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Human-Cobot collaboration's impact on success, time completion, errors, workload, gestures and acceptability during an assembly task

Étienne Fournier^a, Christine Jeoffrion^a, Belal Hmedan^b, Damien Pellier^b,
Humbert Fiorino^b, Aurélie Landry^b

^a*Univ. Grenoble Alpes – LIP/PC2S, Grenoble, 38000, France*

^b*Univ. Grenoble Alpes –LIG, Grenoble, 38000, France*

Abstract

The 5.0 industry promotes collaborative robots (cobots). This research studies the impacts of cobot collaboration using an experimental setup. 120 participants realized a simple and a complex assembly task. 50% collaborated with another human (H/H) and 50% with a cobot (H/C). The workload and the acceptability of the cobotic collaboration were measured. Working with a cobot decreases the effect of the task complexity on the human workload and on the output quality. However, it increases the time completion and the number of gestures (while decreasing their frequency). The H/C couples have a higher chance of success but they take more time and more gestures to realize the task. The results of this research could help developers and stakeholders to understand the impacts of implementing a cobot in production chains.

Keywords: collaborative robot, workload, acceptability, 5.0 industry

1. Introduction

Since 2010, the industry 4.0 pushes the implementation of intelligent technologies in the industrial workplace to increase productivity (Oztemel & Gursev, 2020). In 2020, the industry 5.0 was launched by the European Commission (Xu et al., 2021). This new industry calls on industry players to put humans back at the heart of the industrial system. It promotes Human/Cobot (H/C) collaboration. Therefore, cobots are being increasingly implemented in the industry. “The cobot market is rapidly expanding, and

the academic literature is similarly growing” (Knudsen & KaiVo-Oja, 2020, p. 13). The term cobot refers to ”a robotic device which manipulates objects in collaboration with a human operator” (Colgate et al., 1996, p. 1). Their use could be a way of reducing constraints and increasing performances without replacing the human factor (Peshkin & Colgate, 1999). Cobots work closely to humans; therefore, they are equipped with security features to prevent injuries (Djuric et al., 2019; Gualtieri et al., 2021). However, implementing a cobotic system in the workplace can have other negative effect. Authors have identified a positive effect of the H/C collaboration, such as reduction of musculoskeletal disorders risks factors (Bouillet et al., 2023; Schoose, 2022). However, this implementation puts other strains on the operator and can decrease the output quality (Schoose, 2022). Therefore, it seems important to test the effect of the H/C collaboration on human operators (Kildal et al., 2018). We choose to focus on two types of reports of HC collaboration that are particularly interesting to us because they test real-life direct interaction with cobots: feedbacks from the field which focus on the operators and their perceptions (Barcellini et al., 2023; Catchpole et al., 2019; Cheon et al., 2022; Pauliková et al., 2021; Schoose, 2022; Schoose et al., 2023) and feedbacks from experiments studying their impacts in laboratories’ conditions (Alarcon et al., 2021; Fournier et al., 2022; Hopko et al., 2023; Varrecchia et al., 2023). The cobot adaptation capacities could help dealing with variabilities in the workplace (Hiatt et al., 2011). These studies revealed that H/C collaboration improved worker’s coordination, decreased physical effort (Varrecchia et al., 2023), improved efficiency (Fournier et al., 2022) and decreased exposure to risks (Pauliková et al., 2021). However, studies have reported negative effects of implementing cobotic systems (Cheon et al., 2022; Fournier et al., 2022; Schoose, 2022; Schoose et al., 2023). There have been cases of loss of job identity (Cheon et al., 2022), increased task’s time completion (Fournier et al., 2022; Mariscal et al., 2023) and lack of cobot adaptability to human constraints (Schoose, 2022; Schoose et al., 2023). To be implemented in the industry, cobotic collaboration needs to be effective in terms of results (higher quality of output, faster completion time, lower number of gestures and lower number of errors). Also, realizing the task with less gestures and with a decreased mental workload from the human could be interesting for the industry as cobotic collaboration is designed to increase the operator’s well-being (Bogue, 2016; European Commission, 2021; Salunkhe et al., 2019). The mental workload can be representative of the operator’s wellbeing at work (Fruggiero et al., 2020), therefore, its study in the context

of cobotic collaboration is important. Those variables are all connected to the concept of usability (Bevan et al., 2015) which is “the extent to which a product can be used by specified users to accomplish specific goals with effectiveness, efficiency and satisfaction in a particular context of use” (ISO, 2018). The effectiveness (degree of completion and accuracy) of the cobotic collaboration can be measured by the number of errors and the success of the task. Efficiency (minimal of resources used) can be measured with the time completion and the number of gestures and workload. Finally, satisfaction (meet the user’s expectations) can be measured with the acceptability. According to Fournier et al. (2022), a cobotic collaboration could be useful in the industry to improve the success of a task, unlike Schoose et al. (2023) who reported a less qualitative output. Also, some studies demonstrate a lower time completion of the task (Fager et al., 2019) and others report the opposite (Fournier et al., 2022; Mariscal et al., 2023). Concerning the number of errors, some authors demonstrated a decrease with a cobotic collaboration (Fournier et al., 2022), while other showed an increase (Mariscal et al., 2023). The cobotic collaboration’s impact on workload is also unclear, a study found a decrease working with cobots (Kildal et al., 2019), while another found no significative change (Fournier et al., 2022). Furthermore, only one study (which we conducted) showed a decrease in the number of gestures with a cobotic collaboration (Fournier et al., 2022). Those different variables require further investigations before allowing cobots to be massively implemented in the industry in order to guarantee their acceptation (Bobillier Chaumon, 2016). If they are not accepted by the operators, they won’t use it or they won’t use well (Cippelletti, 2017). Nielsen developed a model of acceptability (Nielsen, 1994) that included the concept of ease of use of the system and usefulness (ease for the system to achieve the set goal). These concepts were used in the Unified Theory of Acceptance and Use of Technology (UTAUT), a model to assess the acceptance of a technology (Venkatesh et al., 2003). In this model, the authors investigate four factors that have positive impacts on the use intention. These factors include:

- Expected performance (or perceived usefulness): the degree to which the individual believes using the system will help him achieve his goal (Venkatesh et al., 2003).
- Expected efforts (or perceived ease of use): the degree to which the user perceives the system easy to be used (Venkatesh et al., 2003).

- Social influence: the degree to which the individual believes that people who are important to him believe that he should use the system (Venkatesh et al., 2003).
- Facilitating conditions: the degree to which an individual perceives that the characteristics of his environment will help to use the system (Venkatesh et al., 2003).

These different factors predicted 56% of behavioral intention and 40% of use of mobile applications on smartphones by 1,512 participants (Venkatesh, 2012). The authors of the UTAUT completed their original model analyzing over 500 articles dealing with technology adoption, adding 3 independent variables (Venkatesh, 2007, in Martin, 2018). The hedonic motivation is the degree of perceived pleasure associated with using the technology. The monetary cost is the perceived financial cost of using the technology. And the “user habits” is the individual habit of using technology. UTAUT2 predict 74% of behavioral intention and 52% of usage (Venkatesh, 2012).

The goal of this study is to determine if the human’s success in a task (Fournier et al., 2022; Schoose et al., 2023), the time completion (Fager et al., 2019; Fournier et al., 2022; Mariscal et al., 2023), the number of errors (Fournier et al., 2022; Mariscal et al., 2023), the workload (Fournier et al., 2022; Kildal et al., 2019), the number of gestures (Fournier et al., 2022) and acceptability of the collaboration are different whether the collaboration is Human/Human (H/H) or H/C by controlling certain variabilities. Variabilities are the variations to which each work situation is subject to (Brangier & Valléry, 2021). They may be individual, i.e. originating from the operator himself, or external (Guérin et al., 1997). For example, a cobotic collaboration is more efficient than its absence when realizing an easy task (Fournier et al., 2022), but it has yet to prove itself flexible enough to be efficient when realizing a complex one, closer to a real-life work situation (Kildal et al., 2018). This task demand (or complexity) variability has to be investigated. Also, to guide the cobot conception, it was necessary to determine if the arm use of the cobot could have a different impact whether it was in tune with the dominant hand of the participant (e.g. using the right arm facing the participant when he was right-handed) or not (e.g. using the right arm facing the participant when he was left-handed). For those reasons, in our research, we aimed to determine how the cobot adapts to those two variabilities (task demand and dominant hand) during

an assembly task. We too decided to create a questionnaire to assess acceptability of the cobotic collaboration. In fact, no research, as far as we know, has investigated the acceptability of cobots before and after use, this is one objective of the study presented. We also want to measure the impact of H/C collaboration on the human workload, which is the amount of mental resources used for a specific task (Verhulst, 2018), and the number of gestures (Catchpole et al., 2019). We define collaboration as two agents working on the same task in the same time (Matheson et al., 2019; Müller et al., 2017).

Our operational hypotheses are:

H1: The increase of the **task demand** has a negative effect on the participants' workload, success, errors, time completion and gestures. This effect is lower in the H/C condition than in the H/H condition.

H2: Adapting the cobot to the operator's **dominant hand** has a positive effect on the participants' workload, success, errors, time completion and gestures.

H3: H/C **collaboration** has more positive effects on the success rate, the number of errors, the completion time, the workload and the number of gestures compared to the H/H collaboration.

H4: Participant's **acceptability score** of the H/C collaboration is higher in the H/C condition than in H/H condition.

2. Material and methods

This study was pre-registered on OSF and registered by the laboratory's director under the authority of the university.

2.1. Participants

120 subjects participated in the study (90 female, 29 males and 1 non-binary). 81% of the participants were right-handed, 16% left-handed and 3% fluid with both hands. This is still higher than in the general French population that counts 12,9% of left-handed (Lesgauchers, 2017). Only 8% of the participants declared having worked with a robot before. Participants were adults, without any color vision impairment and with no pain in the upper limbs prior to the experiment. They were recruited by a post on the website of the university. Psychology students were awarded point in certain courses. Participants were divided into two different groups.

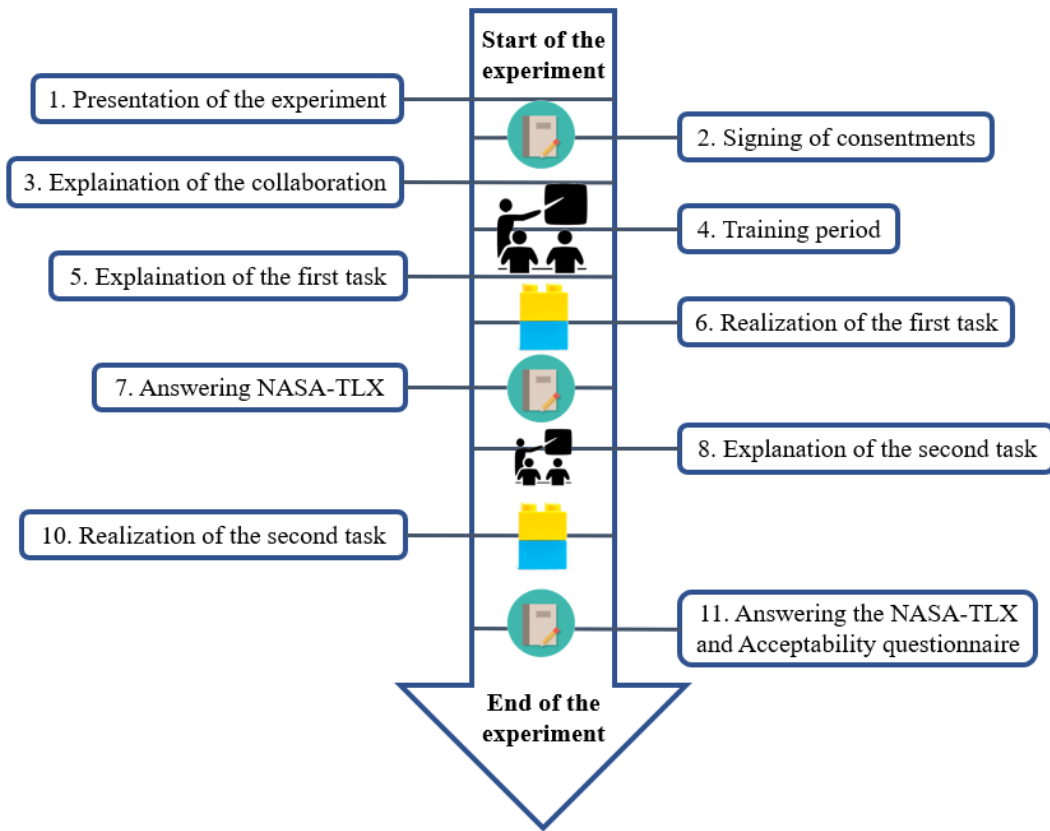


Figure 1: Illustration of the experimental procedure



Figure 2: A participant realizing the task with YuMi (H/C condition)

2.2. Procedure

The experimental procedure is illustrated Figure 1. In our study, two conditions were set up, participants were randomly assigned to two different groups corresponding to those conditions. The use of an intergroup rather than an intragroup modality was justified by logistical constraints and by the desire to avoid learning and fatigue effects. The first group (N=61) realized two Duplo assembly tasks (simple and complex in a randomized order) during a H/H collaboration. The second group (N=59) realized the same tasks with a cobot (H/C condition; cf. Figure 2).

In both conditions, they had to reproduce a model in front of them (A in Figure 2 and 3) in a designated area (B) with Duplos located in an area in front of them (C). In the H/H condition, they could talk to each other. In the H/C condition, they had to interact using in interface next to them (D). During the simple task, participants reproduced a one-level model in collaboration as fast as possible (cf. Figure 3).

During the complex task, participants reproduced a 5-level model in collaboration as fast as possible while answering simple math additions. In both

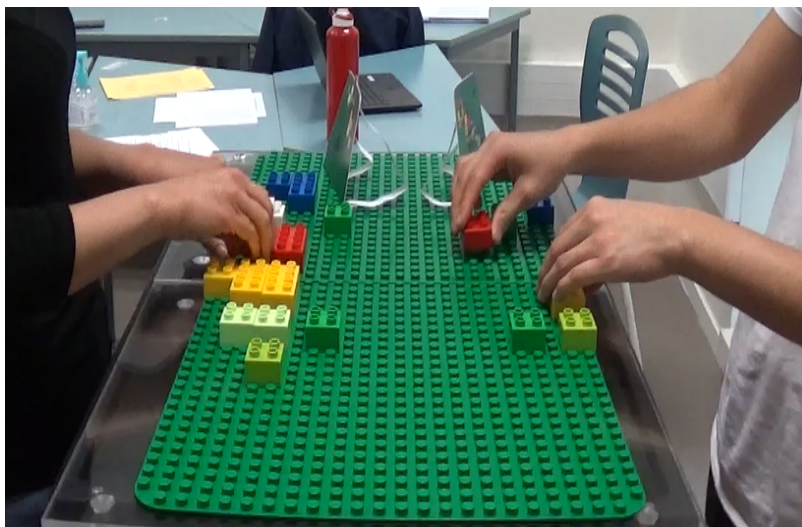


Figure 3: Two participants realizing the task (H/H condition)

conditions, the participant had access to $\frac{3}{4}$ of the Duplo's stock to realize the task. The human collaborator or the cobot had $\frac{1}{4}$ of the Duplo's stock.

The robot used is a Yumi from ABB Robotics. Through a vision camera system the cobot can automatically see what the human chooses to do. This ability was programmed using Python language and OpenCV computer vision library. After a perception stage, the system uses a decision-making interface that uses a planning. The cobot decides what the best next action is, taking into consideration its previous actions and the human previous actions. This stage is performed using Automated Planning techniques. Then, the selected action is executed by YuMi using the RAPID language by ABB. This action is projected on a Graphical User Interface to demonstrate the action to the participant.

After completing the assembly task, two questionnaires were filled by participants. First, a translated version (Cegarra & Morgado, 2009) of the NASA-TLX (Hart & Staveland, 1988) was used to assess perceived workload (Table 1). This scale measures workload using subscales of the mental load, physical load, temporal demand, frustration, effort and performance (Hart, 2006). Participants passed the latest version of NASA-TLX (see Cegarra & Morgado, 2009) after each task (simple and complex). The participant must answer on a 100-point Likert scale to what degree he agrees with each sentence.

Table 1: The NASA-TLX (Hart & Staveland, 1988).

Dimension	Item
<i>Mental workload</i>	How mentally demanding was the task?
<i>Physical demand</i>	How physically demanding was the task?
<i>Time demand</i>	How hurried or rushed was the pace of the task?
<i>Performance</i>	How successful were you in accomplishing what you were asked to do?
<i>Effort</i>	How hard did you have to work to accomplish your level of performance?
<i>Frustration</i>	How insecure, discouraged, irritated, stressed, and annoyed were you?

An adapted version of the UTAUT2 questionnaire was used to assess the acceptability of a collaboration with a cobot (Table 2). Martin (2018) translated this questionnaire in French and adapted it by adding the measure of ease of use developed by Davis (1989) and the measure of trust developed by Martin (2018) to the original questionnaire of the UTAUT2 (Venkatesh et al., 2012). The model fit of the questionnaire was satisfactory and the items explained 89% of the intent of use’s variance. In our version, “this system” was replaced by “the cobot”, and assessed the perceived ease of use, the perceived coherence for the task, the perceived pleasure, the perceived usefulness, the perceived social influence and the trust (Cronbach’s alphas > 0,74). Participants were asked with what degree they agree with the sentence with a Likert scale from 1 (do not agree at all) to 7 (do totally agree). A Principal Component Analysis (SPSS Version 28) revealed that 6 factors were measured by the 6 different scales (this is what we expected) and that these factors combined explained 78,863% of the total variance of answers.

The questionnaire was implemented using LimeSurvey software. This software was made available thanks to SCREEN (Common Resource Service for Experimentation and Digital Equipment) managed by the University of Grenoble Alpes.

Participants were filmed during the tasks. These videos were used to determine the number of gestures (number of arm movements of the partic-

Table 2: The acceptability questionnaire used in the experiment (the questions were asked in French, they were only translated for the article)

Dimensions	N° item	Items
Ease of use	1	Understanding how to collaborate with a cobot would be clear to me.
	2	Collaborating with a cobot wouldn't require much mental effort.
	3	I think it would be easy to work with a cobot.
	4	I could easily do the task the way I want, thanks to a cobot.
Coherence for the task	5	Collaboration with a cobot would be relevant to the content of the tasks I performed.
	6	For the tasks to be carried out, collaboration with a cobot would be appropriate.
	7	Working with a cobot would be a good fit for the tasks I've been doing.
Pleasure	<i>I would like to collaborate with a cobot (to complete with the 5 sentences below)</i>	
	8	Because using a cobot sounds like a lot of fun.
	9	Because using a cobot could be a lot of fun.
	10	Because thanks to the cobot, I could satisfy my curiosity to discover new things.
	11	Because I could have a lot of pleasure interacting with the cobot.
	12	Because the cobot could enable me to learn/do things that I find very interesting.
Usefulness	13	Working with a cobot would improve my performance on the task.
	14	Working with a cobot during this task would increase my performance without tiring me further.
	15	Working with a cobot would improve my task efficiency.
	16	I find that working with a cobot would be useful in this task.
Social influence	17	The people whose opinion I value might encourage me to use the cobot to carry out the task.
	18	The people around me who I'm used to listening to could advise me to use the cobot to carry out the task.
	19	The people around me who are important to me could encourage me to use the cobot.
Trust	20	A cobot seems to provide reliable information.
	21	I trust the information a cobot could provide.
	22	A cobot seems reliable.
	23	I think a cobot can be trusted.

ipant use to click on a button, pick and place a block, and pointing), the number of errors (a block placed in the wrong spot) and the time completion (from the “start” of the experimenter to the “finished” of the participant”). A task was considered “successful” when the model was correctly replicated (no misplaced or missing blocks). The analysis of the videos was made with the software Boris (Friard & Gamba, 2016).

3. Results

Bugs (programming issues or lack of perception by the cobot) impacted the experiments for 71% of the H/C duos. Those issues were fully part of the experiment as cobots are still in development, so the data collected were not removed in case of bugs. It was considered to be a part of the cobotic collaboration variable. On all the variables tested, two participants were outliers on multiples variables (they were not able to realize the task, even alone, due to spatial localization problem). We decided to not include them in the statistical tests. The final sample size for the study is 120 participants. Study results were calculated using IBM SPSS 28. Multi-analysis of variance (MANOVA), ANOVAs and mean comparisons were used. To calculate interaction effects, generalized mixed model were used. Cohen’s D was also calculated for the effect sizes.

3.1. Questionnaires validity

Internal consistency of the NASA-TLX was confirmed: no item was correlated more than 0.70 with another. The Cronbach’s alpha was satisfying (0.761). For the acceptability questionnaire, we performed a principal component analysis to test the reliability of our questionnaire and the validity of the different scales. We removed 4 problematic items (which are not in the right dimension or too close to .50). By removing these 4 items, we explain almost 82% of the responses’ variance. The questionnaire’s Cronbach’s alpha is 0.919.

3.2. The moderative effect of the **task demand** (Hypothesis 1)

The table below presents the descriptive results of the first hypothesis (cf. Figure 3).

An interaction effect was found between task demand and workload [$f(1)=61,134$; $p>0,000$]. The type of collaboration moderates the effect of the type of task in terms of workload. The effect of the task demand on

Figure 4: Bar chart of the workload, success, errors, time completion and gestures in the simple and complex tasks during the collaboration human/human compared to human/cobot

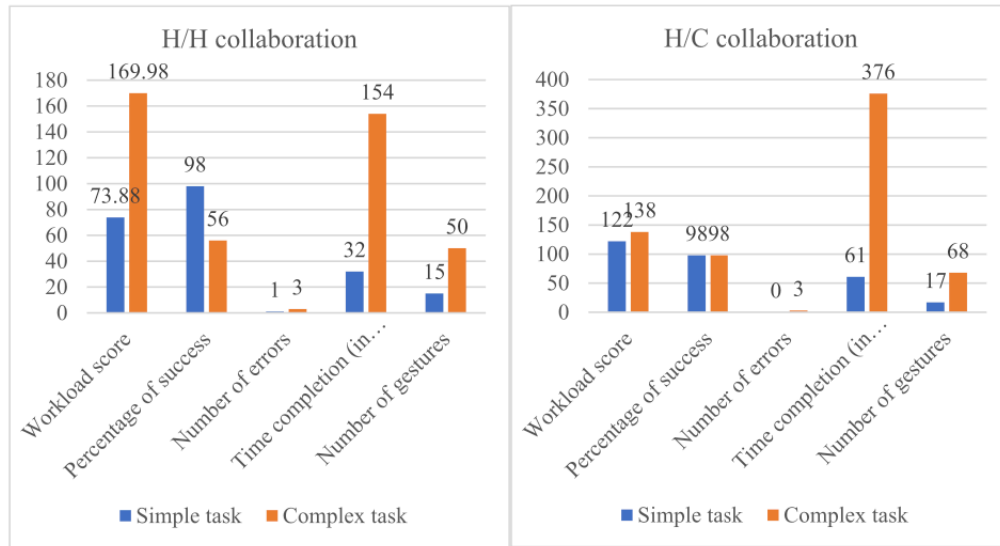
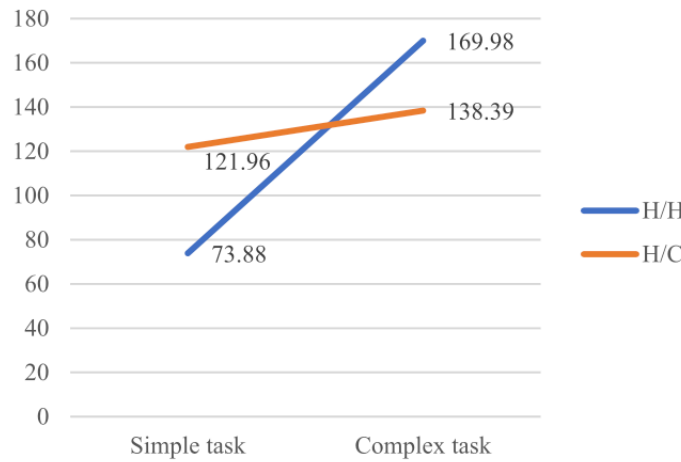


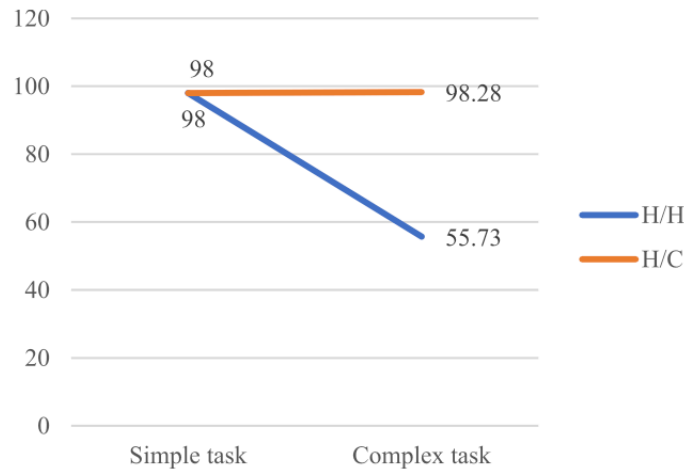
Figure 5: Interaction effect of the type of collaboration on the effect of task complexity on workload



the workload is lower in the H/C condition than in the H/H condition (cf. Figure 4).

An interaction effect was found between task demand and success rate

Figure 6: Interaction effect of the type of collaboration on the effect of task complexity on the success percentage



$[f(1)=2,482; p>0,000]$. The type of collaboration moderates the effect of the task demand in terms of success rate. The effect of the task demand on the success is lower in the H/C condition than in the H/H condition (cf. Figure 5).

No interaction effect was found between task demand and number of errors $[f(1)=1,088; p>0,299]$.

An interaction effect was found between task demand and time completion. The type of collaboration moderates the effect of the task demand in terms of time completion $[f(1)=158,250; p>0,000]$. The effect of the task demand on the time completion is higher in the H/C condition than in the H/H condition (cf. Figure 6).

An interaction effect was found between task demand and number of gestures. The type of collaboration moderates the effect of the task demand in terms of number of gestures $[f(1)=29,066; p>0,000]$. The effect of the task demand on the number of gestures is higher in the H/C condition than in the H/H condition (cf. Figure 7).

3.3. H2: The moderation effect of cobot's adaptation to the type dominant hand

The effect of the cobot's adaptation to the type of dominant hand has no effect on the different independent variables $[f(5)= 1,229; p=0,311]$.

Figure 7: Interaction effect of the type of collaboration on the effect of task complexity on time completion

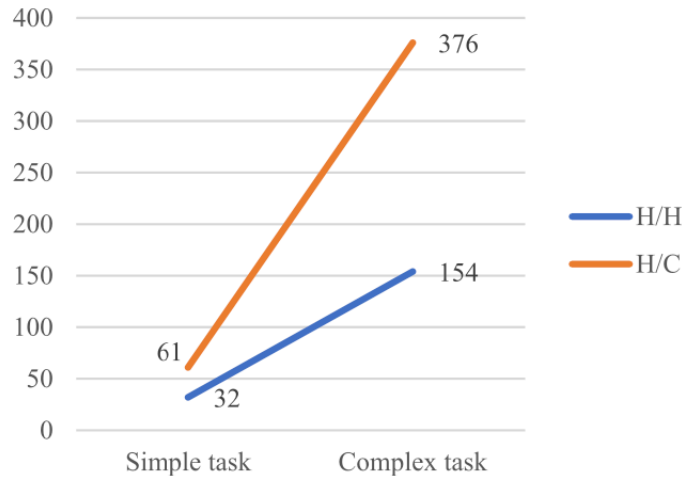
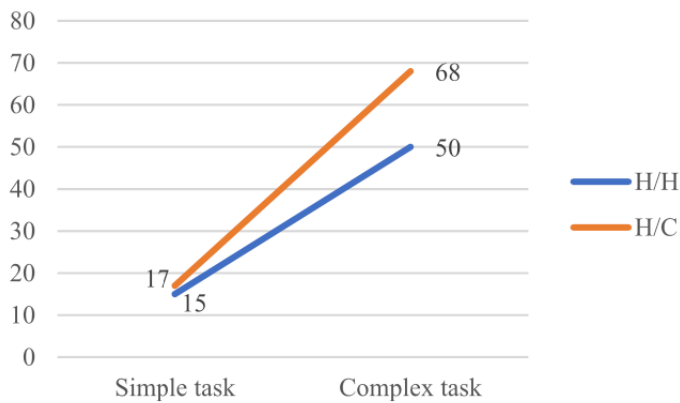


Figure 8: Interaction effect of the type of collaboration on the effect of task complexity on number of gestures



3.4. H3: The effect of the type of collaboration

The figure below presents the descriptive results of the third hypothesis (Figure 8).

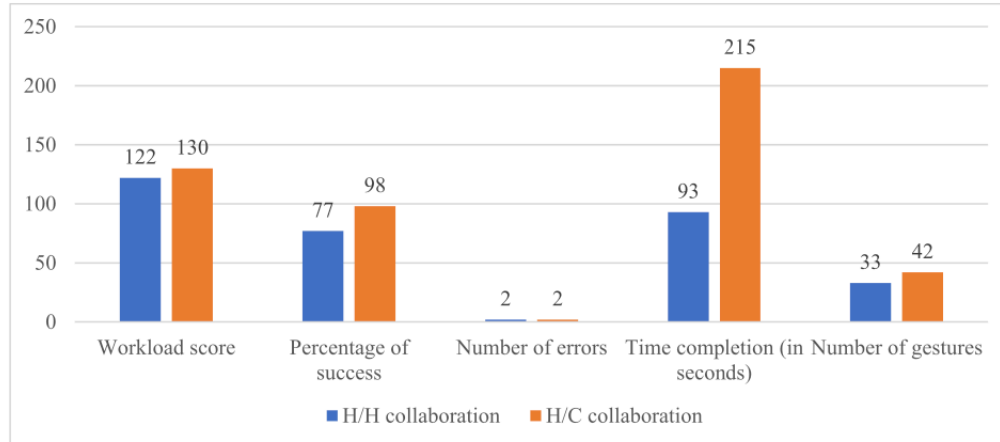
The type of collaboration has an effect on the success of the task, time completion and number of gestures. However, it has no effect on workload and number of errors (cf. Table 3).

The type of collaboration doesn't affect the workload globally. Also, the workload after the simple task in the H/C condition is higher than in the

Table 3: Results of the multi-analysis of variance of the type of collaboration on workload, success, errors, time and gestures (significant effects in bold)

Independent variable	Dependent variable	df	Mean square	F	Sig.	Partial eta-square
Type of collaboration	Workload	1	398,916	,166	,685	,001
	Success	1	1241	32,283	<,001	,225
	Errors	1	4802	1088	,299	,010
	Time	1	419,672,363	158,250	<,001	,588
	Gestures	1	2685,245	29,066	<,001	,208

Figure 9: Bar chart of the workload, success, errors, time completion and acceptance in collaboration with a cobot and with another human



H/H condition [$u=2542,000$; $z=4,327$; $p<0,000$]. The Cohen's D is -0,827, the effect is large. However, the workload after the complex task in the H/C condition is lower than in the H/H condition [$u=1338,500$; $z=-2,154$; $p<0,000$]. The Cohen's D is 0,464, the effect is moderate.

There is no significant effect of the collaboration on the number errors. However, participants did less errors by time spent on the task in the H/C condition than in the H/H condition [$t(111)=5,988$; $p<0,001$]. The Cohen's D is 1,130, the effect is large.

Also, bugs of the cobot impacted positively the time spent on the task [$t(50)=1,966$; $p=0,027$] and the number of gestures [$u=186,500$; $z=-2,014$; $p=0,044$]. Both Cohen's D indicate a moderate effect. The frequency of gesture (number of gesture / time completion) was lower with a cobot [$t(111)=-5,391$; $p<0,001$]. Participants did less gestures considering the time spent in the H/C condition than in the H/H condition. The Cohen's D is 2,660, the effect is large.

3.5. H_4 : The cobotic collaboration acceptability score

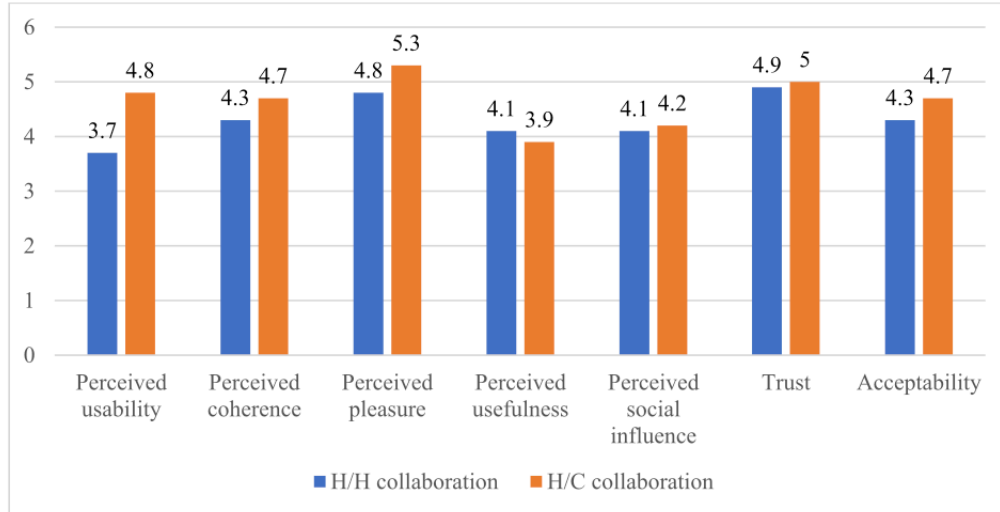
The figure below presents the descriptive results of the third hypothesis (cf. Figure 9).

Working with a cobot has a positive effect on ease of use perceived and on pleasure perceived (cf. Table 4).

Table 4: Results of the multi-analysis of variance of the type of collaboration on the different scales of the acceptability questionnaire (significant effects in bold)

Independent variable	Dependent variable	df	Mean square	F	Sig.	Partial eta-square
Type of collaboration	Ease of use	1	38,265	27,680	<,001	,193
	Coherence	1	6484	2914	,091	,025
	Pleasure	1	7572	5427	0,022	,045
	Usefulness	1	,576	,235	,629	,002
	Social influence	1	,251	,114	,737	,001
	Trust	1	,183	,115	,735	,001
	Acceptability	1	3772	3812	,053	,032

Figure 10: Bar chart of the subdimension of the acceptability scale



4. Discussion

The objective of this study was to identify the impact of a H/C collaboration in an industry-like assembly task. It has brought to light some interesting and innovative results.

First, the cobotic collaboration has decreased the task demand's effect on the human workload and increase the success of the task. During the cobotic collaboration, the human's workload did not change significantly. The success rate remained high no matter the level of difficulty of the task. It was not the case during the collaboration H/H. It led to a higher workload during a complex task and a lower success rate. Also, whether the robot adapted to the dominant hand or not, the results were no different. This could mean that this type of adaptation is not necessary. Liu et al. (2022) found different results. In their study, H/C collaboration did not have the same impact on the workload and the performance according to the type of task they realized. In our case, the difficulty changed, not the type of task. Future studies should investigate both.

Second, H/C collaboration increased the effect of the task demand on the time completion and the number of gestures. A higher time completion can be potentially explained by the correction of errors. Indeed, in the H/C condition, the success rate is significantly higher than in the H/H condition but the number of errors is the same. This means that the cobot encouraged

participants to correct their errors, which involved more gestures and a longer time completion. Furthermore, a test revealed that the cobot's bugs had a positive impact on the number of gestures on the time completion. The participants that collaborated with the cobot experienced bugs that would need to be fixed by doing even more gestures and by waiting for the bug to be fixed. Another study has compared H/H and H/C collaboration and it showed no increase in the completion time (Fager et al., 2019). However, the frequency of gestures is lower in the H/C condition. Participants made fewer gestures with the cobot in relation to the time spent on the task. This is coherent with a previous experiment (Fournier et al., 2022).

The type of collaborations did not impact the workload as a whole, which is coherent with other previous experiment (Fournier et al., 2022). However, it increased the workload during the simple task and decreased it during the complex task. We suspect a novelty effect (Elston, 2021). This mixed effect would create bias in the workload scores. The fact that the workload decreased during the complex task could mean that working with a cobot is less demanding than working with another human in terms of workload.

The type of collaboration had an effect on the success rate. In the H/C condition, participants had a higher success rate than in the H/H condition. This result is not surprising as others studies have found a lower number of errors (Fournier et al., 2022) and a better output quality (Salunkhe et al., 2019) in H/C collaborations. In our study, the number of errors was equivalent in both conditions. However, the frequency of errors was lower in the H/C condition.

Our study explored the H/C collaboration acceptability with 6 different scales. Participants in the H/H condition had high perceptions of pleasure and trust of H/C collaboration. This is coherent with another study that found high scores in trust and pleasure perceived (Cippelletti et al., in revision) in the working population. Participants that worked with the cobot had high perceptions of ease of use, coherence for the task, pleasure and trust of H/C collaboration. There was a significative effect of the type of collaboration on the ease of use and the pleasure perceived. H/C collaboration is perceived as more pleasant and feasible when the participant tried this collaboration before. As far as we know, those results have never been found before.

This study has few limits: the experiments were impacted by bugs that affected some results. Indeed, bugs increased the number of gestures (probably because the participant had to replace some blocks) and the time comple-

tion (the participant had to wait for the issue to be resolved). However, all the other variables, including the workload, were not impacted by the bugs. Participants may have been particularly patient with the cobot, in a real industry setting, it might have been different. In fact, the experiment has to be replicated with a better performing cobot. It should also be replicated with more left-handed participants even if they are less numerous in the population. We did not take age into account in our study since we consider that this variable was not useful to our analysis, but it could be one of the variabilities to be considered. So, we will ask for the age in our next study.

Also, the results bring some new research opportunities. It would be interesting to test the acceptability in the work field with operators that are used to work with cobots (Compan et al., 2023). This way, we would be able to assess the situated acceptance, which is the technology acceptance of concerned operators (Bobillier Chaumon, 2016, 2021). Also, testing the H/C collaboration impacts in different work context would be beneficial for the industry.

Those results have practical implications: cobots are able to adapt to human strategy in an industry-like task. It could decrease the operator's workload and increase the quality of the results. However, we discovered that the cobot adaption to the dominant hand is probably not useful as it doesn't have an impact on the operator and on the results. Also, working with a cobot could increase the time spent on the task. Work engineers should address what is their main goal before implementing a cobot (speed or quality of output).

5. Conclusion

This study has demonstrated that cobotic collaboration can balance the effects of individual variability (strategy) and of task variability (difficulty) on the output quality (success of the task) and on the human workload. By doing so, it increased the time and the number of gestures needed to realize the task (while decreasing their frequency). In this experiment, the cobotic collaboration has proven to increase the output quality and has reduced to human workload in a complicated task. Also, it is the first study to compare the acceptability of cobotic collaboration of people that have never experienced it with people that just did. Results show that all participants have a high level of pleasure perceived and trust associated with cobots. Having

worked with a cobot increases the ease of use and the pleasure perceived. Those results can be of use to the industry that wants to implement cobots.

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6. References

Alarcon, G. M., Gibson, A. M., Jessup, S. A., & Capiola, A. (2021). Exploring the differential effects of trust violations in human-human and human-robot interactions. *Applied Ergonomics*, *93*, 103350. <https://doi.org/10.1016/j.apergo.2020>.

Barcellini, F., Béarée, R., Benchekroun, T.-H., Bounouar, M., Buchmann, W., Dubey, G., Lafeuillade, A.-C., Moricot, C., Rosselin-Bareille, C., Saraceno, M., & Siadat, A. (2023). Promises of industry 4.0 under the magnifying glass of interdisciplinarity: Revealing operators and managers work and challenging collaborative robot design. *Cognition, Technology & Work*, *25*(2-3), 251-271. <https://doi.org/10.1007/s10111-023-00726-6>

Bevan, N., Carter, J., & Harker, S. (2015). ISO 9241-11 Revised: What Have We Learnt About Usability Since 1998? In M. Kurosu (Ed.), *Human-Computer Interaction: Design and Evaluation* (pp. 143-151). Springer International Publishing. https://doi.org/10.1007/978-3-319-20901-2_13

Bobillier Chaumon, M.-E. (2016). L'acceptation située des technologies dans et par l'activité: Premiers étayages pour une clinique de l'usage. *Psychologie du Travail et des Organisations*, *22*(1), 4-21. <https://doi.org/10.1016/j.pto.2016.01.001>

Bobillier Chaumon, M.-E. (2021). Exploring the Situated Acceptance of Emerging Technologies in and Concerning Activity: Approaches and Processes. In M.-E. Bobillier Chaumon (Ed.). *Digital Transformations in the Challenge of Activity and Work* (pp. 237-256). John Wiley & Sons, Ltd. <https://doi.org/10.1002/9781119808343.ch18>

Bogue, R. (2016). Europe continues to lead the way in the collaborative robot business. *Industrial Robot: An International Journal*, *43*(1), 6-11. <https://doi.org/10.1108/IR-10-2015-0195>

Bouillet, K., Lemonnier, S., Clanche, F., & Gauchard, G. (2023). Does the introduction of a cobot change the productivity and posture of the

operators in a collaborative task? *PLOS ONE*, 18(8), e0289787. <https://doi.org/10.1371/journal.pone.0289787>

Brangier, E., & Valléry, G. (2021). *Ergonomie : 150 notions clés*. Dunod.

Catchpole, K., Bisantz, A., Hallbeck, M. S., Weigl, M., Randell, R., Kossack, M., & Anger, J. T. (2019). Human factors in robotic assisted surgery: Lessons from studies ‘in the Wild’. *Applied Ergonomics*, 78, 270-276. <https://doi.org/10.1016/j.apergo.2018.02.011>

Cegarra, J., & Morgado, N. (2009). *Étude des propriétés de la version francophone du NASA-TLX*. COOP’2000. <https://docplayer.fr/21755956-Etude-des-proprietes-de-la-version-francophone-du-nasa-tlx.html>

Cheon, E., Schneiders, E., & Skov, M. B. (2022). Working with Bounded Collaboration: A Qualitative Study on How Collaboration is Co-constructed around Collaborative Robots in Industry. *Proceedings of the ACM on Human-Computer Interaction*, 6(CSCW2), 369:1-369:34. <https://doi.org/10.1145/3555094>

Cippelletti, E. (2017). *Aide à la conception, test de l’usage et de l’acceptation d’un logiciel de maintenance* [These de doctorat, Université Grenoble Alpes (ComUE)]. <https://www.theses.fr/2017GREAH038>

Colgate, J. E., Wannasuphoprasit, W., & Peshkin, M. A. (1996). *Cobots: Proceedings of the 1996 ASME International Mechanical Engineering Congress and Exposition*, 433-439. <http://www.scopus.com/inward/record.url?scp=0030402971&partnerID=8YFLogxK>

Compan, N., Matias, J., Lutz, M., Rix-Lièvre, G., Brissaud, D., Belletier, C., & Coutarel, F. (2023). The impact of Enabling Collaborative Situations in AR-assisted consignment tasks. *Frontiers in Industrial Engineering*, 1, 1258241. <https://doi.org/10.3389/fieng.2023.1258241>

Davis, F. D. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly*, 13(3), Article 3. <https://doi.org/10.2307/249008>

Djuric, A., Rickli, J., Sefcovic, J., Hutchison, D., & Goldin, M. M. (2019, janvier 15). *Integrating Collaborative Robots in Engineering and Engineering Technology Programs*. ASME 2018 International Mechanical Engineering Congress and Exposition. <https://doi.org/10.1115/IMECE2018-88147>

Elston, D. M. (2021). The novelty effect. *Journal of the American Academy of Dermatology*, 85(3), 565-566. <https://doi.org/10.1016/j.jaad.2021.06.846>

European Commission. (2021). *Industry 5.0: Towards a sustainable,*

human centric and resilient European industry (KI-BD-20-021-FR-N). Publications Office of the European Union. <https://data.europa.eu/doi/10.2777/308407>

Fager, P., Calzavara, M., & Sgarbossa, F. (2019). Kit Preparation with Cobot-supported Sorting in Mixed Model Assembly. *IFAC-PapersOnLine*, 52(13), 1878-1883. <https://doi.org/10.1016/j.ifacol.2019.11.476>

Fournier, É., Kilgus, D., Landry, A., Hmedan, B., Pellier, D., Fiorino, H., & Jeoffrion, C. (2022). The Impacts of Human-Cobot Collaboration on Perceived Cognitive Load and Usability during an Industrial Task: An Exploratory Experiment. *IISE Transactions on Occupational Ergonomics and Human Factors*, 10(2), 1-8. <https://doi.org/10.1080/24725838.2022.2072021>

Fruggiero, F., Lambiase, A., Panagou, S., & Sabbatini, L. (2020). Cognitive Human Modeling in Collaborative Robotics. *Procedia Manufacturing*, 51, 584-591. <https://doi.org/10.1016/j.promfg.2020.10.082>

Gualtieri, L., Rauch, E., & Vidoni, R. (2021). Emerging research fields in safety and ergonomics in industrial collaborative robotics: A systematic literature review. *Robotics and Computer-Integrated Manufacturing*, 67, 101998. <https://doi.org/10.1016/j.rcim.2020.101998>

Guérin, F., Laville, A., Daniellou, F., Durrafourg, J., & Kerguelen, A. (1997). *Comprendre le travail pour le transformer* (3ème édition). ANACT éditions.

Hart, S. G. (2006). *NASA-task load index (NASA-TLX); 20 years later*. 50, 904-908.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In P. A. Hancock & N. Meshkati (Eds.), *Advances in Psychology* (Vol. 52, pp. 139-183). North-Holland. [https://doi.org/10.1016/S0166-4115\(08\)62386-9](https://doi.org/10.1016/S0166-4115(08)62386-9)

Hiatt, L. M., Harrison, A. M., & Trafton, J. (2011). *Accommodating Human Variability in Human-Robot Teams through Theory of Mind*. <https://www.semanticscholar.org/paper/Accommodating-Human-Variability-in-Human-Robot-of-Hiatt-Harrison/e1682c374e701733b3b232f3d8f132697aa98992>

Hopko, S. K., Mehta, R. K., & Pagilla, P. R. (2023). Physiological and perceptual consequences of trust in collaborative robots: An empirical investigation of human and robot factors. *Applied Ergonomics*, 106, 103863. <https://doi.org/10.1016/j.apergo.2022.103863>

ISO. (2018). *ISO 9241-11*. ISO. <https://www.iso.org/obp/ui/#iso:>

std:iso:9241:-11:ed-2:v1:en

Kildal, J., Martín, M., Ipiña, I., & Maurtua, I. (2019). Empowering assembly workers with cognitive disabilities by working with collaborative robots: A study to capture design requirements. *Procedia CIRP*, 81, 797-802. <https://doi.org/10.1016/j.procir.2019.03.202>

Kildal, J., Tellaeché, A., Fernández, I., & Maurtua, I. (2018). Potential users' key concerns and expectations for the adoption of cobots. *Procedia CIRP*, 72, 21-26. <https://doi.org/10.1016/j.procir.2018.03.104>

Knudsen, M., & KaiVo-Oja, J. (2020). Collaborative Robots: Frontiers of Current Literature. *Journal of Intelligent Systems: Theory and Applications*, 13-20. <https://doi.org/10.38016/jista.682479>

Lesgauchers. (2017, octobre 31). *9 millions de gauchers* <https://www.lesgauchers.com/information/gaucher-9-millions-en-france>

Liu, L., Schoen, A. J., Henrichs, C., Li, J., Mutlu, B., Zhang, Y., & Radwin, R. G. (2022). Human Robot Collaboration for Enhancing Work Activities. *Human Factors*, 00187208221077722. <https://doi.org/10.1177/00187208221077722>

Mariscal, M. A., Ortiz Barcina, S., García Herrero, S., & López Perea, E. M. (2023). Working with collaborative robots and its influence on levels of working stress. *International Journal of Computer Integrated Manufacturing*, 1-20. <https://doi.org/10.1080/0951192X.2023.2263428>

Martin, N. P. Y. (2018). *Acceptabilité, acceptation et expérience utilisateur: Évaluation et modélisation des facteurs d'adoption des produits technologiques* [Phdthesis, Université Rennes 2]. <https://tel.archives-ouvertes.fr/tel-01813563>

Matheson, E., Minto, R., Zampieri, E. G. G., Faccio, M., & Rosati, G. (2019). Human-Robot Collaboration in Manufacturing Applications: A Review. *Robotics*, 8(4), 100. <https://doi.org/10.3390/robotics8040100>

Müller, R., Vette, M., & Geenen, A. (2017). Skill-based Dynamic Task Allocation in Human-Robot-Cooperation with the Example of Welding Application. *Procedia Manufacturing*, 11, 13-21. <https://doi.org/10.1016/j.promfg.2017.07.113>

Nielsen, J. (1994). *Usability Engineering*. Morgan Kaufmann Publishers Inc.

Oztemel, E., & Gursev, S. (2020). Literature review of Industry 4.0 and related technologies. *Journal of Intelligent Manufacturing*, 31(1), 127-182. <https://doi.org/10.1007/s10845-018-1433-8>

Pauliková, A., Gyurák Babelová, Z., & Ubárová, M. (2021). Analysis

of the Impact of Human–Cobot Collaborative Manufacturing Implementation on the Occupational Health and Safety and the Quality Requirements. *International Journal of Environmental Research and Public Health*, 18(4), 1927. <https://doi.org/10.3390/ijerph18041927>

Peshkin, M. A., & Colgate, J. E. (1999). Cobots. *Industrial Robot*, 26(5), 335-341.

Salunkhe, O., Stensöta, O., Åkerman, M., Berglund, Å. F., & Alveflo, P.-A. (2019). Assembly 4.0: Wheel Hub Nut Assembly Using a Cobot. *IFAC-PapersOnLine*, 52(13), 1632-1637. <https://doi.org/10.1016/j.ifacol.2019.11.434>

Schoose, C. (2022). *From traditional deburring to cobot use: Analysis of the professional gesture in order to prevent musculoskeletal disorders* [Phdthesis, Université Grenoble Alpes [2020-....]]. <https://theses.hal.science/tel-03942554>

Schoose, C., Cuny-Guerrier, A., Caroly, S., Claudon, L., Wild, P., & Savescu, A. (2023). Evolution of the biomechanical dimension of the professional gestures of grinders when using a collaborative robot. *International Journal of Occupational Safety and Ergonomics*, 29(2), 668-675. <https://doi.org/10.1080/10803548.2022.2065063>

Varrecchia, T., Chini, G., Tarbouriech, S., Navarro, B., Cherubini, A., Draicchio, F., & Ranavolo, A. (2023). The assistance of BAZAR robot promotes improved upper limb motor coordination in workers performing an actual use-case manual material handling. *Ergonomics*, 1-18. <https://doi.org/10.1080/00140139.2023.2172213>

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User Acceptance of Information Technology: Toward a Unified View. *MIS Quarterly*, 27(3), Article 3. <https://doi.org/10.2307/30036540>

Venkatesh, V., Thong, J. Y. L., & Xu, X. (2012). Consumer Acceptance and Use of Information Technology: Extending the Unified Theory of Acceptance and Use of Technology. *MIS Quarterly*, 36(1), Article 1. <https://doi.org/10.2307/41410412>

Verhulst, E. (2018). *Contribution de l'étude de l'interaction en environnement virtuel: Intérêt de la charge mentale* [Phdthesis, Université d'Angers]. <https://tel.archives-ouvertes.fr/tel-02157566>

Xu, X., Lu, Y., Vogel-Heuser, B., & Wang, L. (2021). Industry 4.0 and Industry 5.0—Inception, conception and perception. *Journal of Manufacturing Systems*, 61, 530-535. <https://doi.org/10.1016/j.jmsy.2021.10.006>