of the mental workload. Nevertheless, the acquisition of these parameters is affected by noise from the surrounded environment, strong emotional responses, and motor activities (Katmah et al., 2021).
Berberian et al. (2019) suggest that the EEG technique is the most suitable to deploy in a HRC work cell for its portability and versatility. Moreover, EEG analysis provides optimal results of the mental state of the worker regarding his or her excitement working in proximity with the robot.
This study refers to the analysis and monitoring of electroencephalogram signals (EEG), with and without the intervention of a robot during an industrial manual assembly task. The analysis of EEG data allows an easier study of the outermost neural activity of the brain.
Indeed, the collection of EEG signals involved different oscillatory components, more impactful in the different channels placed on the cap. Furthermore, the signals show a good correlation with the MWL in terms of suppression of alpha waves and improvement of theta waves (Fernandez et al., 1995; Ryu and Rohae, 2005).
The goal of the analysis is to define the level of the mental workload variance of the operators when they perform a manual assembly task in a laboratory workstation with and without the assistance of the robot. This paper aims to set the steps for an optimized and efficient analysis of mental workload of the operator working alongside with automated systems such as cobots.

## 3. Design of the Experiments

The experiments were set up in the modular industrial assembly workstation designed for neuroergonomic experiments based at the laboratory of the Faculty of Engineering, University of Kragujevac, Serbia (FINK) in collaboration with Mbtrain company, Belgrade, Serbia (Savkovic et al., 2022).
The participants were University scholars from FINK selected by an open-voluntarily application form, with no previous experience in a HRC application. For this initial analysis, 3 male participants, right-handed, were selected to perform the tasks. The average age of the participant is 22 ± 1 years old. Before conducting the experiments, the candidates signed an agreement consensus for the treatment of their personal and physiological data defined by the University Administration of the laboratory.
The tests consisted of sequential manual assembly tasks, divided in two sequential sessions, each one where the candidates assembled 75 prototypal pieces recalling industrial components. The two sessions were separated by a break of 15 minutes. Each session lasted 90 minutes.
Two scenarios (standard and collaborative), shown in Fig.1 and Fig.2, are set up for the experiments: in the first scenario the participant accomplished the task without any interference in the assembly area; in the second scenario, the

robot carried sequentially the components to the assembly providing them to the operator.

In both scenarios, a touch-screen monitor is set in front of the candidate to guide him during the different phases of assembly of the components. The candidate performed the task seated on an ergonomic adjustable chair. The workstation is also customized according to the anthropometric characteristics of the operator. A video camera is mounted to track and record the sessions. During the tasks, a checklist of the pieces completed allowed to verify which components were accomplished in the correct way.

In both tasks, the components were the same. However, the execution of the task was shown on the PC touchscreen, see Fig.1 and Fig.2: the procedure to assemble the components, inserting the wires in the appropriate allocations, is defined by random illustrations of the component assembled on the screen.

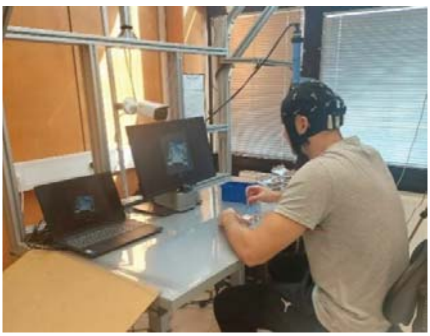

Fig. 1. Standard Scenario: the participant performed the task without the robot. The components were set next to the candidate in the workplace.

Fig. 2. Collaborative Scenario: the participant performed the task with the robot. The components were carried by the robot to the candidate, while the participant perform the current assembly task.

The two experimental scenarios were set in two different periods of the year with a time span of minimum 6 months to reduce the error-bias in the comparative neuroergonomic analysis between standard and collaborative scenario. The two scenarios were set up in the laboratory of FINK.

The goal is to conduct a comparative analysis of the mental workload by the EEG real-time acquisition in the collaborative scenario.

Moreover, to reduce the noise due to internal factors that might influence the workload, experiments started in the morning hours of the day, conducted in an isolated environment and at room temperature (Mijovic et al., 2017).

For the analysis of EEG data, the neuroergonomic Easycap (mBrainTrain, Serbia) was mounted on the scalp of the participant through a detailed protocol set up at FINK. The cap consists of 24 channels to collect different signal waves from the neural activity of the candidates' scalp.

The industrial cobot used for the tests in the second scenario is the MELFA ASSISTA (Mitsubishi Electric). The robot allows a direct interaction with the operator in a fenceless environment moving simultaneously while the operator perform the tasks thanks to the internal sensors revealing the presence of the candidate in the workplace. Furthermore, the logic for the robot to carry the components in the workplace was defined by a pick and place algorithm implemented in the robot software. In this way:

(i) The robot picked the components out of the workplace environment.

(ii) The robot entered the workplace with the component and placed itself in the so-called manual assembly area waiting the operator finishing the current piece.

(iii) The operator grasped the following piece from the robot and started the assembly activity. The end-effector logic of the robot, through a force sensor monitoring the control phase of the piece, acknowledged that the piece was removed and sent the signal to the cobot which returns to the area external the workplace to pick the next component.

The robot moved simultaneously during the assembly activity of the operator. In this way, according to the levels of HRI, the task defined in the second scenario is the one of the collaboration modes (Gervasi et al., 2021). The robot pathway is designed to optimize the cycle-time of the machine to get from the external area to the assembly area. The cobot speed is set in collaborative mode (250 mm/s). The robotic workstation is set at the distance of 1000 mm from the operator (Arai et al., 2010).

## 4. Results and Discussions

EEG signals are very sensitive to artifacts and noise, whose source are not the brain. Regarding the noise, a band-pass filtered 1-40 Hz is applied for its reduction.

Possible sources of artifact in EEG signals include either technical reasons or person's own behavioural and physical activities. These artifacts can be inspected manually by expert eyes, but automatic artifacts detection is encouraged in automated system designs, otherwise artifacts can corrupt the results (Katmah et al., 2021).

Different methods are applied to remove artifacts. In the pre-processing phase, authors applied the Independent Component Analysis (ICA) to remove these artifacts. Finally, EEG signals were re-referenced to their average value (Ochoa, 2002).

Feature extraction is the further step after the pre-processing phase of EEG signals. The goal of this paper is to show the mental workload index (MWL). Hence MWL was defined as:

$$MWL = \frac{f(\theta)_{frontal}}{f(\alpha)_{parietal}} \tag{1}$$

The MWL indexes for both sessions are shown for the two scenarios for each participant in Table 1-2 below.

The MWL index is generally higher for the participants in the collaborative scenarios. These results showed a higher cognitive workload when candidates performed the task alongside the cobot. These initial results are in line with previous research studies in which, according to questionnaires, the candidates felt a certain level of fatigue when performing a task with the robot (Arai et al., 2010; Kong, 2018). Furthermore, the MWL index in the first sessions is higher than the second one. An explanation of this reduction is due to the higher awareness and confidence that participants perceived due to the repetitiveness of the activity when they re-performed the assembly tasks in the second session (Wheatley et al., 2018).

Table 1. MWL index in the standard (SS) and collaborative (CS) scenario for each participant in the session 1

| Subject | MWL (SS) | MWL (CS) |
|---|---|---|
| 1 | 1.6171 | 1.6705 |
| 2 | 1.2153 | 2.1777 |
| 3 | 2.2513 | 2.9994 |

Table 2. MWL index in the standard (SS) and collaborative (CS) scenario for each participant in the session 2

| Subject | MWL (SS) | MWL (CS) |
|---|---|---|
| 1 | 1.3303 | 1.5355 |
| 2 | 0.9905 | 1.131 |
| 3 | 3.0495 | 3.056 |

## 5. Conclusions

The goal of this paper is to show through a comparative analysis the impact of the cobot in an assembly task in terms of mental workload through the EEG methodology. The power of the EEG method consists of a direct observational method that allows to acquire real-time data from the brain activity of humans. Furthermore, the method avoids any form of bias.

The design of the experiments was set up to conduct neuroergonomic tests in a laboratory assembly task. The initial results showed a higher level of MWL index in the collaborative scenario. These results are promising for further studies regarding the impactful aspects of MWL in industrial assembly activities. The comparative analysis is crucial to determine the rate of MWL when the robot co-participate in the tests. However, the study needs further tests and correlations with other data to provide a thorough explanation of the behavioural state of the operator during these activities. Electromyogram (EMG) data would allow to offer a more comprehensive analysis of the physiological state of the operator. Furthermore, an analysis of productivity, in terms of pieces successfully completed, would allow a better representation of the correlation of workload with the efficiency of the overall task. Further analyses would be conducted for more participants and more data would be provided from the tests.

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