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To collaborate or not to collaborate: understanding human-robot collaboration

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Abstract— **In the last years, collaborative robotics have been experiencing a continuous dramatic diffusion. Notwithstanding, they are often used in human-robot collaboration scenarios that do not fully leverage humans and robots capabilities. This paper aims to investigate how human individuals perceive collaboration with robots, comparing it to collaboration with another human agent. To this end, we design a collaborative task in the form of a joint motor action, where the human agent shares actions in a dyadic interaction with a robot or a human confederate. Our aim is to assess quality of the task and perceived pleasantness or discomfort in the two collaborative situations. The achieved results show that differences exist when participants collaborate with another human agent or a robot. Specifically, when working with the robot, on average the task was carried out more cautiously, and less errors were made, thus leading to the assumption that participants were aware that the robot is a non-intentional agent. They acted faster and made more errors in the human-robot condition. Moreover, they reported that collaborating with the human federate was more pleasant, although more competitive. Ultimately, the study paves the way to understanding human attitude towards the collaboration with robots and shaping human-robot collaboration around it.**

I. INTRODUCTION

Despite their initial introduction as automatic tools, nowadays robots are being used as interactive agents that share tasks, information and intentions with human users. This has been possible thanks to the introduction of collaborative technologies. The market for collaborative robots has experienced robust growth in the last years and recent estimates[1] predict it will be worth 7.5 billion by 2027. This would equate to roughly 29$\%$ of the global industrial robot market. One of the main features that have promoted such diffusion lies in the fact that collaborative robots combine the advantages of automation, such as accuracy and repeatability, with the flexibility and cognitive soft skills of humans. Indeed, collaborative robots not only enable coexistence between human operators and robots, but also allow for close collaboration such that tasks can be shared and carried out jointly by the two [1], [2]. In particular, collaborative robots can be involved in joint actions, which are a particular form of cooperation, where two agents have to synchronise and to coordinate each other in order to succeed in a common goal [3]–[6]. Ultimately, this allows to build teams where agents with complementary skills work together, thus (potentially) reaching goals that are not attainable for teams made by humans only.

Notwithstanding such a promising perspective, it can be easily observed that the potentials of collaborative robotics are not fully exploited in the majority of applications. Indeed, common applications boil down to trivial tasks such as pick and place, assembly or material handling [1], [7]. In these cases, robot features, such as accuracy, speed and cost, are valued. However, from the point of view of human-robot collaboration (HRC), these tasks are trivial, since humans are usually involved in repetitive tasks and their high level cognitive skills are not exploited.

To overcome this, different strategies can be considered. On the one side, it is important to enhance robot capabilities to perceive and act in the surrounding environment. This can be achieved by augmenting robot sensing capabilities [8] and using new gripper technologies [9], [10]. Additionally, improving control strategies may render the robot more reactive, in compliance with safety regulations [11], [12]. Other solutions resort to dynamic task scheduling that allocates tasks to the human or the robot considering constraints related not only to job efficiency but also to human's variability in task execution and fatigue or comfort [13], [14].

The use of proper interaction paradigms is important as well, since they allow to reduce any gap due to communicating and understanding intentions. A lot of research has been carried out in this regard, spanning from including interaction requirements in early phases of design [15] to implementing communication modalities inspired by human-human communication, such as gestures or vocal commands [16], [17]. Additionally, approaches based on adaptive interaction, where the behavior of the robot is dynamically changed considering user's current needs and status, have been considered [18], [19].

A. Proposed contribution

While the above mentioned strategies, especially if combined and applied jointly, have allowed significant improvements in HRC, here we want to explore the prerequisites for successful HRC. During a joint action, individuals make predictions concerning the actions of the other agent. In

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contrast, during HRC, agents are continuously engaged to adapt their behavior in accordance to the feedback generated by the robot, because the human agent is aware that the robot is a non-intentional agent. Consequently, the knowledge of how humans share actions in a dyadic interaction with a robot compared to a human-human interaction is fundamental for the involvement of robots in industrial and everyday environment, in terms of both quality of the task and perceived pleasantness or discomfort. Existing studies on comparing human-human and human-robot dyadic interactions have mostly focused in handover tasks [20], [21]. The use of biologically inspired motion patterns has been explored in [22], while human preference has been used in [23] to select robot motion configurations. Other studies have investigated human-robot and human-human teams in co-manipulation tasks, to understand how haptic feedback guides co-manipulation between human dyads and could be used to design human-robot interaction.

With this study, we aim to assess how human agents react to interaction with robots. In particular, we intend to explore how individuals are engaged in online interactions focusing on different dyads (human-human or human-robot) and how the awareness of interacting with a human agent or robot affects the motor action. This means to understand how humans perceive the interaction with a robot and act accordingly, coordinating their actions with those of others (either human or robotic agents). To this end, we formulate the following research question:

How do human subjects perform in a collaborative task carried out with a robot compared to the same task carried out with another human? Do they perceive different levels of discomfort or competitiveness during the collaboration with a robot or a human agent?

To answer this research question, a joint motor action was designed and implemented. Specifically, a joint action was defined as a motor paradigm in which cooperative handover of items is carried out by either two human agents (H-H condition) or a human and a robot (H-R condition). We designed a handing-over task in which a human participant was the receiver and either another human agent (a confederate) or a robot was the giver. The giver picked an object with a particular shape and passed it to the receiver, who was required to decide whether it fitted in one of the slots available on a box. Results showed that when participants interacted with a human agent their performance and subjective rating differed as compared to when they interacted with the robot.

The outcome of this study will be a deeper understanding of how robots can be efficiently used to collaborate with humans and when their use is beneficial. We want to investigate whether human-robot teams are efficient when robot and humans peculiar capabilities are not fully exploited, as in many application scenarios. Related findings will be leveraged to identify the optimal strategies to shape HRC around the human user. Additionally, our study will shed light on human attitude towards the collaboration with robots and investigate how pleasant or competitive they find it.

The rest of the paper is organized as follows. Section II presents the study we carried out and the experimental methodology implemented to answer the research question. Then, Sec. III presents and discusses the achieved results, while Sec. IV follows with some concluding remarks.

II. METHODS

In this section, we describe the experiments carried out to answer the considered research question.

A. Experimental protocol

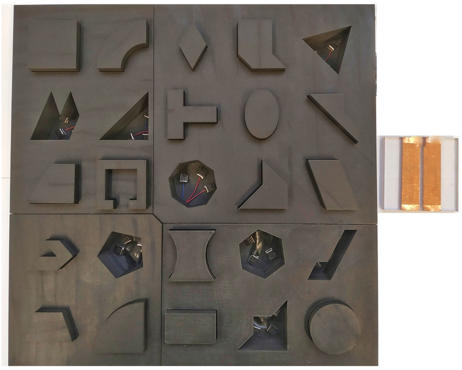
The experimental protocol was inspired from the ones in [24], [25]. Specifically, we designed a cooperative shape sorting task performed either by two human agents (Human-Human or H-H condition) or by a human agent and a robot (Human-Robot or H-R condition). A shape sorter box, shown in Fig. 1(a), was designed, consisting of a box with perforated slots where a corresponding piece fits into. Additionally, non matched shape pieces, which did not fit into any slot, were designed.

According to the setup shown in Fig. 1(c), agent 1, who was a confederate of the experimenter (H-H condition) or a robot (H-R condition), picked one of the shapes and put it on a pad (shown also in Fig. 1(a)). Agent 2, who was the experimental participant, had to pick the shape and decide whether the shape could be inserted in one of the slots of the box. If this was the case, she/he had to insert the piece in the corresponding slot; otherwise she/he had to press a button located on the left side of the box and insert the piece in a secondary box, which was placed next to the participant.

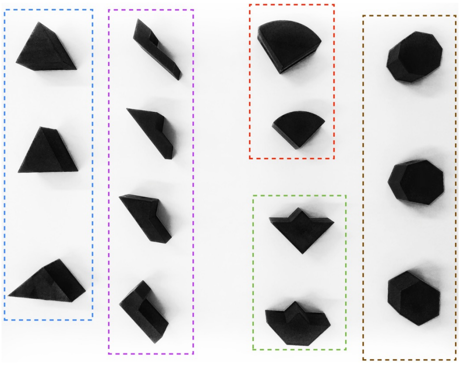
The box presented 25 slots, while the shapes were 40. As a result, 15 shapes were not matched with any slot in the box and hence had to be discarded. Pieces presented similar shapes and were designed such that identifying whether a corresponding slot existed in the box required some effort. Examples are reported in Fig. 1(b): in the figure dashed lines indicate pieces with similar shapes. Not all of them have a corresponding slot in the box, as can be seen from Fig. 1(a).

The same setup and procedures were used in the two conditions (i.e., H-H and H-R conditions). In both conditions, at the beginning of the trial all the pieces laid in fixed positions and were picked one by one during the experiment. A barrier was introduced to prevent the participant from seeing how many pieces were left until the end of the experiment.

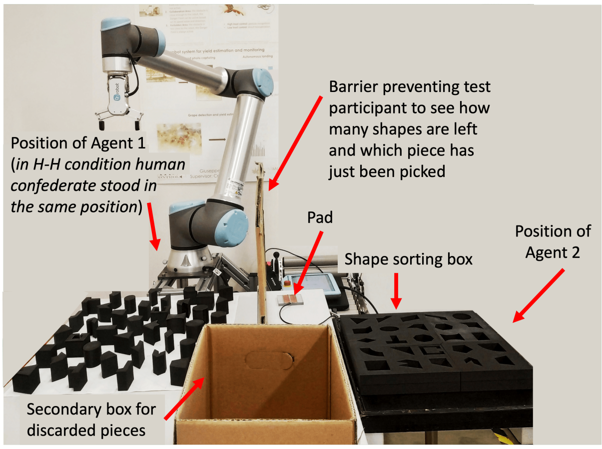
Four experimental sessions were administered to each test participant, according to Fig. 2. In each session, all the 40 available shapes were presented to the participant. Shapes were presented in a pseudo-random order, which was varied among sessions but was the same for all participants. In two sessions, the shapes were presented by a robot manipulator (H-R condition); in the other two sessions, the shapes were presented by a human agent (H-H condition). As a result, the test consisted in 160 trials for each subject, 80 carried out with the robot (H-R) and 80 with the human (H-H). To counterbalance any learning effect, for half of the participants, the first two sessions were carried out with the



(a) Shape sorting box (left) and pad (pad).



(b) Example of shapes: dashed lines group similar shapes.



(c) Complete setup of the experiment.

Fig. 1. Experimental setting.

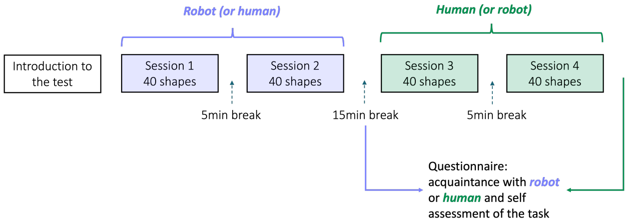


Fig. 2. Experimental protocol.

robot, while for the other half the first two sessions were carried out with the human agent.

At the beginning of the first session for each of the two conditions, participants received the instruction on how to perform the task. At the end of the two blocks of each condition, a questionnaire was administered to assess the participant's acquaintance with the robotic or human agent (Sec. II-C) and his/her perception of the task and of the interaction (Sec. II-D).

B. Experimental setup

The shape sorter box and shapes were 3D designed on purpose for the considered experimental task and 3D printed in plastic material. Box size is $430 \times 430 \times 45$ mm. Shapes are 40 mm tall and their 2D sizes vary around 40×40mm.

As visible in Fig. 1, all the tools (box, shapes and pad) were sensorized to allow tracking task progress and participant's performance (Sec. II-D). An Arduino Nano[2] board was placed in the box to this end, thus allowing data storage on a text file for later processing. As regards the robot, we used a Universal Robot UR5, equipped with the OnRobot RG2 gripper as end effector for picking pieces. The robot was controlled with ROS [26]. As regards statistical analysis, MATLAB R2021a and its Statistics and Machine Learning Toolbox were used.

C. Test participants

A total of 22 (11 females, 11 males, age rage: 21-28 years, mean age: 23.5 years), volunteer students were enrolled in the experiment. They are all students of either management (7) or mechatronics (15) engineering, working at their undergraduate or graduate final project in the ARSControl (Automation, Robotics and System Control) lab of the University of Modena and Reggio Emilia (Italy). All of them were completely naïve to the experimental task and goals. Moreover, four had never seen the robot used in the experiment before, while the remaining had seen it, but none of them had ever used it.

In the H-H condition, agent 1 was a confederate who was matched to the participant for gender. Eight participants reported that they had never met agent 1 before. Among the remaining, one reported that she/he had met agent 1 once before the experiment, ten reported they had met sometimes, two reported they often met each other and one reported that they were classmates.

The study protocol followed the Helsinki declaration and compliance to participate in the study was obtained from written informed consent before starting the experiment. All the data were analyzed and reported anonymously.

D. Measurements

Behavioral data (task progression and participant's performance) and individual ratings were measured. Behavioral data were related to task performance and included:

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[2] `https://docs.arduino.cc/hardware/nano`

TABLE I

MEAN NUMBER OF ERRORS (MEAN VALUE ± STANDARD DEVIATION) AND MEAN ERROR RATE IN THE TWO EXPERIMENTAL CONDITIONS. EACH SESSION INCLUDED 40 TRIALS AND TWO SESSIONS PER CONDITION WERE CARRIED OUT.

	Mean number of errors		**Mean error rate**	
	H-R	**H-H**	**H-R**	**H-H**
Trials in both sessions	2.5 ± 1.8	3.2 ± 3.3	3.2%	4.0%
Trials in the first session	1.6 ± 1.6	1.9 ± 1.9	4.1%	4.7%
Trials in the second session	0.9 ± 0.9	1.4 ± 1.9	2.3%	3.4%

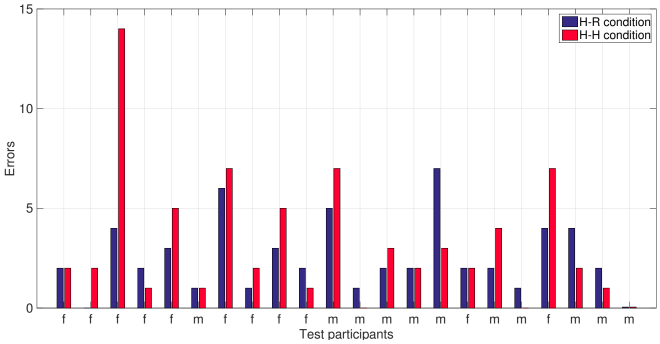

Fig. 3. Number of errors made by each test participant in the two experimental conditions (blue: H-R, red: H-H).

- count of errors for shape misplacements: an error was counted when a piece for which a slot exists was released in the secondary box for discarded pieces;
- time a shape stood on the pad, after having being placed by either the confederate or the robot and before being picked by the test subject (T_{pad} in the following);
- time required to find the correct slot in the box for the current piece or put it in the secondary box (T_{pos}).

Individual ratings we'ree collected at the end of the two sessions of each condition by means of a questionnaire. Participants were presented with the following statements:

- While you carried out the shape sorting task, the situation was easy/difficult
- While you carried out the shape sorting task, the situation was pleasant/unpleasant
- While you carried out the shape sorting task, the situation was positive/negative
- While you carried out the shape sorting task, the situation was competitive/non competitive.

For each statement they were required to rate on a Likert scale ranging from 1 (corresponding to the left attribute: easy, pleasant, positive, competitive) to 7 (corresponding to the right attribute: difficult, unpleasant, negative, non competitive).

III. RESULTS AND DISCUSSION

In this section, we report and discuss the results achieved during experimental sessions, comparing the H-H and H-R conditions.

A. Behavioral data

As introduced in Sec. II-D, behavioral data take into account test participant's performance while collaborating with the human or the robot. Such measurements include number of errors and time needed to complete each trial.

As regards errors, we counted how often participants erroneously placed a shape in the secondary box for discarded pieces, although a corresponding slot did exist in the shape sorting box. Table I reports the average number of errors made by test participants, together with its standard deviation. Specifically, in the table we report the average number of errors made while collaborating with the robot and with the human agent (counting errors made by each participant over 80 trials per condition, averaging over all test participants), and the average number considering separately the first and the second experimental session of the two conditions (counting errors made over 40 trials per session and condition, averaging over all test participants). Additionally, we report the mean error rate. Results in the table show that, on average, more errors were made in the H-H condition than in H-R. Moreover, in each condition, more errors were made, on average, in the first session.

Figure 3 reports the count of errors for each test participant, considering both the experimental session of each condition (blue for H-R condition, red for H-H). The figure shows that, out of 22 test participants, 5 (2 females and 3 males) made the same number of errors in the two conditions, 7 (2 females and 5 males) made more errors when collaborating with the robot, and 10 (7 females and 3 males) made more errors in the H-H condition. In particular, one participant, namely the third from left, performed much worse when collaborating with the human than the robot (14 errors in the H-H condition and 4 in the H-R one). The performance in the H-H condition of this subject notably differs from the average performance of all the other subjects. In the H-H condition, her/his error rate was as high as 17.5%, while the average error rate considering the other participants was 3.4%; in the H-R condition, the difference is reduced since her/his error rate was 5.0%, while the average error rate considering the other participants was 3.1%. The difference in the H-H condition can be explained considering that this subject started the experiment in this condition: thus, a possible assumption is that gaining acquaintance with the shapes and the task resulted in less errors in the H-R condition. Excluding this participant from computing the mean number of errors reduces the difference between the two conditions: averaging results over the other 21 participants, the mean number of errors remains 2.5 ± 1.8 in the H-R condition, while it reduces to 2.7 ± 2.3 in the H-H condition. Similar, although opposite, assumption can be made for the fifteenth participant, who started the experiment in the H-R condition, and made 7 errors when working with the robot and 3 with the human agent.

Measurements of time to complete the shape matching task included time elapsed from the instant when the shape was released on the pad by the confederate or the robot until

TABLE II

TIME REQUIRED TO COMPLETE THE SHAPE MATCHING TASK WHEN COLLABORATING WITH THE ROBOT (H-R) AND WITH THE HUMAN AGENT (H-H): MEAN VALUE ± STANDARD DEVIATION. STATISTICALLY SIGNIFICANT DIFFERENCE (S.S.D.) FOR T_{pad} AND T_{pos} BETWEEN THE EXPERIMENTAL CONDITIONS H-R AND H-H IS REPORTED CONSIDERING P-VALUES $p < 0.05$ $(^{\star\star})$.

	T_{pad} [s]			T_{pos} [s]		
	H-R	**H-H**	**s.s.d.**	**H-R**	**H-H**	**s.s.d.**
Trials in both sessions	1.97 ± 0.68	1.51 ± 0.55	$(^{\star\star})$	4.34 ± 1.15	3.76 ± 2.30	–
Trials in the first session	1.98 ± 0.68	1.58 ± 0.56	$(^{\star\star})$	4.72 ± 2.32	4.19 ± 1.80	–
Trials in the second session	1.97 ± 0.70	1.45 ± 0.57	$(^{\star\star})$	3.84 ± 1.97	3.45 ± 1.42	–

it was picked by the test participant, and time from when the shape was picked until it was put in the corresponding slot of the box or the button for non-matching shapes was pressed. We denote these time intervals as T_{pad} and T_{pos}, respectively. As in the case of errors, times T_{pad} and T_{pos} were averaged over all the test participants, considering together the two sessions in each condition and considering the trials in the first and in the second experimental session separately. The table shows that, on average, test participants performed faster in the H-H condition, rather than the H-R one, for both T_{pad} and T_{pos}.

Furthermore, we assessed whether differences found on average are statistically significant. To this end, data normality was checked by conducting a Shapiro-Wilk test on the distributions [27]. In all the conditions considered in Table II, deviations from normality were found for T_{pad} and T_{pos}. Thus, statistically significant difference was tested conducting a two-sample t-test. All the average T_{pad} turned out being statistically significantly different with p-value $p < 0.05$, while no statistically significant difference was observed for T_{pos}.

B. Individual ratings

Subjective reporting was collected by administering questionnaires at the end of the experimental sessions for the H-R and H-H conditions, according to the protocol in Fig. 2. Questions in the questionnaire are reported in Sec. II-D.

Table III reports the mean, median and modal values of ratings returned by test participants, while Fig. 3 reports the replies given by each test participant. As reported in Sec. II-D, replies were on a scale from 1 to 7, where 1 corresponded to the left attribute and 7 to right one. The table shows that, on average, test participants found collaboration with the robot slightly easier than with the human, but the H-R condition was also slightly less pleasant and positive than the H-H one. As regards perceived competitiveness, difference between the two conditions is clearer: 9 test participants reported that collaborating with the robot was not competitive at all (rating 7) and one of them reported it to be very competitive (rating 1), 6 reported the highest rating (rating 1) of competitiveness in the H-H condition and 3 reported it was not competitive at all (rating 7). Interestingly, subjects who reported high competitiveness in the H-H condition had different degrees of acquaintance with their confederate, as those who reported the task was not competitive at all. As regards the H-R condition, the participant who reported that the experiment was very competitive had never seen the robot before (although she/he was not the only one), while all those who reported not competitiveness at all had seen the robot before. A two-sample t-test on participants replies to the questionnaire confirmed that the difference on competitiveness is the only one statistically significant different (p-value $p = 0.0137$). These findings on perceived competitiveness support the considerations reported at the end of Sec. III-A on test participants performance in terms of errors and times T_{pad} and T_{pos}.

TABLE III

MEAN, MEDIAN AND MODAL VALUES OF REPLIES TO QUESTIONNAIRE ADMINISTERED AT THE END OF SESSIONS IN THE H-R AND H-H CONDITIONS. THE FULL QUESTIONS ARE REPORTED IN SEC. II-D AND INVESTIGATED HOW THE COLLABORATIVE SITUATION WAS PERCEIVED. RATING WAS EXPRESSED IN A LIKERT SCALE FROM 1 (LEFT ATTRIBUTE) TO 7 (RIGHT ATTRIBUTE).

	Mean		**Median**		**Mode**	
	H-R	**H-H**	**H-R**	**H-H**	**H-R**	**H-H**
Easy / Difficult	1.4	1.7	1.0	1.0	1	1
Pleasant / Unpleasant	1.8	1.6	1.0	1.5	1	1
Positive / Negative	1.7	1.3	1.0	1.0	1	1
Competitive / Non competitive	5.2	3.6	6.0	3.5	7	1

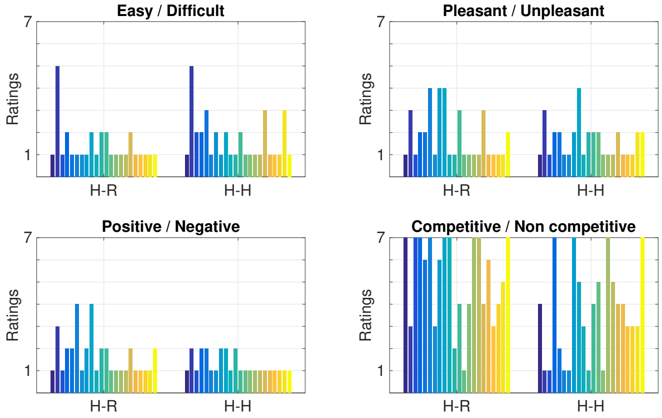

Fig. 4. Test participants replies to questionnaire administered at the end of sessions in the H-R and H-H conditions. Each bar represents a reply given by a subject.

C. Overall discussion

An overall analysis of the achieved results shows that human subjects collaborate differently with robotic or human agents. According to the observed differences, resorting to human-robot collaborative scenarios might introduce some drawbacks, when compared to settings where humans work together at the same task. Specifically, in our experimental setup, HRC negatively affected human participant's performance and comfort. From the analysis of behavioral data, significant differences have been observed in terms of time required to complete the task: test participants were faster when working with another human subject (H-H condition), although they made more errors. However, analysing the errors made by each participant, we have noticed that most subjects made similar number of errors in the two conditions, exception made for one of them who made a notably larger number of errors in the H-H condition than in the H-R condition. Discarding data from this subject, the overall difference in error rates in the two conditions notably reduces. Considering results in Table I and Table II jointly, it is possible to observe that, on average, test participants acted faster while collaborating with the human agent, but this led them to make a larger number of errors. Possible explanations of increased pace of participants actions are twofold. Firstly, it is noteworthy that human confederates moved intrinsically faster than the robot to pick pieces, thus influencing participant's rate. Additionally, it can be assumed that, in the H-R condition, participants were more attentive since they were collaborating with a non-intentional agent, thus reacting more cautiously and, hence, making less errors. Conversely, in the H-H condition, the confederate was perceived as an intentional agent, thus inducing a less cautious attitude. Complementary to this, it can be assumed that participants perceived collaboration in the H-H condition more taxing due to the presence of another human and, hence, on the one side, increased the pace of their actions, while, on the other hand, making more errors. This last assumption is confirmed by the analysis of individual ratings. Indeed, as regards comfort, test participants reported more competitiveness when collaborating with another human, either they were acquainted with or they had just met for the first time. However, the H-H condition was still reported as more pleasant and, generally positive.

For the sake of fairness, it should be pointed out that these results were achieved considering an experimental task that does not strictly rely on specific robot's capabilities, since it could be executed in H-H or H-R condition without any impact on task outcome. However, as discussed in Sec. I, in common application scenarios of HRC, the use of collaborative robots is often limited to simple and trivial tasks, similar to the one considered in our experiments. Additionally, it should be pointed out that the participants recruited for this study are all engineering students. Although they had never used the robot used for the experiment before, they still hold a technical background and attitude. This might have influenced the achieved results. Therefore, it becomes important to extend the experimental campaign enrolling subjects from a different population, in order to consolidate the validity of the achieved results.

IV. CONCLUSIONS

In this paper we investigated how human subjects collaborate with robots, in comparison to human-human collaboration. The motivation behind the study was the understanding of how individuals are engaged in interactions with other agents, either robotic or human, and how the nature, intentional or non-intentional, of the other agent affects human actions.

To this end, we designed and implemented a joint motor action based on a shape sorting task. The action required the collaboration between two human agents (a confederate and a test participant) or a human and a robot. The study was carried out involving 22 participants and collecting their behavioral data and subjective ratings about the two collaborative conditions. As a consequence, we could assess and compare participant's performance and perceived comfort while interacting with another human agent or a robot. Results showed that participants acted differently in the two experimental conditions. Briefly, when collaborating with a human confederate, they carried out the joint action faster and made, on average, more errors than when collaborating with the robot. Moreover, the human-human condition was perceived more competitive, but, still, more pleasant and positive.

As a future work, we plan to extend the study in order to consolidate the achieved results. Perspectively, related findings will allow to identify the scenarios where collaboration with robots is truly advantageous and shape such collaboration around human attitude.

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