TYPE Original Research
PUBLISHED 02 November 2023
DOI 10.3389/fieng.2023.1258241

OPEN ACCESS

EDITED BY
Denis A. Coelho,
Jönköping University, Sweden

REVIEWED BY
Lorenzo Maccioni,
Free University of Bozen-Bolzano, Italy
Serena Finco,
University of Padua, Italy

*CORRESPONDENCE
Fabien Coutarel,
fabien.coutarel@uca.fr

RECEIVED 13 July 2023
ACCEPTED 10 October 2023
PUBLISHED 02 November 2023

CITATION
Compan N, Matias J, Lutz M, Rix-Lièvre G, Brissaud D, Belletier C and Coutarel F (2023), The impact of Enabling Collaborative Situations in AR-assisted consignment tasks.
Front. Ind. Eng. 1:1258241.
doi: 10.3389/fieng.2023.1258241

The impact of Enabling Collaborative Situations in AR-assisted consignment tasks

Nathan Compan[1], Jérémy Matias[2], Matthieu Lutz[3], Géraldine Rix-Lièvre[1], Daniel Brissaud[4], Clément Belletier[2] and Fabien Coutarel[1]*

[1]ACTé, Université Clermont Auvergne, Clermont-Ferrand, France, [2]CNRS, LAPSCO, Université Clermont Auvergne, Clermont-Ferrand, France, [3]Michelin Recherche et Développement, Innovation Procédés Industriels, Clermont-Ferrand, France, [4]CNRS, Laboratoire G-SCOP, University Grenoble Alpes, Grenoble, France

The introduction of emerging technologies is often an opportunity to redesign the workstation. The Enabling Collaborative Situation (ECS) is a theoretical proposal that aims to deploy the operator's activity in a collaborative situation with an emerging technology. This approach often seems to be neglected by designers. It is a practical tool for industrialists to guide the design of new work situations as well as for the evaluation of existing situations. An experiment was designed to reproduce a consignment operation. The initial situation corresponded to a classic situation with a paper-based operating procedure. The second situation was assisted by an augmented reality (AR) device and corresponded to either a good intensity of ECS or a low intensity of ECS (which is classically observed in a factory). This study has succeeded in creating an ECS, and it is well perceived as such by the subjects, but the different improvements are not perceived as important enough to make the overall experience better (satisfaction, comprehension, accessibility, performance, etc.). As it was a first attempt, the transformations of the situation were limited. This low intensity of change may explain some of the results of the experiment, but this first attempt also shows the originality and the interest of this work.

KEYWORDS
5.0 industry, new technologies, augmented reality, human–technology collaboration, Enabling Collaborative Situation

1 Introduction

Industry is massively introducing emerging technologies in industrial processes, mainly to increase productivity and flexibility in production. These industrial processes make many promises (Barcellini et al., 2023) and are changing and impacting organisations and workstations. Modern industries underline the importance of the "human factor" (HF) and the human–technology interaction. Proposals for a "5.0" industry are emerging that emphasise the importance of considering the HF and the human–technology interaction. It is quite common to invest in a technology to "clarify technological possibilities" without studying the implementation conditions (Lafeuillade et al., 2021, p. 125). These motivations for introducing more HF could be insufficiently precise to guide the design of the usage situation. As the operator is the focus of these innovations, it is important to question the improvement of the working conditions such that the operator is no longer an adjustment variable and to increase their responsibility and autonomy. The operator must be able to deploy their capacities for action and be able to sustain them over time (Wisner, 1997). These are points about which the activity ergonomists (Daniellou and Rabardel, 2005), of which we claim to be, are particularly sensitive. Unfortunately, it is typical that the operators are scarcely considered, especially the social environment, just like the implementation environment. The "technopush" method is still widely used. The way in which these technological changes are implemented can have an important effect on their acceptance in the workplace (Bobillier Chaumon, 2021). It would, therefore, be interesting to allow the operators to evolve in an enabling situation, so that the operators can have control over the situation and use their capabilities (Sen, 1999; Sen, 2004). The conditions that could meet such objectives have been defined through Enabling Collaborative Situation (ECS) design (Compan et al., 2021; Compan, 2022). The research work (in particular, the narrative analysis of literature) presented in Compan (2022) allows us to address the question of how to take HF into account when implementing an emerging technology. It is this research work that has enabled us to extract the theoretical underpinnings of ECS that we present here. The ECS is a theoretical proposal to facilitate the deployment of operator activity during the implementation of an emerging technology. To achieve this, we propose three criteria: "learn a new and more efficient way of doing things," "increase the available possibilities and ways of doing things," and "adjust the human–machine couple attributes according to the evolution of situations over time."

After a detailed presentation of the ECS and its criteria, the objective is to verify the performance criteria targeted in the framework of a work situation that would better respect the ECS criteria. This document presents this experimental work situation and our research protocol. The experimentation setup includes a reference situation. Subsequently, an emerging technology (augmented reality glasses) is introduced in this situation in order to obtain two different situations (with the criteria of the ECS more or less respected), according to the level of enabling induced in the collaborative situation. Forty-eight subjects participated in the first situation and then one of two second situations with different degrees of ECS in order to test if the collaborative situation is more enabling when the characteristics are put in place, if the technology is more understood and accepted in the work situation, and to show potential performance improvement. The rest of the article presents a multi-level discussion of the results obtained and offers suggestions for practitioners.

2 Related work

2.1 The Enabling Collaborative Situation theoretical foundations

The ECS is a pragmatic contribution to the topic of activity deployment during the implementation of an emerging technology. No original concept is proposed here; the objective is to combine different concepts. The ECS integrates theoretically compatible proposals and tests these criteria from an activity-centred approach. Activity ergonomics focuses primarily on questions of technology use and developmental relationships in human–machine interaction (Rabardel and Béguin, 2005; Bobillier Chaumon, 2021). Moreover, this proposal is in line with the instrumental approach proposed by Rabardel (Rabardel, 2002; Folcher, 2003). Without going into the details of the instrumental approach, the process of instrumental genesis is at the heart of ECS: the possibility of this genesis conditions the effective acceptance of the technology. This genesis proceeds from a two-fold focus: toward the subject by instrumentation (accommodation of the schemes to the new artefacts) and toward the artefact by instrumentalisation (specification and enrichment of the artefact's properties by the subject who gives it the status of a means for the activity). The instrumental genesis thus supports the evolutions of the artefact itself and does not only support the individuals in adapting to the artefact. This support is two-fold:

- For the user and their close social environment (colleagues, close hierarchy). As Folcher (2003) reminds us, the artefact (emerging technology in our case) can aim to support the subsequent development of instrumental geneses (Rabardel, 2002), in particular, through continuous design in use. When future users are not known, or when they are not able to be mobilised (or only belatedly), the design criteria of the artefact can more or less favour a later instrumental genesis.
- For the organisation, when certain transformations of the artefact require the intervention of other actors and other means (decision-makers, engineers, etc.). These transformations can lead to a new design cycle for an artefact of a very different nature (Rabardel, 2002).

Falzon (2005) and other authors have proven the value of designing enabling environments. Falzon (2005) grants a developmental character to this environment: it would be favourable to the development of individuals' possibility to act and their disposition to learn. It would also allow individuals and collectives to succeed, for example, by using their abilities in an efficient and profitable manner (Falzon, 2014). In enabling environments (Falzon, 2005), development is used in a general way, similar to learning. The focus of the ECS in terms of the environment, in an activity ergonomic approach (Daniellou and Rabardel, 2005), places the emerging technologies in a relationship of use, meaning, and significance for the user. The ECS, therefore, encourages an increase in the possibilities of action through the use of the technology.

2.2 Enabling Collaborative Situation characteristics

The ECS is interested in collaborative situations between a human and an emerging technology. The collaboration assumes that the instrument is the tool of deployment of the subject's activity, in particular, via the ECS. Defining human–technology collaboration is a difficult task; there is no consensus on the topic as illustrated by the many existing classifications (Barthe and Queinnec, 1999; Jansen et al., 2018; Kolbeinsson et al., 2018). Collaboration can be viewed as a continuum of weak to strong interactions (Kolbeinsson et al., 2018).

The ECS is thus a collaborative situation between the individual and the technology by which the individual deploys their activity and increases their possibilities to act. The ECS is relative because it is studied in relation to a previous reference situation. The ECS contains three criteria: learn a new and more efficient way of doing things, increase the available possibilities and ways of doing things, and adjust the human–machine couple attributes according to the evolution of situations over time.

Learn a new and more efficient way of doing things.

Learning a new and more efficient way of doing things is the first criterion of an ECS: the ECS makes it possible to maintain, but above all, to increase the performance at the workstation relative to the previous situation. Therefore, it is a question of identifying the relevant performance criteria in the system under consideration, in particular, from the stakeholder's perspective (especially the operator). The assessment of this performance can only be ecological and very close to real-life situations of use. Indeed, the expected future performance is often estimated from aseptic simulations of the daily variability of the human work as illustrated by Compan (2022).

This criterion incorporates proposals from the literature on utility (Nielsen, 1994) and, more indirectly, those relating to affect, emotions, and moods (Ekkekakis, 2013), hedonic aspects of the user experience (Hassenzahl, 2003), and the subject's sensitivity and orientation (Récopé et al., 2019). Indeed, one of the fundamental orientations of ergonomics lies in the structuring relationship of performance and health: professional performance is a condition for health construction through work (Delgoulet and Vidal-Gomel, 2014). Therefore, the feeling of performing well in the workplace is directly associated with the subject's affect and emotions on the one hand, and with the subject's own focus regarding their activity on the other (Récopé et al., 2019). The operator must accept, in the situation, the emerging technology (Bobillier-Chaumon and Clot, 2016; Bobillier-Chaumon, 2021).

Increase the available possibilities and ways of doing things.

The second criterion of an ECS is the increase of available possibilities and ways of doing things. The deployment of the subject's activity implies the expansion of their possibilities of action via the expansion of their situational leeway (Coutarel et al., 2015). Situational leeway corresponds to "the possibility for the operator, in a specific situation, to develop an efficient operating mode (i.e., one that is effective for performance and compatible with self-preservation or even self-development through work)" (Coutarel et al., 2015, p. 21). The expansion of the expressible capabilities can be achieved by the acquisition of new capabilities for the individual, and by the use of new possibilities enabled by technology and responding to previously limited individual capabilities. The introduction of emerging technologies is sometimes associated, for individuals, with a restriction of their possibilities of action and of their situational leeway as illustrated by Compan (2022). The design of the technology must consider the possibilities of multiple and diversified uses, for example, to be able to work with two people on a workstation designed for one operator, to take control of certain process steps, or to let the technology take control of some of these steps, depending on the circumstances. This is why it is important to know the work activity before introducing the technology.

Adjust the human–machine couple attributes according to the evolution of situations over time.

The third criterion of an ECS concerns the adjustment of the couple (human–technology) attributes according to the evolution of situations over time. Confronted with changes in their work situation, the operator will need to modify the technology, for example, to adjust the speed during rush periods or to adjust the workstation to their personal specificities that change over time. Therefore, it is necessary to encourage and support the process of instrumental genesis over time (Rabardel, 2002; Folcher, 2003) and to make continuous design in use possible. Several conditions are identified for this: the individual must have the various skills and authorisations necessary and/or be able to call upon the collective and the organisation during the day-to-day running of the organisation to design the necessary adjustments to the couple. This presupposes that the operator has a sufficient understanding of the functioning of the technology, which Rabardel (2002) calls operative transparency. It is also necessary for "supportive coworkers" (Hon et al., 2014) to be present and to help with implementation, thanks to their knowledge of the complexity of the technologies and the multiple strategies required for implementation (Schoville, 2017). The individual must not be overwhelmed by the situation (Falzon, 2005). The operator must be able to think about their own activity, to simulate, to test, or to ask for advice or help. This implies a certain level of trust and responsibility toward the individual, which some authors call "empowering" management (Srivastava, Bartol, and Locke, 2006). Evidently, in certain contexts and due to the very nature of the desired changes, this change cannot be rapid and/or achievable by the operator or their immediate environment. These cases require help from the organisation that authorises and supports the requests for change in its day-to-day operations. Spaces for work debate and times for collective regulation (Falzon, 2005; Clot, 2012; Hon, Bloom and Crant, 2014) may support this, as can any efficient continuous improvement process in general.

The ECS and its characteristics are summarised in Table 1.

The interest of using the ECS as a framework to evaluate human–technology collaboration situations has been described through a multiple case study (Compan et al., 2021). The results of this qualitative survey showed that the ECS is more refined in its analysis than the simple expression of satisfaction by the different actors in the situation. The ECS makes it possible to report the project's contrasted reality. It also seems that certain characteristics are not spontaneously considered, such as the increase in possibilities and ways of doing things.

However, there is still a fog regarding the ECS. We have seen that the ECS is demanding and allows a critical analysis of situations. We can also note that not all the workstations studied fully respect the ECS characteristics. Although all the concepts used by the ECS have demonstrated their positive impact through their approach of considering human activity, it remains worthwhile to design an ECS experimentally, in order to measure its effects on operators and on performance. Indeed, designing an ECS directly in the workshop would represent a significant cost for a company. Our research questions are the following: how does the level of the ECS impact performance and the user's perception of their work situation? In what way do the three characteristics of the ECS converge in an

TABLE 1 Summary table of the ECS and its associated criteria.

ECS characteristic	Related literature	Related pragmatic criteria
Learn a new and more efficient way of doing things	Utility (Nielsen, 1994)	The operator must be able to do what they want to do, and the technology must not get in the way
	Affects, hedonic aspects of the user experience, and subject's sensitivity (Hassenzahl, 2003; Ekkekakis, 2013; Récopé et al., 2019)	The relationship of meaning constructed by the operator when using the emerging technology, what the operator values while working, and how they feel when in contact with the emerging technology must be conducive to the smooth running of the activity
	Situated acceptance (Bobillier-Chaumon and Clot, 2016; Bobillier-Chaumon, 2021)	The operator must accept, in the situation, the emerging technology
Increase the available possibilities and ways of doing things	Situational leeway (Coutarel et al., 2015)	The operator must have several efficient ways of working (at least two distinct and satisfactory operating modes) according to their preference and the variability encountered
Adjust the human–machine couple attributes according to the evolution of situations over time	Instrumental genesis over time and continuous design in use (Rabardel, 2002; Folcher, 2003)	The operator must be able to appropriate the emerging technology and the work situation (instrumental genesis: instrumentation/instrumentalisation). The operator must also be able to modify both the work situation and the emerging technology
	Supportive coworkers (Hon et al., 2014; Schoville, 2017)	The operator, in activity, must have a source of support among their peers (information sharing, help, etc.)
	Operative transparency (Rabardel, 2002)	The operator must have a sufficient understanding of how the technology works. The operator must be able to interpret the current situation in terms of history and be able to interpret the effects of actions
	Individual reflexivity (Falzon, 2005)	The operator must be able to use their own work activity as an object of analysis. The operator must not be overwhelmed by the situation
	Empowering management (Srivastava, Bartol, and Locke, 2006)	The operator's autonomy and sense of responsibility must be encouraged by management
	Spaces for work debate and times for collective regulation (Falzon, 2005; Clot, 2012; Hon, Bloom and Crant, 2014)	The operator must be given time for collective regulation and discussion of the work, so that their voice can be heard. Most individuals (hierarchy, engineers, peers, etc.) must be present on a regular basis

"optimal" collaborative situation toward a better deployment of the operator activity?

This study analysed the impact (performance, operational leeway, operative transparency, etc.) of this emerging technology (augmented reality) on the situation and the difference of this impact according to the level of the ECS (how well the ECS characteristics were met in the situation).

3 Materials and methods

3.1 Objectives and experimental conditions

The objective was to design an experiment that reproduced working environment of a maintenance operator. The experiment is about the simulation of a consignment operation, lock out tag out (LOTO), composed of a set of actions to be done by the operator. These actions are made to be representative of a consignment operation (closing valves, pushing levers, connecting wires, etc.). The consignment consists of isolating certain parts of the process and machines in order to be able to carry out maintenance operations. The aim was to experimentally measure the activity of the subjects and to analyse the impact of an augmented reality device in their work in a more or less ECS. To do this, two scenarios were simulated (as depicted in Figure 1), a classic one with a paper-based operating procedure (as is usual in industry) and another one assisted by augmented reality glasses (HoloLens 2). In this experiment, we did not evaluate certain dimensions of the ECS, such as the collective and the organisation (one aspect of the third ECS characteristic).

3.2 Experiment design

In order to reproduce a consignment, an experimental room (60 m^2) (as shown in Figure 2) was designed and composed of many stations reproducing a machine. These different stations are composed of real machine parts, isolated so that the operator can interact with them. These different parts include valves, pressure buttons, circuit breakers, computers, etc. Each station is equipped with different labels describing the different elements of the machine (one label per valve, switch, etc.). The different areas of the room were coloured to facilitate the participants' understanding. The layout of the different room elements was made in order to

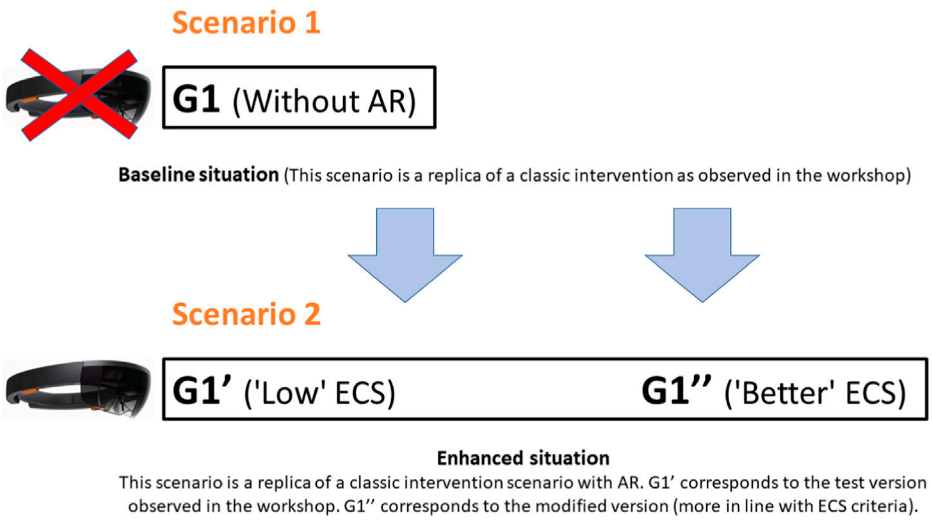


FIGURE 1
Visual representation of our experimental conditions.

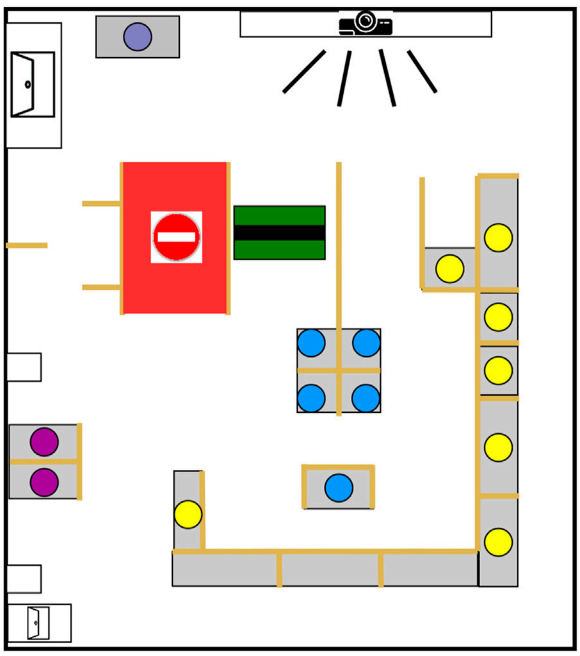


FIGURE 2
Experimental room plan (each dot represents a station; colours are to guide the participant about the location of the station).

create a kind of labyrinth simulating the complexity of a consequent machine in a production workshop. A forbidden path was included in the room, representing the various prohibited zones of circulation in a production workshop. Different safety pictograms were also added in the room (e.g., electrical or heat hazard). This room was also equipped with an overhead projector and a speaker. An ambient sound was broadcast in the workshop at a constant high between 60 and 65 dB (which corresponds to a classical industrial noise measurement in the workshop). The overhead projector was used to display a recording of a production workshop and, in particular, the passage of a forklift truck to provide more representativeness and immersion for the subjects.

The augmented reality device is composed of augmented reality glasses, HoloLens 2 (Microsoft, Redmond, WA; Marketed since 2019). Augmented reality lies on the continuum of mixed reality (Milgram and Kishino, 1994), ranging from the real environment to the virtual environment. Augmented reality refers to any instance in which an otherwise real environment is augmented by means of virtual objects (Milgram and Kishino, 1994). The information is added to the real environment, allowing the operator to have their hands free. The 3D environment (arrow, instructions, etc.) was created and mapped onto the experimental room using Vuforia Studio software.

The operating mode must approach a real situation, so this one was divided into various sets and subsets. Each subset was composed of different tasks to be done at the different stations. The operating mode included the set and the subset in question (e.g., "Step 6a"), the task to be done (e.g., "Lowering the air inlet valve [blue]"), the global location of the workstation (e.g., "Blue"), the title of the station (e.g., "J") and, finally, the part of the machine on the station involved in the task (e.g., "01"). A picture specifying the part of the machine to be used was also present to guide the operator in their task. An example of the operating mode is shown in Figure 3.

The variables studied and their nature and type are summarised in Table 2.

The experiment focused on intragroup measures for assessing the value of the ECS. Each subject was confronted with both the baseline and enhanced scenario (G1′ or G1″). The subjects in our G1 group followed a paper-based procedure. This procedure was placed at different places in the room with a map so that the subject could refer to it regularly. The procedure for G1 was as follows:

- Welcoming the participant.

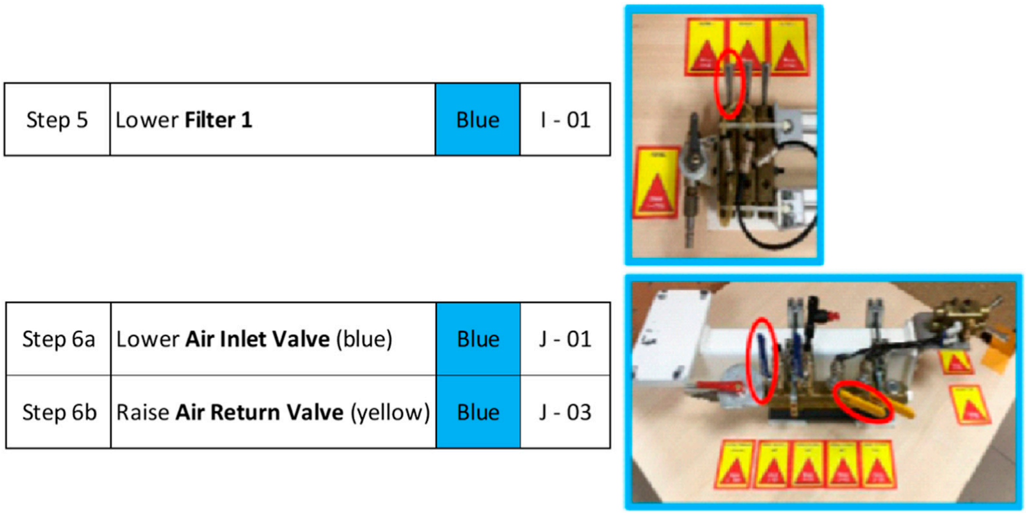


FIGURE 3
Operating mode subsets.

- Signing the consent form and completing the socio-demographic questionnaire.
- A researcher introduced the room (accompanied by a physical movement through the room) and stated the different instructions.
- The subject performed a mini consignment operation consisting of activity at two stations for training purposes.
- The subject started the protocol, and the researchers left the room. The subject had total autonomy and was not recorded. The performance was only measured at the end of the experiment.
- Once the full consignment operation was over, the researchers proceeded to a quick debriefing followed by the completion of the raw NASA-TLX questionnaire and, subsequently, a more substantial interview with a researcher (refer to Table 2).

Afterwards, the subjects of group G1 were divided into two groups: G1′ and G1″ (refer to Table 3). This time, they followed the procedure using the augmented reality device (HoloLens 2) (examples in Figures 4 and 5). Some elements of the room were modified to avoid a learning bias. In order to avoid a learning curve, the forbidden path was in a different location, and the tasks and positions used were different (the type of task was unchanged, but the machine parts and their locations were different).

The procedure for G1′ and G1″ was as follows:

- Welcoming the participant.
- Signing the consent form and completing the socio-demographic questionnaire.
- A researcher gave the participant a tour of the room and stated the different instructions.
- The subject performed a mini consignment operation consisting of activities at two stations for training purposes.
- In the G1″ subset, the subject could set up the glasses according to the modalities explained before.
- The subject started the protocol, and the researchers left the room. The subject had total autonomy and was not recorded. The performance was only measured at the end of the experiment.
- Once the complete consignment operation was over, the researchers proceeded to a quick debriefing followed by the completion of the two questionnaires (raw NASA-TLX and TAM), and, subsequently, a more substantial interview with one of the researchers (refer to Table 2).

3.3 Research sample

Our population was made up of 53 subjects, five of whom were removed from the experiment due to various problems: one dropped out, one took pictures of the operating mode in G1 (this was forbidden), one was removed because of equipment malfunctions, and two were removed because they had major misunderstandings of the operating mode (some parts were almost completely missed). Forty-eight subjects completed G1. One participant had to be removed from G1′ because the device malfunctioned during the second passage. For our analyses, there were 47 subjects in G1, who, during the second session, were divided into 23 for G1′ and 24 for G1″. One person in G1′ and two people in G1″ had problems with the TAM questionnaire. All data have been kept except the TAM questionnaire, which could not be used by these subjects.

Regarding the characteristics of this population, the average age was 38.68 years; participants were mostly men (13.6% women), spoke French as their first language (97% of the subjects), worked in various professions and were mainly from an industrial environment. Only three participants were students. On average, participants had worked at their current employer for 13.3 years, the median level of education was a bachelor's degree. More than half (61.1%) of the subjects declared that they worked in an office, 17.8% declared that they worked in a workshop, and 21.1% worked in both areas. Their habit of consignment

TABLE 2 Summary table of the studied variables, their nature, and type.

Studied variable	Nature	Type
Performance (number of errors (omission and overaction), number of steps in the forbidden path, and time used to perform the whole procedure)	Quantitative data	Post-experiment observation and laser counter
Workload (including mental load, physical demand, temporal demand, performance, and effort, frustration level)	Quantitative data	Post-experiment raw NASA-TLX questionnaire (Hart and Staveland, 1988; Hart, 2006) translated into French
Acceptability (including intent to use, perceived ease of use, and perceived usefulness) (only for G1′ and G1″)	Quantitative data	Post-experiment "TAM" questionnaire (Davis, 1985) translated into French
Behavioural intention	Quantitative (dichotomous question) and qualitative data (explanation)	Post-experiment interview
Overall feeling of satisfaction	Quantitative (Likert scale) and qualitative data (explanation)	Post-experiment interview
Perceived performance	Quantitative (Likert scale, dichotomous question) and qualitative data (explanation)	Post-experiment interview
Perceived usefulness of the technology	Quantitative (Likert scale, dichotomous question) and qualitative data (explanation)	Post-experiment interview
Operating strategies (as well as their variation according to the situation)	Qualitative data (open questions)	Post-experiment interview
Perceived situational leeway (as well as their variation according to the situation)	Quantitative (Likert scales, dichotomous question) and qualitative data (explanation)	
Operative transparency of the operating mode and the technology (through its three dimensions of perceptibility, accessibility, and comprehensibility (Rabardel, 2002))	Quantitative (Likert scales) and qualitative data (explanations)	Post-experiment interview
Perception of the continuous design in use possibilities	Quantitative (dichotomous question) and qualitative data (explanation)	Post-experiment interview
Feeling of taking control of the technology	Quantitative (Likert scale) and qualitative data (explanation)	Post-experiment interview
Feeling of technology adjustability	Quantitative (Likert scale) and qualitative data (explanation)	Post-experiment interview
Feeling of involvement in the development of the technology	Quantitative (dichotomous question) and qualitative data (explanation)	Post-experiment interview
Representativeness of the study	Quantitative (dichotomous question) and qualitative data (open question)	Post-experiment interview

operation was on average 4.47 of 7 (7 is the maximum). Most of the subjects (76.9%) declared never having used augmented reality; the use of augmented reality by the other subjects was largely anecdotal (test, demo, etc.). Finally, the participants' vision toward augmented reality was mostly positive (5.62/7 on average, 7 is the maximum).

3.4 Analysis methods

For the intragroup analyses (G1 vs G1′ and G1 vs G1″), the differences between our continuous quantitative variables were statistically treated with the Student's t-test (paired samples) when the conditions were parametric or the Wilcoxon W-test when the data were not parametric. When the variables were of nominal type (1/2, yes/no, with/without, etc.), a McNemar test was used.

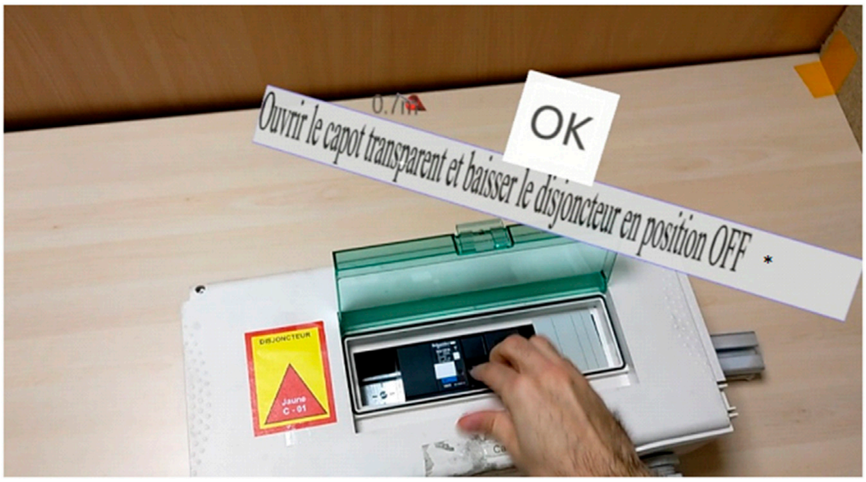
For the intergroup analyses (G1′ vs G1″), the differences between our quantitative variables of continuous type were statistically treated with the Student's t-test (independent samples) when the conditions were parametric or the Mann–Whitney U test when the data were not parametric. When the variables were of nominal type (1/2, yes/no, with/without, etc.), a chi-squared test was used.

The open-ended responses were analysed qualitatively through a thematic analysis (Saldana, 2021). The subjects' verbatim responses were then categorised and counted. These categories were classified in order of representativeness. The answers in G1 can be classified into five categories of general representativeness (the number of repetitions is shown in brackets), which are: very low (1), low (2), medium (3–5), high (6–10), and very high (11 and more). G1′ and G1″ have the same classification, but the number of subjects is approximately half that of G1, and the number of repetitions required is approximately half. We thus obtain the following categories: very low (1), low (2), medium (3), high (4–5), and very high (6 and more). To be clear and concise, only the most relevant and most represented categories are discussed in this article, which are the high and very high categories.

Verbatim analytical groupings were performed blindly by another researcher (who did not take part in the experiment) to identify potential emergences according to socio-demographic

TABLE 3 Summary of the different points concerning the ECS in the three conditions.

ECS characteristic	G1	G1′ (“low” ECS)	G1″ (“high” ECS)
Learn a new and more efficient way of doing things	The paper-based procedure was divided into various sets and subsets with the tasks, the location, and title and part of the specific workstation	The glasses displayed various prescriptions of the operating mode within the participants’ field of vision and had a navigation aid (an arrow indicating the direction of the workstation in the absolute and the number of metres separating the subject from the post).	The glasses displayed various prescriptions of the operating mode within the participants’ field of vision and had a navigation aid (an arrow indicating the direction of the workstation in the absolute and the number of metres separating the subject from the post)
Increase the available possibilities and ways of doing things	There was no possibility of varying the tasks assigned	There was no possibility of varying the tasks assigned	Twice during the procedure, the subject had a choice in the order of the next three tasks
Adjust the human–machine couple attributes according to the evolution of situations over time		Continuous design in use: small, non-editable arrow at the top of the field of view; the text was black on a white background. These parameters followed the ones observed in the workshop during the tests	Continuous design in use: the subject could modify (before and after the training) the colour of the text (white on a black background, black on a white background, or black on a yellow background), the position of the direction arrow (“upper” position or “lower” position), and the size of the direction arrow (“big” or “small”)
		Operative transparency: the settings were standard, and nothing was done to improve this aspect	Operative transparency: the forbidden path was obstructed by a virtual red wall so that the subject could better understand the “intentions” of the machine, forbidding this traffic zone. The subject had a real-time indication of their progress within the operating mode (e.g., Step 4/18)



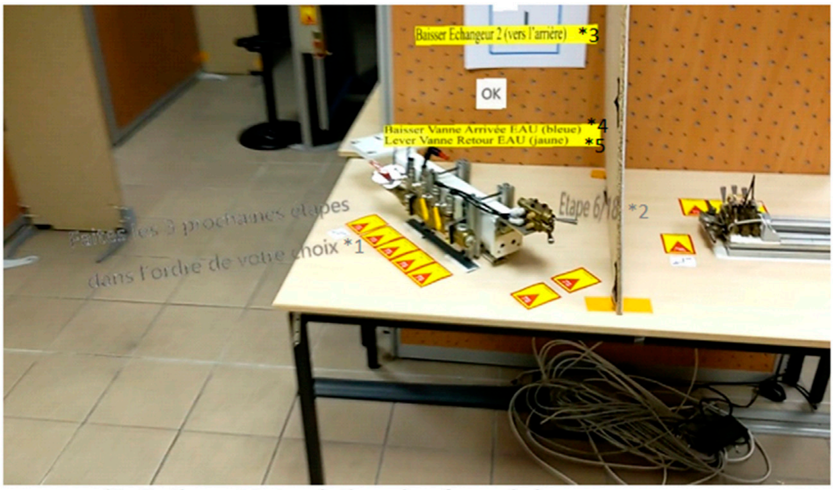
*Open the transparent cover and turn the circuit breaker to the OFF position

FIGURE 4
Example of the G1′ glasses interface.

variables. The researcher analysed the groups of subjects who spent more time in the workshop than the office (only those who answered “workshop” to the question), those who have developed an expertise in the consignment operations (6 or 7 on a Likert scale of 7), and those who identified their profession as maintainer or operator.

4 Results

To enhance the readability of the article, all the statistics (including non-significant or minor results) are placed in appendices.



*1 : Do the next 3 steps in the order of your choice
*2 : Step 6/18
*3 : Lower Exchanger 2 (towards the rear)
*4 : Lower WATER Inlet Valve (blue)
*5 : Raise WATER Return Valve (yellow)

FIGURE 5
Example of the G1″ glasses interface.

4.1 Study representativeness and duration

The study is considered largely representative in all three conditions, in relation to the subjects' experience of the factory. To verify this, our distribution was compared to an equivalent distribution (50% for yes and 50% for no). Our results appear significantly different (table to be found in Appendix 6), so our conditions are representative. G1′ is not considered more representative than G1 (χ^2 (1, N = 23) = 0; p = 1), G1″ is not considered more representative than G1 (χ^2 (1, N =23) = 0.5; p = .48), and G1′ is not considered more representative than G1″ (χ^2 (1, N = 47) = 1.37; p = .24). The common reason given by all the groups concerns the representativeness of the environment (sound, material, etc.) (G1: N = 14; G1′ : N = 6; G1″: N = 4). G1 is also sensitive to the good representativeness of the work (tasks, procedures, etc.) (N = 14), as is G1′ (N = 7).

The entire procedure had an average duration of 1037.13 s without the technology (G1, paper-based procedure) and 561.52 s with the augmented reality glasses (G1′ and G1″).

4.2 Contributions of technology (G1 vs G1′ and G1 vs G1″)[1]

In accordance with what we can observe in Table 4, the augmented reality system reduces both the global workload and the mental load. The subjects also declare a better overall feeling of satisfaction with the emerging technology. These points seem to be related because the verbatim responses associated with the question on the overall feeling of satisfaction clearly express that with the technology, the work is faster (N = 6) for G1′ and easier/simpler for G1′ (N = 5). Meanwhile, the G1 subjects state that the number of return trips is constraining (N =18), they make mistakes (N = 6), and they have difficulties in memorising (N = 6).

The feeling of performance is also improved with the augmented reality device. The subjects in G1 are negatively impacted by the number of back and forth trips required (N = 15), the low speed (N = 13), and their number of errors (N = 8), even if some underline their performance in terms of low number of errors (N = 11). The participants of the G1′ group mention the impact of their good speed (N = 9), as well as the decrease of their mental load and the ease of memorisation (N = 5). People in the G1″ group emphasise the same type of points for performance, including speed (N = 11) and less back and forth (N = 7), and also mention the low error rate (N = 4) and less doubts/questioning (N = 6).

The strategies differ between the groups, especially in terms of reflexivity. The G1 subjects have two main strategies: the first consists of going back and forth throughout the procedure (with potentially minor attempts to memorise the information) (N = 16), and the second consists initially of memorising several steps of the procedure and then abandoning this strategy to resume the back and forth (N = 11). With technology, both groups are guided by the instructions that appear in the environment and by the directional arrows (N = 29 for G1′ and N = 23 for G1″).

The participants feel that they have increased their situational leeway in G1″ compared to the situation in G1. Without the augmented reality glasses, the subjects report a lack of situational leeway about the order of the tasks (N = 30) and about the

1 Some subjects did not answer all the questions, so the N may vary.

2 Cohen's d for the Student's t-test and rank-biserial correlation for the Wilcoxon W-test.

TABLE 4 Significant differences in the contributions of technology.

Studied variable		Statistic	Groups	Mean	SD	p	Effect size[2]
Workload (average out of 20 of the raw NASA-TLX)	Student's t	2.95	G1	9.92	2.43	.007	0.62
			G1′	8.37	2.83		
	Student's t	7.04	G1	10.67	2.62	<.001	1.44
			G1″	7.22	1.56		
Mental load (specific raw NASA-TLX item) (over a maximum of 20)	Wilcoxon W	234	G1	12.13	3.57	<.001	0.85
			G1′	7.52	4.18		
	Wilcoxon W	272.5	G1	13.81	4.36	<.001	0.97
			G1″	6.60	3.14		
Overall feeling of satisfaction (out of 10)	Student's t	4.45	G1	6.35	0.35	<.001	0.93
			G1′	8.17	0.22		
	Student's t	6.20	G1	5.96	2.07	<.001	1.27
			G1″	8.71	0.91		
Feeling of performance (out of 10)	Wilcoxon W	2.50	G1	6.09	1.59	<.001	0.97
			G1′	8.09	1.08		
	Student's t	7.26	G1	5.83	1.49	<.001	1.48
			G1″	8.13	0.74		
Operational leeway (out of 10)	Student's t	5.04	G1	4.04	1.81	<.001	1.03
			G1″	6.25	1.85		
Operating procedure operative transparency (average of the three dimensions) (out of 10)	Student's t	4.95	G1	7.19	1.48	<.001	1.03
			G1′	8.83	1.03		
	Wilcoxon W	29.50	G1	7.63	1.24	<.001	0.80
			G1″	8.69	0.96		

Studied variable (McNemar)		G1	G1′	χ^2	N	p
		Yes	No			
Continuous design in use	Yes	N = 0	N = 0	1	23	.32
	No	N = 1	N = 22			
Studied variable (McNemar)		**G1**	**G1″**	χ^2	**N**	**p**
		Yes	No			
Continuous design in use	Yes	N = 1	N = 0	21	24	<.001
	No	N = 21	N = 2			

movements (N = 22), and they find that the operating mode is very prescribed and left little situational leeway (N = 22). The subjects of G1″ note the increase of their situational leeway on the order of the tasks (N = 16) and on their various possibilities and ways of doing things (N = 6).

The introduction of the emerging technology, whatever the condition, has increased the operative transparency of the operating mode for the operators. People in the G1′ group saw an improvement in their perception of the information, particularly in terms of the visibility (N = 6) and clarity of the information (N = 6). People in the G1 group mainly noticed that the instructions were visible (colour-coded, bold-type words, details, etc.) (N = 14), even if the pictures were small or not very readable (N = 9), although other participants found these instructions readable (N = 6). The accessibility of the operating procedure was improved for the G1′ and G1″ groups because the field of vision and the visibility of the information are satisfactory (G1′: N = 6; G1″: N = 10), even if some people in G1″ think the opposite (N = 4). People in the G1′ group also mentioned the ease of obtaining information at the station (N = 6). In contrast, people in the G1 group mentioned their concerns about going back and forth (N = 23), which negatively impact this point of accessibility. Finally, the comprehensibility is

TABLE 5 Significant differences in the contributions of the ECS.

Studied variable		Statistic	Group	Mean	SD	p	Effect size[4]
Intent to use (TAM) (average of seven of the four questions on intent to use)	Mann–Whitney U	161	G1′	5.57	1.11	.055 (strong tendency)	0.34
			G1″	6.08	1.05		
Overall feeling of satisfaction (out of 10)	Student's t	1.89	G1′	8.17	1.03	.065 (strong tendency)	0.55
			G1″	7.71	0.91		
Operational leeway (out of 10)	Mann–Whitney U	85.5	G1′	3.65	1.87	<.001	0.69
			G1″	6.25	1.85		
Perception of the operational leeway evolution (range of −10 to 10)	Mann–Whitney U	74	G1′	−0.57	4	<.001	0.73
			G1″	5.21	2.86		
Evaluation of the perceptibility of the information transmitted by the technology (out of 10)	Student's t	2.09	G1′	7.130	1.890	.043	0.6083
			G1″	8.08	1.176		
Evaluation of technology adjustability (out of 10)	Student's t	3.40	G1′	5.26	1.94	.001	0.99
			G1″	6.96	1.46		

Studied variable (Chi²)		G1′	G1″	χ^2	N	p
Perception of the operational leeway variation	Yes	N = 3	N = 21	26.1	47	<.001
	No	N = 20	N= 3			
Operating strategies evolution	Yes	N = 9	N = 16	3.19	44	.074 (strong tendency)
	No	N = 12	N = 7			
Continuous design in use	Yes	N = 1	N = 22	35.8	47	<.001
	No	N = 22	N = 2			

improved for the G1′ group compared to the G1 group because the instructions are explicit and clear (N = 12), and the subjects in G1 mentioned the same qualities (N = 21).

The possibilities of continuous design in use are perceived as changed by introducing the emerging technology for the G1″ group. People in the G1′ group did not think they could modify their work situation (N = 9) and did not feel the need to do so (N = 5). In contrast, people in the G1″ group perceived the possibility of modifying the situation, especially before the activity (N = 10), and chose mainly interface modifications (N = 8). In the initial situation, people in the G1 group justified a weak continuous design by respecting the procedure (N = 20) and ignorance of the context/overview (N = 14), which resulted in the subjects letting themselves get carried away by the procedure (N = 13).

4.3 ECS contributions (G1′ vs G1″)[3]

We have taken the points that are significantly different from Table 5 to discuss the contribution of the ECS. The points that are not statistically different or whose justification is not qualitatively interesting (interviews) will not be mentioned.

In the TAM questionnaire, we note a strong tendency on the dimension of intent to use, which was increased in G1″. However, the qualitative responses for both groups to the question on behavioural intention are similar. The subjects in G1′ feel cognitively lighter (N = 8) than those in G1″ (N = 11); the technology allows them to avoid going back and forth because the information is displayed on the workstation. More people in the G1′ group perceive the change as an improvement of the work situation (N = 8) than the G1″ (N = 6); the work situation is experienced as easy/simple equally in G1′ (N = 5) and G1″(N = 5).

The overall feeling of satisfaction tends to improve in a high ECS. The elements of satisfaction noted in G1′ mainly concern the ease/simplicity of the work situation (N = 5), whereas the subjects in G1″ are more likely to mention the gain in speed compared to the initial situation (N = 6).

The two groups seem to diverge in their perception of situational leeway. People in the G1″ group seem to perceive more situational leeway thanks to the high ECS. The subjects in G1′ perceive very directed instructions (N = 9), an inflexible operating mode (N = 8), and a low situational leeway about the order of the tasks (N = 6) and the actions to be carried out (N = 4), although the situational leeway on the movements is satisfactory (N = 5). The subjects in G1″ still emphasise the inflexibility of the operating mode (N = 4), but this seems to be secondary to the situational leeway gained on the

3 Some subjects did not answer all the questions, so the N may vary.

4 Cohen's d for the Student's t-test and rank-biserial correlation for the Mann–Whitney U-test.

flexibility about the order of the tasks (N = 16), the different possibilities of action (N = 6), and the freedom of movement (N = 5).

The technology lends itself to a change in operating strategies between the G1′ and G1″ groups. People in G1′ reported no change in strategies (N = 4), while people in G1″ emphasised the decrease in mental load (N = 7) and their focus on guidance and the device interface (N = 4).

The differences between the groups concerning the operative transparency (of the operating mode and of the technology itself) do not seem significant, except for the perceptibility of the information transmitted by the technology that seems better in the G1″ group than in the G1′ group. The justifications provided by people in G1′ mainly relate to perceptibility concerns, especially about the arrow and the guidance, which was too small and jerky (N = 13), as it was for people in G1″, even if the point seems less important (N = 4). People in G1″ also mentioned the good visibility of information (N = 7).

The subjects in G1′ have a significantly different feeling of the possibility of continuous design in use compared to those in G1″. People in G1′ mentioned their perception of the impossibility of being able to modify the situation (device and operating mode) (N = 9); they also underline the fact that they did not feel a need to modify the situation (N = 5). People in G1″ found continuous design in use over time, especially before the activity (N = 10). These modifications mainly concern the interface of the device (N = 8) and their situational leeway about the choice of the order of the tasks (N = 4).

The feeling of glasses adjustability is significantly higher in the G1″ group than in G1′. The possibilities of adjustment are perceived as less important by the subjects of G1′, in particular about adjusting the virtual functionality, because they either did not find the adjustment or did not realize they could adjust the interface (N = 7), they did not try to modify it (N = 6), or thought that it was impossible (N = 5). On the other hand, they did perceive that the physical part of the headset was adjustable (N = 17), as did people in G1″. In addition to adjusting the physical headset, people in G1″ discovered that the glasses were virtually editable (arrow, colour, etc.) (N = 7) and thought that the possible modifications were satisfactory (N = 5), even though they would like more personalisation options (N = 9).

5 Discussion

The introduction of augmented reality technology does not seem to have the same impact depending on whether the characteristics of the ECS are more or less respected, although we observe several limitations. The contributions of ECS to this experiment are summarised in Table 6.

The ECS allows us to note that:

- From a macro point of view, this study succeeded in creating a more Enabling Collaborative Situation, and it was well perceived as such by the subjects. Some of the characteristics measured that indicate the level of ECS of the situation were well perceived by the subjects. The situational leeway is noted as significantly increased, as well as the possibilities of continuous design in use. Regarding the operative transparency, it was difficult for the subjects to perceive these increases in the situation, and the perceived difference is only on the perceptibility of the information transmitted by the glasses (such as the forbidden path in G1″, which did not appear in G1′). On the other hand, this improvement does not concern comprehension and accessibility, which are the other factors of operative transparency. We can largely believe that these factors would be better perceived in a more ecological situation. Furthermore, it is possible that our mixed results are induced by a limited intensity level of the ECS, even in the situation that most fulfils the characteristics of ECS (G1″). Perhaps the results would be even more convincing if we had an emerging technology that was better able to track the characteristics of the ECS, especially in terms of the device and its adjustment.

A higher ECS does not seem to significantly improve participants' overall performance or even their sense of performance. We find the same result about the ease of use or the device usefulness. Based on the analyses of the verbatim responses grouped according to socio-demographic groups, we did not observe any differences that appear qualitatively significant, compared to the main analyses. Our previous research question asked, "How does the level of the ECS impact performance and the user's perception of their work situation?" It would seem that the improvement in situational leeway and the possibilities for continuous design in use have been well perceived. The results concerning operative transparency are more mixed. As far as performance is concerned, in this case, an ECS does not seem to have any negative (or positive) impact. This could also be conditioned by the limitations of an experimental work situation. However, although the results are not significant, a more Enabling Collaborative Situation tends to favour the intention to use and tends to improve the general satisfaction in our study. The participants seem to perceive diffuse interests in the technology, but this was not sufficiently intense to be expressed significantly. Based on results, it is difficult to answer our second research question: "in what way do the three characteristics of the ECS converge in an 'optimal' collaborative situation toward a better deployment of the operator activity?" Although the deployment of the operator activity seems to have been improved by the increase in situation leeway (ECS criterion 2) and continuous design in use possibilities (ECS criterion 3), this was only partially observed in terms of operational transparency (ECS criterion 3) and not in terms of performance (ECS criterion 1).

This beckons us to reflect on the following: activities are always situated, so it does not seem possible to capture or to really understand the potential of an ECS outside of ecological use. On the one hand, experimentation allows us to isolate certain variables in order to study them precisely. It also sets up conditions that aim to bring the subject closer to a situation that is as real as possible, but it seems difficult to claim that the subject lives the situation as it could be lived if they were immersed in it. In addition, it raises the question of the costs of testing and validating the choices associated with the implementation. Measurements in real situations are often difficult to implement and are expensive. This process of validating and measurement also takes place well into any implementation. The difference between G1′ and G1″ was not perceived as important enough to make the overall experience better. Each criterion carried by the ECS implies aspects of the scientific literature that have been largely proven. On the other hand, we can question the visible, accessible character of these improvements. It seems quite

TABLE 6 Summary of ECS contribution.

ECS characteristic	Related criteria	G1′ ("low" ECS) vs G1″ ("better" ECS)
Learn a new and more efficient way of doing things	Utility	No significant difference in actual and perceived performance
	Situated acceptance, affects, hedonic aspects of the user experience, and subject's sensitivity	We quantitatively observed a strong tendency on the dimension of intent to use, which was increased in G1″
		The overall feeling of satisfaction tends to improve in G1″. The subjects mainly mentioned a gain in speed with a higher ECS. With a lower ECS, they emphasised the simplicity of the work situation
Increase the available possibilities and ways of doing things	Situational leeway	The subjects in G1″ perceive a satisfying situational leeway (flexibility about the order of the tasks, the different possibilities of action, and freedom of movement). G1, an inflexible operating mode, and a low choice about the order of the tasks and the actions
Adjust the human–machine couple attributes according to the evolution of situations over time	Instrumental genesis over time and continuous design in use	Subjects in G1′ did not perceive a possibility of modifying the technology and the situation but also did not feel the need to do so. On the other hand, subjects in G1″ took advantage of the possibilities for modifying the technology, particularly for the interface and their situational leeway in choosing the order of tasks
	Operative transparency	Perceptibility of information transmitted in G1″ seems better (subjects could adjust the interface)
	Individual reflexivity	G1″ subjects emphasised the decrease in mental load and their focus on guidance and the device interface while G1′ subjects did not change their strategies during the work
	Supportive coworkers, empowering management, and other collective and organisational factors	Could not be tested during this experiment

conceivable that the participants do not understand the scope and implication of the improvements they have benefited from, particularly as this work situation was simulated without any real consequences and was of limited duration. The future thinking (Colin et al., 2021) could be very difficult. Therefore, there would likely be a form of threshold from which the improvement of an ECS characteristic translates into an improvement of certain criteria, such as the perception of utility or acceptability. Our subjects noted the differences between the situations, but they did not express interest in exploring these differences. This is why it is important that the operators themselves be integrated into the design of the future system (Garrigou et al., 1995), which conditions the quality of the future ECS. Loup-Escande and Loup (2021) have recently emphasised this form of complementarity in the different methods of analysis. Although specialised in the acceptability of emerging technologies, they underline that the experimental, ecological, and prospective approaches would not have the same results, although they are complementary.

- From a more micro point of view, the overall feeling of satisfaction seems to be very much linked to the feeling of performance (statistically and qualitatively). These are the same verbatim types that we find in G1′ and G1″, in particular, the speed and simplicity/ease of working with the augmented reality device.
- The evolution of the situation leeway perception is also significantly different between G1′ and G1″. The notable point is that in G1′, the situational leeway seems to have decreased (−0.565) compared to G1, whereas in G1″, it increased (5.21) compared to G1. As a result, the participants felt the increased situational leeway in connection with the increase in the ECS intensity. However, the increase in situation leeway is only perceived between G1 and G1″. This means that the potential loss of situational leeway between G1 and G1′ cannot be demonstrated. A small situational leeway can result in various consequences. The total absence of situational leeway (Coutarel et al., 2015) leads to situations where it is impossible to achieve the objectives, even at the cost of costly mobilisation. Our study provides an improvement in this situational leeway by giving subjects a choice during certain key steps of the operative mode.

According to Coutarel et al. (2015), a low situational leeway can lead to a deterioration of the work group and/or a decrease in performance. The glasses could potentially impose mandatory passages that experts usually bypass depending on the context. In terms of continuous design, for example, in our study, some texts were displayed above the workstation, and the subjects had to raise their heads regularly to read them. In this case, the information was absent from the main field of vision, which could lead to them developing constrained postures.

Only certain parts of the ECS have been tested here. Some important aspects seem to be assessable only in ecological studies. Collective and organisational aspects, which are a part of the third characteristic of our ECS, could not be evaluated in this experiment. When setting up an ECS in an ecological situation, it is essential to study the type of management as well as the possibilities of continuous design in the longer-term use requiring the intervention of the collective or the organisation. This complete empowerment of the operator in their work situation may require the implementation of spaces for debate about the work or collective regulation times (Falzon, 2005; Clot, 2012; Hon, Bloom, and Crant, 2014). Some studies focus on project or change management, characteristics related to the design and support processes that would be favourable to technological implementation (Davis, 1989; Nielsen, 1994; Galli, 2018; Trischler et al., 2019). These aspects cannot be implemented and studied through this type of experimentation. Therefore, these important points of the ECS are studied in ecological situations (Compan et al., 2021). This is why we favour mixed methods between experiments and field studies.

This experimentation is the first attempt to operationalise the ECS. We have raised several limitations related to this first attempt. It seems important that this new model can experimentally demonstrate its interest. This first experimentation explains the limits of the study and also the originality of this work. As it was a first attempt, the transformations of the situation were limited. This low intensity of change may explain the partial results of the experiment. Future work must take care to provide a more important/consequential situational leeway and continuous design.

In view of the results of this study, it will be important to test the creation of an ECS in an ecological situation. The study highlights several important points for practitioners. The implementation of an ECS has experimentally demonstrated that it is possible to promote the deployment of operators' activity without impacting their performance (although it is possible that performance will be positively impacted in the longer term). We encourage practitioners to promote an ECS, in other words, situational leeway, operative transparency, and possibilities for continuous design in use (see Table 1). In concrete terms, it is important that operators have several ways of doing their work, that they have a sufficient understanding of the technology they are using, and that they are able to modify their workstation (including the technology) over time. However, as in this case, operators may not immediately perceive the benefits of these new possibilities.

6 Conclusion

Contemporary changes in work are opportunities for operators to deploy their capabilities in situations. The ECS and our proposals guide the activity of the workstation designers in order to enable such situations for the operators. This experimental study allows us to emphasise that the ECS is an applicable and valid proposal that can improve the work situation from the operator's point of view. Although the implementation of an ECS did not improve performance in this study, neither did the ECS degrade performance. The introduction of an emerging technology is an opportunity to rework the work situation and rethink the work. In concrete terms, this would mean offering the operator different ways of acting, such as choosing, when appropriate, the order of the steps in the operating procedure. These measures promote the development of situational leeway. The choice to personalise the interface of the glasses can allow the process of instrumental genesis that the ECS aims to support. Although not widely perceived by the participants themselves, the promising results of this study would be replicated in a more ecological environment. The implementation of an ECS in a workshop would certainly allow expert operators to see the benefits in their daily work in the longer term, which could drastically change the collaborative relationship they have with the technology. We potentially see the emergence of symbiotic (Gerber et al., 2020) relationships between humans and machines, which would lead to a better acceptance of technology or even a dependence on it. The ECS appears as a credible and beneficial support alternative for the design of new workstations.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material; further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by the Université Clermont Auvergne Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

NC: conceptualisation, formal analysis, investigation, methodology, and writing–original draft. JM: investigation and writing–review and editing. ML: investigation, methodology, and writing–review and editing. GR-L: validation and writing–review and editing. CB: writing–review and editing, methodology, and supervision. FC: funding acquisition, project administration, supervision, and writing–original draft.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. The authors wish to acknowledge the support they received from the National Research Agency of the French government under the Investments for the Future Programme (16-IDEX-0001 CAP 20-25), from I SITE cap 2025 challenge, and from the Ministry of Higher Education via the doctoral school.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors, and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fieng.2023.1258241/full#supplementary-material

References

Ajzen, I. (2006). *Behavioral interventions based on the theory of planned behavior.*

Amalberti, R. (2013). *Navigating safety: necessary compromises and trade-offs-theory and practice. (132).* Heidelberg: Springer.

Barcellini, F., Béarée, R., Benchekroun, T. H., Bounouar, M., Buchmann, W., Dubey, G., et al. (2023). Promises of industry 4.0 under the magnifying glass of interdisciplinarity: revealing operators and managers work and challenging collaborative robot design. *Cognition, Technol. Work* 25, 251–271. doi:10.1007/s10111-023-00726-6

Barthe, B., and Queinnec, Y. (1999). Terminologie et perspectives d'analyse du travail collectif en ergonomie. *L'Année Psychol.* 99 (4), 663–686. doi:10.3406/psy.1999.28501

Baslé, D., Noël, F., Brissaud, D., and Rocchi, V. (2021). Improving design of enabling collaborative situation based on augmented reality devices. *IFIP Int. Conf. Prod. Lifecycle Manag.*, 433–446. doi:10.1007/978-3-030-94335-6_31

Bobillier-Chaumon, M. E. (2021). *Digital transformations in the challenge of activity and work: understanding and supporting technological changes.* New York, United States: John Wiley and Sons.

Bobillier Chaumon, M. É., and Clot, Y. (2016). Clinique de l'usage: les artefacts technologiques comme développement de l'activité. synthèse introductive au dossier. *Activités* 13 (2). doi:10.4000/activites.2897

Canguilhem, G. (2001). The living and its milieu. *Grey Room* 3 (3), 7–31. doi:10.1162/152638101300138521

Clot, Y. (2012). Sanar el trabajo, palanca para una nueva empresa. *La Nouv. Rev. Du. Trav.* (1). doi:10.4000/nrt.108

Colin, C., Martin, A., Bonneviot, F., and Brangier, E. (2021). Unravelling future thinking: a valuable concept for prospective ergonomics. *Theor. Issues Ergonomics Sci.* 23, 347–373. doi:10.1080/1463922x.2021.1943045

Compan, N., Coutarel, F., Brissaud, D., and Rix-Lièvre, G. (2021). *Enabling collaborative situations in 4.0 industry: multiple case study. Congress of the international ergonomics association.* Cham: Springer, 614–620.

Compan, N. (2022). *Intérêt de la situation de collaboration capacitante pour une approche ergonomique des situations de travail industrielles intégrant des technologies émergentes (Doctoral dissertation).* Auvergne, France: Université Clermont Auvergne UCA.

Coutarel, F., Caroly, S., Vézina, N., and Daniellou, F. (2015). Marge de manœuvre situationnelle et pouvoir d'agir: des concepts à l'intervention ergonomique. *Le. Trav. Hum.* 78 (1), 9–29. doi:10.3917/th.781.0009

Daniellou *, F., and Rabardel, P. (2005). Activity-oriented approaches to ergonomics: some traditions and communities. *Theor. issues Ergonomics Sci.* 6 (5), 353–357. doi:10.1080/14639220500078351

Davis, F. D. (1985). *A technology acceptance model for empirically testing new end-user information systems: theory and results. PhD diss.* Cambridge: Massachusetts Institute of Technology.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Q.* 13 (3), 319–340. doi:10.2307/249008

Delgoulet, C., and Vidal-Gomel, C. (2014). The development of skills: a condition for the construction of health and performance at work. *Constr. Ergon.*, 3–16.

Ekkekakis, P. (2013). *The measurement of affect, mood, and emotion: a guide for health-behavioral research.* Cambridge: Cambridge University Press.

Falzon, P. (2014). *Enabling environments, enabling organizations*, 4.

Falzon, P. (2008). Enabling safety: issues in design and continuous design. *Cognition, Technol. Work* 10 (1), 7–14. doi:10.1007/s10111-007-0072-1

Falzon, P. (2005). *Ergonomics, knowledge development and the design of enabling environments*, 8.

Folcher, V. (2003). Appropriating artifacts as instruments: when design-for-use meets design-in-use. *Interact. Comput.* 15 (5), 647–663. doi:10.1016/s0953-5438(03)00057-2

Garrigou, A., Daniellou, F., Carballeda, G., and Ruaud, S. (1995). Activity analysis in participatory design and analysis of participatory design activity. *Int. J. Industrial Ergonomics* 15 (5), 311–327. doi:10.1016/0169-8141(94)00079-i

Gerber, A., Derckx, P., Döppner, D. A., and Schoder, D. (2020). "Conceptualization of the human-machine symbiosis–A literature review," in Proceedings of the 53rd Hawaii International Conference on System Sciences, Maui, Hawaii, USA, January 7-10, 2020.

Hart, S. G. (2006). "NASA-task load index (NASA-TLX); 20 years later," in Proceedings of the human factors and ergonomics society annual meeting, Sydney, Australia, 20-22 November 2006 (Los Angeles, CA: Sage CA Sage publications), 904–908. 50 (9).

Hart, S. G., and Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): results of empirical and theoretical research. *Adv. Psychol.* 52, 139–183. North-Holland. doi:10.1016/S0166-4115(08)62386-9

Hassenzahl, M. (2003). The thing and I: understanding the relationship between user and product. *Funology* 31-42. Springer, Dordrecht. doi:10.1007/978-3-319-68213-6_19

Hon, A. H., Bloom, M., and Crant, J. M. (2014). Overcoming resistance to change and enhancing creative performance. *J. Manag.* 40 (3), 919–941. doi:10.1177/0149206311415418

Jansen, A., Beek, D., Cremers, A., Neerincx, M., and Van Middelaar, J. (2018). *Emergent risks to workplace safety; working in the same space as a cobot*, 79. Ministry of Social Affairs and Employment.

Joseph Galli, B. (2018). Change management models: a comparative analysis and concerns. *IEEE Eng. Manag. Rev.* 46 (3), 124–132. doi:10.1109/emr.2018.2866860

Kolbeinsson, A., Lagerstedt, E., and Lindblom, J. (2018). "Classification of collaboration levels for human-robot cooperation in manufacturing," in Advances in Manufacturing Technology XXXII: Proceedings of the 16th International Conference on Manufacturing Research, Incorporating the 33rd National Conference on Manufacturing Research, University of Skövde, Sweden, September 11-13, 2018, 151–156.

Kotter, J. P. (2008). *Corporate culture and performance.* New York, United States: Simon and Schuster.

Lafeuillade, A. C., Barcellini, F., Buchmann, W., and Benchekroun, T. H. (2021). Integrating Collaborative Robotics into Work Situations: the intentions of sme managers in the digital transformation of their companies. *Digital Transformations Chall. Activity Work Underst. Supporting Technol. Changes* 3, 115–127. doi:10.1002/9781119808343.ch9

Loup-Escande, É., and Loup, G. (2021). Designing acceptable emerging technologies: what contribution from ergonomics? *Theor. Issues Ergonomics Sci.* 22 (5), 581–602. doi:10.1080/1463922x.2020.1836568

Milgram, P., and Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE Trans. Inf. Syst.* 77 (12), 1321–1329.

Nielsen, J. (1994). *Usability engineering.* Massachusetts, United States: Morgan Kaufmann.

Rabardel *, P., and Beguin, P. (2005). Instrument mediated activity: from subject development to anthropocentric design. *Theor. Issues Ergonomics Sci.* 6 (5), 429–461. doi:10.1080/14639220500078179

Rabardel, P. (2002). People and technology—a cognitive approach to contemporary instruments. *Univ. paris* 8, 188.

Récopé, M., and Barbier, D. (2015). Œuvrer au développement professionnel des enseignants afin que les élèves apprennent mieux. L'apprentissage en situation de travail. *Itinéraires Du. développement Prof. Des. enseignants d'éducation Phys.* 12, 17.

Récopé, M., Fache, H., Beaujouan, J., Coutarel, F., and Rix-Lièvre, G. (2019). A study of the individual activity of professional volleyball players: situation assessment and sensemaking under time pressure. *Appl. Ergon.* 80, 226–237. doi:10.1016/j.apergo.2018.07.003

Saldaña, J. (2021). *The coding manual for qualitative researchers.* New York, United States: sage.

Schoville, R. R. (2017). Discovery of implementation factors that lead to technology adoption in long-term care. *J. gerontological Nurs.* 43 (10), 21–26. doi:10.3928/00989134-20170914-06

Schoville, R. R., and Titler, M. G. (2015). Guiding healthcare technology implementation: a new integrated technology implementation model. *Cin. Comput. Inf. Nurs.* 33 (3), 99–107. doi:10.1097/CIN.0000000000000130

Sen, A. (1999). *Development as freedom.* Oxford: Oxford University Press.

Sen, A. (2004). Elements of a theory of human rights. *Philosophy public Aff.* 32 (4), 315–356. doi:10.1111/j.1088-4963.2004.00017.x

Srivastava, A., Bartol, K. M., and Locke, E. A. (2006). Empowering leadership in management teams: effects on knowledge sharing, efficacy, and performance. *Acad. Manag. J.* 49 (6), 1239–1251. doi:10.5465/amj.2006.23478718

Trischler, J., Dietrich, T., and Rundle-Thiele, S. (2019). Co-design: from expert-to user-driven ideas in public service design. *Public Manag. Rev.* 21 (11), 1595–1619. doi:10.1080/14719037.2019.1619810

Venkatesh, V., Morris, M. G., Davis, G. B., and Davis, F. D. (2003). User acceptance of information technology: toward a unified view. *MIS Q.* 27 (3), 425. doi:10.2307/30036540

Wisner, A. (1997). Psychological aspects of anthropotechnology. *Le. Trav. Hum.* 60 (3), 229–254.