2022 IEEE International Conference on Metrology for Extended Reality, Artificial Intelligence and Neural Engineering (MetroXRAINE) | 978-1-6654-8574-6/22/$31.00 ©2022 IEEE | DOI: 10.1109/MetroXRAINE54828.2022.9967677

A comprehensive UX index to evaluate industrial tasks from a human-centered perspective

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***Abstract*—Recent advances in physiological monitoring devices have supported the diffusion of a human-centric approach also within industrial contexts, where often severe working conditions limit the analysis of the operators' User eXperience (UX). Several methodologies have been presented to the scientific community to assess the overall UX of workers performing industrial operations. These methodologies have also tried to encompass the diverse aspects of the physiological response (e.g., mental workload, stress conditions and postural overloads). The current study aims to refine a unique and comprehensive UX index to identify the specific causes of the user discomfort in advance and to optimize the overall system design. A full set of non-invasive wearable devices was applied to a virtual reality (VR) simulation while performing manual operations to collect relevant physiological parameters and to finally assess the overall UX. The results demonstrated the effectiveness of the proposed index in anticipating the operator's critical conditions by specifying the possible causes of the ergonomic discomfort. Future works will focus on investigating the theoretical foundation of proposed solution and on providing a statistical validation on a larger population.**

Keywords - User Experience; Human-Centered Design; Industry 5.0; Virtual Reality; Human Monitoring; Ergonomic Index

I. INTRODUCTION

The new-born concept of Industry 5.0 endorsed by the European Commission implies how "the wellbeing of the worker is placed at the centre of the production process and uses new technologies to provide prosperity beyond jobs and growth while respecting the production limits of the planet".[1] Since designing human-centric products and processes is an already known practice but scarcely adopted, Industry 5.0 aims at a more resilient and sustainable approach to the design of industrial systems, from production, logistics, up to maintenance operations. Indeed, the importance of analysing users' needs and ergonomics to optimize the workers' wellbeing as well as the working conditions and to ultimately improve the industrial results has been widely emphasized by the recent literature.[2] This inevitably implies rethinking the factory processes from a human-centric perspective, by successfully integrating human factors (HF) in system design and deployment. Specifically, HF consider environmental, organizational, and job-related aspects, as well as human individual characteristics, which can highly affect health and safety during the human interaction with current technologies. On this last point, the human factors integration (HFI) technique forced the adoption of the most suitable technology in validating new processes and in creating renovated interaction features and interfaces to valorise human competences. Nonetheless, as stated in [3], an important literature deficiency has been identified in terms of designing human-machine interactions at multiple levels.

Thus, the current study contributes to the definition and the implementation of the Human in The Loop (HIL) concept in the modern industrial scenario, which is seeking for sustainable, resource-efficient, and flexible production models, enhancing interactions between people, machines, and products. To this end and compared to previous similar proposals by the authors [4], the following research work proposes an improved tool suited for the industrial context and aimed at analysing the operator UX in carrying out any sort of industrial tasks. The paper presents a comprehensive and renovated ergonomic index, differentiating between postural workload, cognitive workload and stress, and the relative technological setup to investigate the operator's experience and to support the design of industrial products and processes. The paper is structured as follows: section 2 is entirely dedicated to the research background and deepens the role of modern operator within the factory of the future and the importance of adopting UX-based design methods; section 3 presents the research approach and how the proposed index is defined; section 4 describes the experimental testing on a real industrial case; section 5 presents test's results and discusses experimental limitations; finally, section 6 contains the conclusions and future works.

II. RESEARCH BACKGROUND

Nowadays, a mutual and deeper support between operators, machines and products is required during the execution of industrial tasks and in the everyday decision-making. The role of the human operator is changing within modern productive systems, being increasingly assisted by machines in physically intensive or dangerous tasks, while controlling processes and facing high-level and cognitively demanding tasks [5]. Indeed, the technological enhancement is proposing new working protocols such as Cyber Physical Socio Systems (CPSS) which aim at integrating "computation with physical processes whose behaviour is defined by both cyber and physical parts of the system" [6]. Ansari et al.

foresee a mutual transition from a human-machine interaction to active collaboration, promoting cyber-physical-socio interactions, knowledge exchange and reciprocal learning [7]. In order to create an effective smart factory context, Long et al. suggest that human performance should be therefore monitored when driving smart system adaptation [8]: in fact, modern operators are required to be highly flexible and to demonstrate adaptive capabilities in a very dynamic working environment without incurring in postural and cognitively overloading situations. Thus, to analyse the users' needs and ergonomics according to a human-centred approach, specific software tools and devices need to be provided to modern engineers. In [9], a human-centred mixed-reality simulation environment has been provided to optimize postural ergonomics in the workstation design. Brunzini et al. proposed a minimum set of non-invasive wearable devices to monitor human activity and physiological parameters, in addition to subjective self-assessment questionnaires [4]. Several issues arouse when considering human tracking device, from occlusion phenomena up to the environmental lightening conditions: therefore, it is fundamental to understand the context of use and how the testing environment could impact on the data collection. Then, the successful implementation of an appropriate methodology which integrates the user performance assessment with the system adaption could boost the industrial productivity while providing flexibility, sustainability and scalability. Grandi et al. focused in analysing the features of machines, equipment and workers in order to combine human skills and system capabilities to carry out industrial tasks in the most efficient and effective way [10]. Guaranteeing a communication channel that is always open between the user and the system through which information can be exchanged is of absolute importance. In this direction, transdisciplinary engineering (TE) methods can be successfully adopted to solve complex problems related to digital manufacturing [11]. These transdisciplinary approaches include the digital knowledge management, digital prototyping, virtual simulation, collaborative practices and methods to include HF within the factory process design. In particular, TE aims at bridging the gaps between the technical and the social sciences by bringing the needed intelligence into the shop floor to ultimately provide factories with flexible and adaptive behaviours. Hence, the adoption of UX approaches is strategic to move the attention from industrial systems back to people inside modern factories and to include human aspect into design processes.

III. METHODOLOGY

The purpose of the following paragraph is to present the proposed approach to evaluate, in an effective and reliable way, the ergonomic aspects related to the activities of interest. A revised version of the methodology presented by the same research group in [4] for the UX assessment has been here defined (Fig.1) . The main objective is to simplify the approach by avoiding interruptions of the task intended for the compilation of the self-assessment questionnaires and by introducing a unique ergonomic score. Then, the inclusion of this index in an advanced procedural methodology will be tackled in a separate publication. Specifically, this study offers a single and innovative index to interpret the human performance, where all the typical physiological components of the user's discomfort are comprised, appointing to future research its statistical validation. The ergonomic components considered within this index, defined as the User Experience Index (UXI), are:

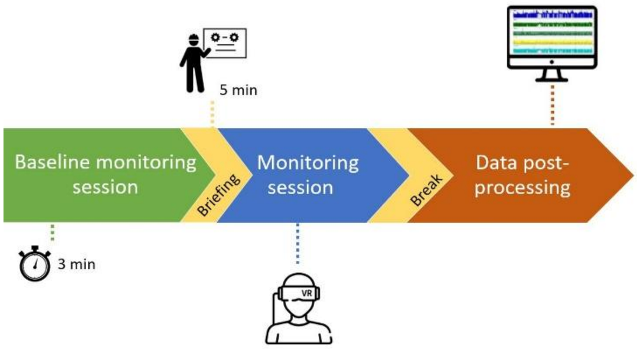

Figure 1 *Sequence of operations performed by each user.*

• Mental Workload (*MWL*): it emerges from the interaction between the requirements of a task, the circumstances in which it is performed and the skills, behaviours and perceptions of the operator,

• Stress (*S*): it describes the physiological response of the sympathetic nervous system,

• Postural Workload (*PWL*): expressed by the RULA score ("Rapid Upper Limb Assessment"), it is an ergonomic index that evaluates the posture assumed by the user, identifying the problems related to the musculoskeletal system. It provides a numerical value between 1 and 7.

Compared to [4], the current algorithm redefines each of the UX components by avoiding the baseline reference and it does not consider the time that the operator needs to accomplish the task due to the lack of any reference time: in future revisions, this parameter will be kept as one of the variables defining the level of user task's experience. In addition, seeing that the task is performed in a virtual scenario, there could have been a mismatch in the execution time compared to the real working context.

Three main equations are determined:

$$UX\ Index \begin{cases} MWL = Mental\ Workload \\ S = Stress \\ PWL = Postural\ Workload \end{cases}$$

In the assessment of the *MWL*, which provides an analysis of the mental load associated with the specific simulated activity, three main variables are considered: the Pupil Activity (PA), the Heart Activity (HA) and the Electro-dermal activity (EDA). Respectively, they analyse the change in pupil diameter, the numbers of heartbeats per unit of time, and the variation of the skin's conductance. All the involved variables are obtained by post-processing raw data collected by devices: as explained in the next paragraph, the choice of such parameters was made in accordance with [4]. In fact, each physiological parameter is based on the definition of a unique evaluation scale for the various activities. Note that the data normalization considers a scale of variation between the maximum and the minimum value of the specific variable recorded throughout the task: then, the variation of the average value registered during the task's execution from the minimum is computed. The formulas used for normalization are shown below.

$$HA_{task} = \frac{HR\ mean - HR\ min}{HR\ max\ - HR\ min} \quad (2)$$

$$PA_{task} = \frac{PD\ mean - PD\ min}{PD\ max\ - PD\ min} \quad (3)$$

$$EDA_{task,MWL} = \frac{EDA\ mean - EDA\ min}{EDA\ max\ - EDA\ min} \quad (4)$$

HR mean is the mean value of the user's HR as collected during the task execution, *HR min* and *HR max* are respectively the maximum and minimum HR values. Similarly, PA and EDA parameters are then calculated.

The normalization according to the minimum value allows to evaluate how much the user deviates, in reference to his average condition, from the condition of minimum effort within the specific task. This choice was justified by the desire to favour both *intra-task* consistency and numerical stability: this entailed the choice of both a local minimum and maximum (i.e., the minimum and maximum value recorded within the single task) rather than global ones (i.e., the minimum and maximum value recorded between several repetition of the task or when analysing multiple tasks).

Thus, the *MWL* parameter is computed as in (5):

$$MWL_{task} = HA_{task} + PA_{task} + EDA_{task,MWL} \leq 3 \quad (5)$$

The stress assessment was based on considering two physiological parameters: EDA and IBI ("Inter Beat Interval", index that defines the time interval between two successive heartbeats). Both values were calculated considering the difference, in absolute value, between the average value recorded during the task and the average baseline value (i.e., the value as recorded during a baseline session of 3 minutes in a resting position). It was assumed that the baseline session represented the stress-free condition for the operator.

The *S* parameter was calculated as in (6),

$$S_{task} = EDA_{task,S} + IBI_{task} \leq 2 \quad (6)$$

where:

$$EDA_{task,S} = \left| EDA_{mean,task} - EDA_{mean,baseline} \right| \quad (7)$$

$$IBI_{task} = | IBI_{mean,task} - IBI_{mean,baseline} | \quad (8)$$

Regarding the *PWL*, it considers the mean value of RULA score during the entire task. Specifically, since the RULA score can be computed separately for both the right and left part of the human body, the maximum value between the two was considered for each instant of time: thus, a single score representative of the worst postural condition is determined. To sum up, the *PWL* is defined as in (9):

$$PWL = mean\ (RULA) \leq 7 \quad (9)$$

Since the *MWL* returns a score between 0 and 3, the Stress returns a value between 0 and 2, and the RULA by definition is defined in the range between 1 and 7, it could be deduced that the UXI assumes values between 1 and 12. This implies that the higher the UXI value, the more the associated task presents critical issues that must be analysed by retracing the steps that led to the definition of the index itself and by identifying which parameter influence the overall performance.

IV. USE CASE

The use case relates to the Oil&Gas sector; in particular, it analyzes a manual operation (i.e., tracing and welding of structural elements on the pressure cans) for pressure vessels manufacturing as shown in Fig.2. The task is characterized by great variability in term of user interactions (seeing that the operator interacts with several mechanical tools) and by continuous change of posture (from standing up to being kneel down while welding). In succession the operator carries out the following sub-tasks:

I. Interpretation of the technical drawing relating to the exact positioning of the support to be welded;
II. Measurement by means of a ruler and indication of the exact position by means of some chalk;

(a) (b)

Figure 2 *A real operator positioning the portal (a) and welding it to the can (b).*

III. Positioning of the portal on the can;
IV. Welding of the portal to the can.

where all the previous operations are performed on top of a can's section with a diameter of 3.5 meters.

According to Brunzini et al., the most suitable non-invasive set of COTS (Commercial-Off-The-Shelf) wearable sensors, providing a sufficient level of detail is selected [4]. In particular, the setup (Fig.3) integrates:

- HTC Vive Tracker suite, to track the human body angles,
- Leapmotion controller, an optical hand tracking module that captures the movements of the hands,
- Empatica E4 wristband, to collect a set of physiological signals,

(a) (b)

Figure 3 *(a) shows the complete sensors' setup for the virtual simulation; (b) shows the disposition of the Vive Trackers according to the ErgoForce user profile within the XRErgo software.*

- HTC Vive Pro Eye headset supplied with Tobii eye tracking system, to collect relevant data regarding the cognitive and visual effort of the user.

Theses choices were made keeping in mind the industrial needs and a possible industrialization of the setup. The physiological parameters are then processed through the following software platforms:

- iMotions platform for the Tobii system's signal processing,
- XErgo software for the on-time postural load assessment: it returns the RULA ergonomic index computed with a frequency of 1 Hz,
- Empatica E4 Realtime to monitor cardiac parameters and the skin response: subsequently, .csv report files are downloaded from the Empatica developer portal to be further manipulated.

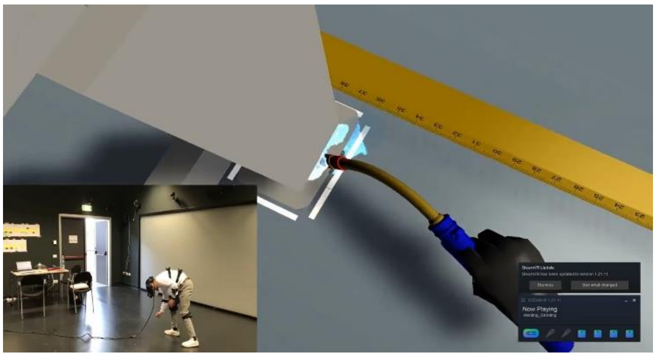

Figure 4 *Double view of the user performing the virtual simulation and the headset view.*

After the analysis of the provided video support concerning the task, the simulation is developed within the Unity engine trying to reproduce as faithfully as possible the real working conditions (background noise, welding flame visual effects, the use of real technical drawing etc.).

Before proceeding with the simulation, a baseline session of 3 minutes is performed to collect physiological parameters in conditions of rest. Then, each user undergoes a briefing session where the task is thoroughly explained. Fig.4 shows a user while testing the simulation during the monitoring session.

V. RESULTS AND DISCUSSION

The study involved 11 participants, including 7 male users and 4 women, with no previous experience on the simulated task and a mean age of 26.9 years (σ = 1.044). Participation in the test was voluntary and no reward was given. A Shapiro-Wilk test returned respectively $W = 0.97736$ and *p-value* = *0.9497* in testing population normality for what concern the height feature (μ = 175.72 cm, σ = 10.946): thus, a normal distribution for the height could be accepted. The demographic survey provided us with information about users' gender, age, height and weight, level of familiarity with the use of mechanical tools and with the use of monitoring devices. Table 1 summarizes the main characteristics of the users' population: the ANSUR [12] value in relation to the specific human percentile for each

TABLE I. TESTING POPULATION CHARACTERISTIC

Operator	**Demographic Info**		**Physical Data**				**Previous Experience (5-point Likert Scale)**	
	Gender	***Age***	***Height (cm)***	***ANSUR Height percentile***	***Weight (kg)***	***ANSUR Weight percentile***	***In using mechanical tools***	***In using monitoring devices***
1	M	25	173	40p	63	10p	3	4
2	M	28	178	65p	65	10p	3	1
3	M	27	180	75p	74	40p	4	5
4	M	26	193	99p	85	75p	2	3
5	M	26	173	40p	75	40p	1	3
6	F	28	155	10p	47	2p	3	1
7	M	25	185	90p	85	75p	3	1
8	F	28	166	70p	54	20p	5	5
9	F	28	170	85p	52	10p	2	4
10	F	27	170	85p	52	10p	1	3
11	M	26	189	98p	90	85p	3	2

feature has been provided for completeness. Table 2 collects the parameters recorded for all the users: for each of the component of the algorithm the relative mean value and standard deviation are reported.

As a result, the *tracing* task reported an average UX Index score of *6.78*, where the *PWL* was predominant (Fig.5): according to the RULA suggestion, the reported result does not involve the danger of musculoskeletal disorders for the operator and minor changes must be provided to the task. Nonetheless, it is worth mentioning that in general both *MWL* and *S* scores are affected by some implementation aspects, such as the level of reality of the simulation. For example, real operators perform the task while being tied with safety cables, experiencing a stressful condition: the virtual environment cannot fully propose the same situation. Similar considerations can be made with reference to the last sub-task about welding. Moreover, no real working tools are provided during the simulation, limiting the recording of the actual physical exertion. In conclusion, the external harsh conditions of the working environment as well as task's responsibility can impact on the physiological response of the operator.

TABLE II. UX INDEX RESULTS

Operator	UX Index components			
	MWL	***Stress***	***RULA***	***UX Index***
1	1.28	0.17	4.63	6.07
2	1.63	1.60	4.34	7.58
3	1.47	0.04	5.55	7.06
4	1.72	0.23	4.96	6.91
5	0.88	1.25	5.79	7.92
6	1.29	0.39	4.09	5.78
7	1.06	0.84	4.91	6.82
8	1.20	1.77	4.38	7.36
9	0.79	0.06	5.22	6.06
10	1.94	0.38	4.86	7.18
11	0.70	0.36	4.82	5.88
Mean	***1.27***	***0.64***	***4.87***	***6.78***
Standard Deviation	***0.396***	***0.624***	***0.511***	***0.70***

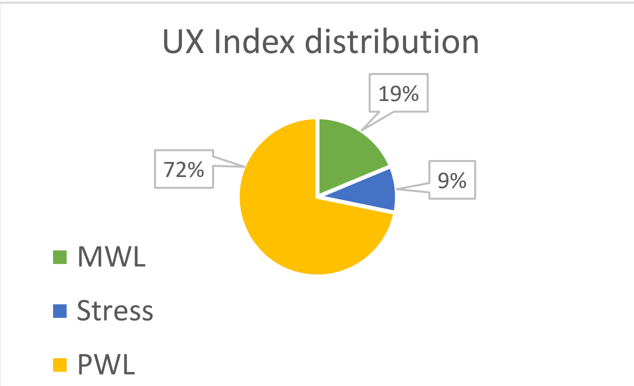

Figure 5 *Percentage of relevance of each component of the UX Index*

The proposed index is a valid tool in supporting analyses relating to factory ergonomics, in highlighting the criticalities of industrial activities and in suggesting the appropriate redesign. It should be noted that it can be used both in the initial stages of design to outline the future steps to tackle and in the final ones, with the overall aim of improving the UX of the worker. Furthermore, this index results innovative in the engineering field by considering not only the physical but also the cognitive effort, providing a complete view of the user experience.

However, the study presents limitations in terms of the selected hardware and the statistical validity of the data analysis. In the first case, a technical constraint is represented by the signal instabilities encountered during the execution of dynamic tasks, as explicated in [4]: furthermore, sensors are strictly dependent on the user physiognomy and on the environment conditions (e.g., level of humidity, external temperature), altering the parameter recording. In future studies, a clear procedure that takes these facets into account should be implemented. Moreover, a state of the art of sensors and smart devices should be performed, and different solutions should be compared and tested to understand their strengths and the specific field of application. In relation to the distinct objective, a functional choice will then have to be made. These considerations become relevant depending on the type of monitoring that is pursued: as proposed in [4], on field solutions should consider possible external factors influencing the recording session. The second downside of the study is represented by the limited population of involved users, which is not sufficiently relevant and dispersed to carry out a statistical validation.

Increasing the reliability and the accuracy of the instrumentation and integrating other types of technologies (such as tactile systems to be used during virtual simulations) could provide further data in the analysis of the human response: returning tactile feedback whenever there is an interaction in a simulated environment could improve the UX Similarly, when operating on-site, providing the operator with a smartwatch to get feedback on the user's physiological conditions could help the system to stay constantly updated on the UX evolution. Thus, the integration of a specific parameter considering the perceived stress assessed by submitting self-subjective assessment structured questionnaires such as NASA-TLX [13] or NAS [14], or by simply interrogating users after task execution.

VI. Conclusion and Future Works

The study represents a step forward in the in-depth analysis of the user experience for both simulated and real industrial tasks. The paper aims to propose an innovative ergonomic score based on an already tested numerical model to support factory redesign by identifying critical issues in terms of physical effort, mental workload, and stress level. Indeed, only with a punctual analysis of the human-machine interaction and of all the working conditions that may cause discomfort and/or stressful events, it would be possible to improve the human performance, and consequently, the industrial quality. Nonetheless, future works will aim at applying the UX index on the real on-site task analysis to understand the potential of a possible integration of the approach into industrial systems workflow.

From the analysis of the results, it can be stated that the provided UXI can help designers and engineers to identify the most critical physiological component in a specific task sequence in order to redesign the process or the product preventing work related diseases and by avoiding time losses due to the difficulty of identifying the exact cause of the operator's discomfort. Compared to the initial proposal described in [4], the formulation of the algorithm has been modified according to experimental discrepancies and to avoid numerical instabilities.

Future developments will focus on the introduction of specific corrective weights that can be tuned according to the task to be investigated: they should mitigate the effect on the UXI computation of the individual biometric parameter to reflect the specificity of the task. To overcome the problem of subjectivity inherent in the very mathematical foundation of the index, the definition of an ad hoc profile for the single user that keeps track of the history of the analysed tasks and that can be adapted by means of artificial intelligence algorithms could be proposed. Lastly, the integration of the presented algorithm within a methodological framework for the optimization of the user experience and of the overall productive system should be performed. In conclusion, the design of a single platform that could process and manipulate the collected data in real time by filtering out single signal's components or compute instantaneously the UXI should be studied.

ACKNOWLEDGMENT

This research was funded by the European Community under the HORIZON 2020 programme, grant agreement No. 958303 (PENELOPE).

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