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A kinematic study on social intention during a human-robot interaction

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Abstract—In this study, we investigate the possible effects on the human movement kinematics of the presence of a humanoid robot during an interaction. We conducted an experiment in which 11 participants were required to grab a cube and to drop it in the hands of a robot, a human and in a rectangular box. Using this setup, we explore whether the kinematics of the participants' gestures would be particularly influenced by the presence of the robot and whether this influence would be due to the fact that the robot is considered as a possible social partner. The results show that the condition that includes the robot partner leads to kinematic modulation that are similar to the condition including the human partner. Furthermore, there are significant differences between the condition including the robot and the one with the box. Finally, our results show that the participants pro-social behavior is correlated with the perceived agency of the robot as evaluated by a user questionnaire.

Index Terms—social robotics, human movement analysis, social cognition, human-robot interaction

I. INTRODUCTION

In the context of voluntary actions, the movement is preceded by a prior intention defined by Searle as an "intention to act that precedes the action itself" [21]. However, different prior intentions can lead to the same movement, for example, the same reach to grasp action can be produced by a person aiming to eat an apple or to throw it away. Human movement kinematics is sensitive to this prior intention as humans modulate their reaching motion according to the action to perform next [7]. The intrinsic properties such as the size or the texture of the manipulated objects and targets can have a considerable effect on the dynamics of the gesture and motor trajectories planning. For example, reaching gesture kinematics is affected by the size of the target during a game that consists in placing an object in a large or a small box [9] [12].

Some studies analyzed kinematic modulations by differentiating social prior intention, e.g. grabbing a bottle of water to pass it to another person, and non-social ones, e.g. grabbing the same bottle to put it on a table [7] [3]. In this line, Becchio et al. [2] show that the reaching gesture kinematics is sensitive to a social vs non-social intention. In their work, participants were requested to reach towards, grasp an object, and either pass it to another person (social condition) or put it on a

concave base (single-agent condition). They show that, for the reach-to-grasp phase, humans have a tendency to lower the maximum hand aperture and the amplitude of peak grip closing velocity when they interact with a social partner. For the 'place' phase, subjects wrist pathway was longer and the wrist trajectory height was higher for the social condition. In summery, the results suggest that "passing an object into the hand of another person entails a more careful action".

One can ask what happens if a person interacts with robots. Will humans prior intention be different ? Will humans modulate the movements kinematics similarly ? We propose to address these questions in the current study.

With the development of social robotics, robots have been proposed to be used as partners in several interaction contexts: assistants for the elderly and handicapped [10], [15], tutors or peer learners in education for children [4], [11] or tools to provide repeatable interaction in the study of social cognition, often to explore pathologies with social deficits [5], [8]. The latest advances in robotics have allowed the appearance of increasingly sociable robots with communication, assistance and even playful interaction capabilities. With this technological development, accurately measuring how robots are perceived by humans has become increasingly important. However, our assessment tools remain mostly limited to overt questionnaires [17] [6]. These questionnaires usually focus on the acceptability aspect of social robots, and neglect the covert effects of a social interaction on our behavior. In particular, it is necessary to ensure not only that robots can be accepted by humans, but also to analyse how human kinematics are affected by robots, compared to human partners. This is of specific importance to design valid experiments where social robots are used for the study, diagnosis or therapy that involve human motion [1], [8], [23]. This question constitutes the core of this work and still in debate in the scientific community.

Kilner suggests that robots do not trigger any kinematic interference when interacting with a human, as opposed to human partners [16]. In a similar experiment with a humanoid robot, [19] obtained contradicting results, showing that the robot was able to trigger kinematic interference. Some authors defend the idea that human-like appearance may facilitate human kinematic modulations [22]. On the other hand, other have argued that motor resemblance and motor resonance are

more important than physical appearance [18].

To explore the effect of a humanoid robot on the modulation of human gesture kinematics, we propose in this work to exploit the paradigm initiated by Becchio et al. [2] in human-human interaction by generalizing it to human-robot interaction. We compare the effect of the robot presence to that of a human and of an inanimate object (i.e., a static box). Our goal is to assess how the robot is perceived through its influence on human motion. Furthermore, to evaluate if the obtained results are related to the way we perceive the robot, we propose to use a Mind Perception Questionnaire dedicated to the exploration of two dimensions, namely the *agency* and *experience* aspects of mind perception [13].

II. PROPOSED APPROACH

To answer the question posed, we conducted an experiment during which we asked participants to grasp an object from a given point and to drop it on a target in three different conditions. In the first condition, the participant has to grab an object and drop it in a rectangular box. In the other two conditions, the participant interacts with a partner (a human or a robot) by similarly grabbing the object and then dropping it in the hands of the partner. To set up these different conditions, we reproduced partially the protocol from Becchio et al. [2]. The main difference consists in the addition of the robot condition, where the partner is a humanoid robot instead of a human. Furthermore, in our scenario, the partner does not reposition the object to its starting position as we decided to limit the unnecessary movements of the robot. Thus, the participant performs the action of grabbing and dropping as well as repositioning the object to its initial place. Nevertheless, the repositioning phase is not measured here. Figure 1 shows the proposed experimental setup including the three conditions.

III. MATERIALS AND METHODS

A. Participants

Eleven peoples (3 women and 8 men, aged 23 to 37) of different levels of education took part in this experiment. Among them, 2 were left-handed and the other 9 right-handed. All participants had normal vision and were naive with respect to the purpose of the experiment. Before starting, each participant had to sign a written consent and then a description of the experiment was provided to them after signing the consent.

B. Experimental Setup

The experimental setup was similar to the one depicted in Figure 1. It includes human participants and a humanoid Reachy robot [20]. The environment of the experiment consists in a classic table on which the experiments take place. The action stimulus is a small cube with 3×2.5 cm. A rectangular box of size $9 \times 8 \times 1.5$ cm is used to carry out our experiments in the box condition. In order to compare our results to the state of the art, we setup up an experiment similar to [2]. As illustrated in figure 1, point S is located 3cm from the edge of the table and marks the starting position of the participant's

hand which operates the action during the interaction. The stimuli (the cube) is placed at the O position, 21cm from the starting point S , thus facilitating an ergonomic extension of the participant's arm. The second point S' indicates either the position of the human hand or the robot hand or the position of the rectangular box depending on the different conditions. To capture the movements kinematics, we use 4 infrared cameras placed in the corners of the experiment room. Passive markers were attached to the wrist, the index finger, and the thumb of the dominant hand of the participants. The wrist marker was used to measure the reaching components of the action. The finger and the thumb markers were used to measure the grasping components of the action. Participants movements were recorded using Qualisys OQUS infrared cameras. The cameras captured the movement of the markers in 3D space.

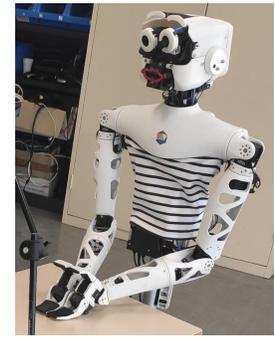
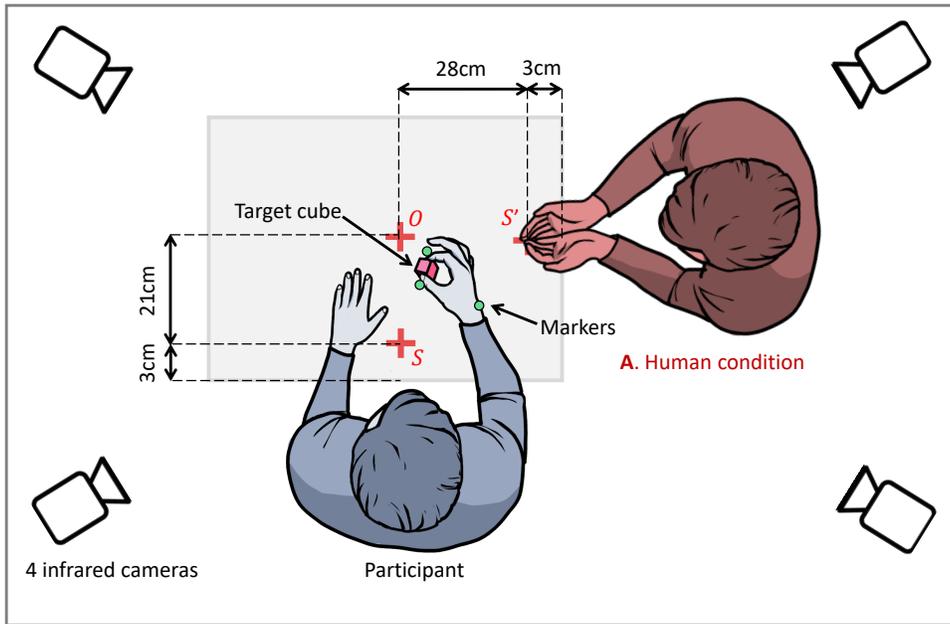
C. The humanoid robot Reachy

Reachy is a humanoid robot designed by the company *Pollen Robotics* with 7 degrees of freedom in the arm, 3 degrees of freedom in the neck and 1 for the grippers. It is able to perform actions such as grabbing and putting down objects, moving its head, and other complex actions. The robot's head has been modified to enhance its capacity to display facial expressions, as the original expressive capacities of the Reachy robot was limited to mobile antennas. The new expressive head includes mobile eyes, eyebrows and lips, such as shown on fig.1.B. Using only movements of the expressive head, we implemented a set of 3 behaviors composed of small variations of the movements of the eyes, neck, eyebrows and lips. This movements consists in a gaze toward points S , O and a gaze directed to the participant with a smile. We limited the behavior to subtle movements to avoid drawing all the attention of the participant to the robot movements.

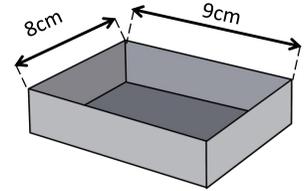
D. Procedure

First, the passive markers were placed on the wrist, on the thumb and on the index finger of each subject. Before each trial, the marked hands of the participant were placed in a resting position. No guidance was given on how to move the object from point O to the target. The participant were asked to start the action after the experimenter said the word "Go". During this "Go" phase, the participant had to move the object from the starting point to the target and then put his hands back at the resting point. The experimenter's second "Put it back" cue instructed the participant to re-position the object at the starting point. There were three experimental conditions:

1) *Rectangular box condition*: The first phase of the experiment consists in a non-social condition including a main participant and a static target (a rectangular box) located to his right. In this condition, the participant is asked to put his hand on the starting position S before the start of the action. The movements performed by the participant consists first in a reach-to-grasp movement in order to grab the cube at its starting point O . Once the cube has been grasped, the



B. Robot condition



C. Box condition

Fig. 1. Experimental setup. The participant (in blue) is seated at a table. His dominant hand initially rests at position S , marked by a cross. The tasks consists in reaching and grasping a cube at position O to drop it on a target situated at point S' . The target changes depending on the condition. A. Human condition: the target is the joint hands of a human partner (in red). B. Robot condition: the target is the joint grippers of a humanoid robot. C. Box condition: the target is a rectangular box.

participant operate the second phase of the movement which consists in moving the cube from point O and place it in the rectangular box located on S' at his right. This second phase of the movement is called the drop phase which characterizes the finality of the targeted action. Once the two steps have been completed, the participant has to re-position the cube at its starting point O and to re-position his right hand at the starting position S . This last phase of action is called the re-positioning phase. The kinematics data is only collected in the first two phases (namely the grabbing and dropping phases).

2) *Human partner condition*: In the human partner condition, the main participant is required to carry out the same actions as in the previous box condition. In the human condition, the dropping phase consists in putting the cube in the hands of the other partner placed on point S' (see fig.1.A). The other partner simulates the rectangular box with his joint hands in order to maintain consistency in the actions performed.

3) *Robot partner condition*: The two first conditions are similar to those described in [2]. The novelty of our experience lies in the inclusion of another type of co-participant, namely the Reachy robot. In this new condition, the robot simulates a partner and promotes social interaction by performing facial expressions. The robot grippers are positioned on the target S' to simulate two joint hands, similarly to the other two conditions. The participant is required to start from position S , to grab the cube at position O and to drop it in the hands

of the robot (fig.1.B). The facial expression are performed with a Wizard of Oz system. The experimenter triggers a facial expression among 3 predefined behaviors using a specific key. The behavior is triggered only when the last phase of the movement is over in order not to interfere with the participants action. The participant is asked to re-position the cube at its starting point O and his hands at the starting point S .

The order of the conditions was randomized between participants. Each subject performed 15 trials for each condition. After having carried out the condition with the robot, the participant was asked to leave the experimentation room and then fill out the questionnaire in order to evaluate Reachy. Between each condition, the participant was asked to leave the room to install the next experimental setup. This is particularly important for the robot condition, as seeing the robot manipulated by the experimenter could impact negatively the perception of its capacities.

E. Data processing

Once the kinematics data were collected, we analyzed them using the QTM software with which we performed a 3d reconstruction of the motion trajectories to obtain the (x, y, z, t) time series. We were thus able to extract the kinematic parameters of the movement. Since the motion capture during each trial was not done separately but during the entire condition, we separated each trial for each condition, and this for all participants. For each try, we separate the

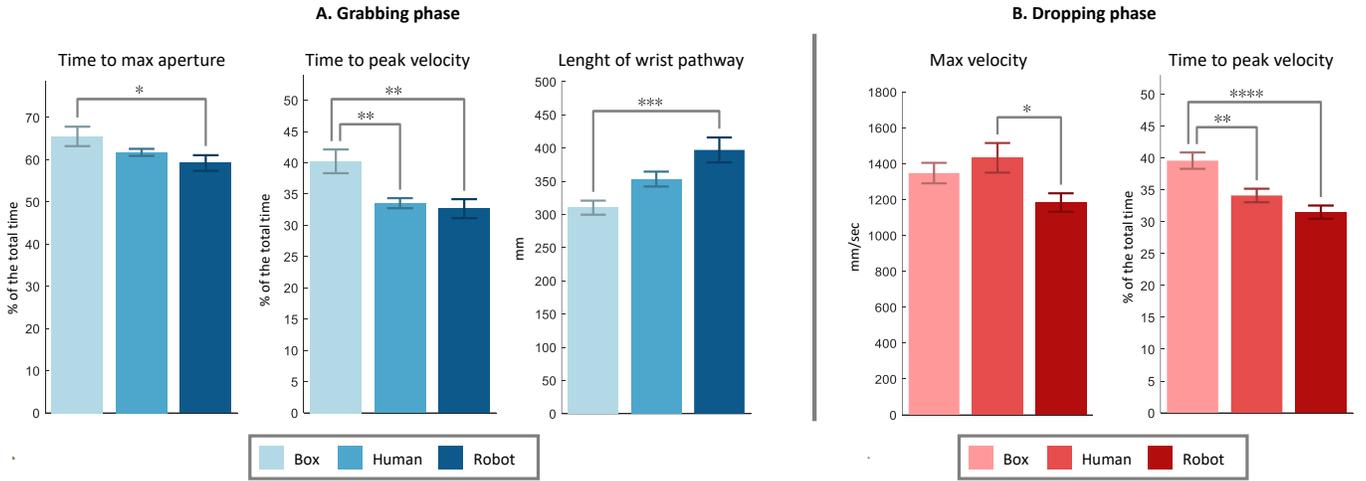


Fig. 2. Comparison of the parameters obtained in the box, human and robot conditions during the **A.** grabbing phase and **B.** dropping phase. **** indicates a very high significant difference (p-value < 0.0001), *** indicates a high significant difference (p-value < 0.001), ** indicates a moderate significant difference (p-value < 0.01), and * indicates a low significant difference (p-value < 0.05). Significance levels are evaluated with an ANOVA and a post-hoc Tukey test.

grabbing and dropping phases. The re-positioning phases have been ignored.

F. Measures

1) *Kinematic parameters:* In the analysis of the collected data, the grabbing and the dropping phases were analyzed separately.

Grabbing phase: During the phase of the action consisting of reaching out to grasp an object, we analyzed:

- the maximum distance between the two markers positioned on the index finger and the thumb (amplitude of maximum grip aperture),
- the time of the maximum grip aperture,
- the time and amplitude of peak velocity of the wrist,
- and the length of the wrist pathway.

Dropping phase: For the ‘drop’ phase, we considered:

- the time and amplitude of peak velocity of the arm,
- and the length of the wrist pathway.

The averages over the 15 trials were calculated for all the parameters, and for each of the participants for each conditions. A one-way within-subjects analysis of variance (ANOVA) were carried on the mean of each participant and the within subjects factor was the experimental conditions (Rectangular box, human partner, robot partner). Since the ANOVA results do not indicate which groups have different means, we then perform pairwise comparisons using a Tukey-Test comparison to identify the groups that have significantly different means.

2) *Perception of the robot:* Humans are influenced by the presence and their perception of other social agents [14]. To assess how the participants perceive the robot after the interaction, we used a Mind Perception Questionnaire (MPQ) based on [13]. This questionnaire focuses on two dimensions, namely the agency and experience perception. The *agency* dimension is dedicated to assess if participants perceive the robot as

an agent, able to memorize, have self-control, recognize the emotions of others, plan, and communicate. The *experience* dimension measures how participants evaluate the capacity of the robot to experiment joy, awareness, physical or emotional pain, personality traits and fear. The questionnaire is composed of 10 questions (5 items for agency and 5 items for experience) on a 7-option Likert scale (1 = Strongly disagree, 2 = Disagree, 3 = Somewhat disagree, 4 = Neither agree or disagree, 5 = Somewhat agree, 6 = Agree, 7 = Strongly agree). We then calculate for each person an average on the 2 criteria (agency and experience) and a general average. We also estimate the correlation between the kinematic parameters and the answers to the questions.

IV. RESULTS

A. Grabbing phase

The main factor here was statistically significant for the time to peak velocity ($F(2,30) = 7.83, p < .005$), and the time at which the fingers (thumb and index) reached the maximum distance ($F(2,30) = 3.22, p < .06$). There is also a significant difference for the length of wrist pathway ($F(2,30) = 7.83, p < .005$). Post hoc analyzes on ANOVA showed that time to peak velocity was significantly lower for the human partner and robot partner conditions than box condition (Tab.I). The time at which the fingers (thumb and index) reached the maximum distance is significantly lower for the robot partner condition than for box condition (Tab.I). This shows that the robot partner condition have times of reaching maximum speeds similar to the human partner and not to the box condition.

B. Dropping phase

For this phase, we notice a significant difference for the maximum amplitude of the peak velocity ($F(2,30) = 3.29, p < .05$) and for time to peak velocity ($F(2,30) = 13.09, p$

Group/Ref	Grabbing phase						Dropping phase			
	Time to max ap.		Time to peak vel.		Wrist pathway		Max vel.		Time to peak vel.	
	Diff.	p-value	Diff.	p-value	Diff.	p-value	Diff.	p-value	Diff.	p-value
Box/human	3.78	0.3	6.68	0.008	-43.05	0.09	-63.61	0.75	5.47	0.005
Box/robot	6.31	0.04	7.56	0.003	-86.929	0.0003	157.05	0.20	8.08	0.001
Human/robot	2.53	0.57	0.88	0.9	-43.879	0.08	220.66	0.047	2.62	0.25

TABLE I

PAIRED SAMPLES TUKEY-TEST RESULTS ON ALL SIGNIFICANT PARAMETERS DURING THE GRABBING AND THE DROPPING PHASE.

<.01). Post hoc contrasts revealed that the peak velocity is significantly lower for the robot partner condition compared to the human partner condition (Tab.I and Fig.2). Time to peak velocity is significantly lower for both human partner and robot partner than for box condition (Tab.I and Fig.2). Again, for the dropping phase, the human partner and robot partner (social conditions) conditions shared similar results as opposed to the box condition.

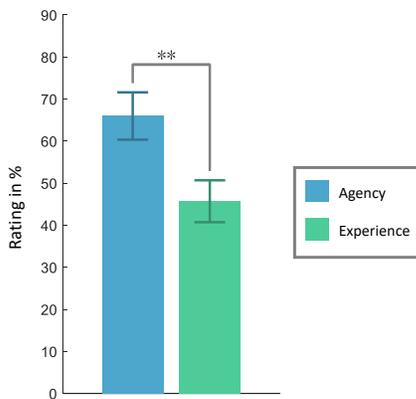


Fig. 3. Average ratings obtained with the Mind Perception Questionnaire on both agency and experience dimensions in percentage. ** indicates a moderate significant difference (p-value < 0.01). Significance level is evaluated with an ANOVA.

C. Analysis of the user questionnaire

The analysis of the Mind Perception Questionnaire dedicated to evaluate the interaction with the Reachy humanoid robot shows a high average rating of 66% for the *agency* dimension, evaluating if the robot is perceived as an agent. The experience dimension's rating is lower, with an average of 46%. The difference between these two dimensions is statistically significant, $F(1, 20) = 7.27$, $p = .014$. Furthermore, we explored the correlation between the agency and experience ratings with each of the statistically significant variables extracted from the movement kinematics. We found a moderate negative correlation between the agency rating and the time to peak velocity in the grab phase ($r(9) = -0.64$, $p = .03$). This shows that participants who attribute a lot of agency to the robot have a tendency to reach peak velocity earlier during the grabbing phase of the movement. To further explain this correlation, we also explored the correlation between each question included in the agency dimension and the time to peak velocity. We found a moderate negative correlation of this parameter with the rating on the planning capacity of the

robot ($r(9) = -0.60$, $p < .05$), and a strong negative correlation with the rating on the self control capacity of the robot ($r(9) = -0.74$, $p < .01$).

V. DISCUSSION

In the present study, we conducted an experiment inspired by [2] by adding a new condition involving a robot. We aimed to confirm the initial results and to explore how kinematics would be affected when the interacting partner is a robot. The results from [2] show that the kinematics of the gesture is sensitive to a social vs non-social interaction (Box vs Human partner) and impacts some specific kinematic parameters of the grabbing and dropping phases of a movement such as the maximum grip aperture, the wrist trajectory, the amplitude and the time of peak velocity.

Considering the two first conditions of our study (Box and Human conditions), we partially confirmed these results. In fact, for both the grabbing and the dropping phases, the time of peak velocity is reached earlier in the human partner conditions compared to the box condition. This reflects, as concluded in [2], a more careful action when interacting with a human partner (more time was taken for the deceleration phase). Nevertheless, we obtained results contradicting [2] on both the maximum velocity reached by the wrist and the wrist pathway. Indeed, for these parameters, we did not observe any significant difference between the human partner condition and the box condition, while [2] noted a lower peak velocity and a higher and longer wrist pathway for the social condition. Different hypothesis can explain this observation. First, in the experiment conducted by [2], the target during the non-social condition is a rigid concave box, while in our case, the box was made of cardboard. This might have affected the drop speed since the cardboard box could be supposed to slightly move during the dropping of the object, maybe leading to a more careful gesture. An alternative hypothesis is that the box was smaller compared to that of [2], as we know that gesture kinematics is very sensitive to the task's difficulty. This result corroborate the conclusions of De Marco et al. [9]. They used a similar experimental setup and procedure with different boxes having different sizes. They confirmed (as in [2] and in the present study) a more careful motor planning in the social condition but also found significant kinematic modulations induced by the modification of the box size. These different results reflect the multi-factorial aspect of human kinematic modulation.

By analyzing all the conditions of our study, including the robot partner one, we show that time to peak velocity is sig-

nificantly lower for the robot partner condition compared to the box condition but similar when compared to the human partner condition. Besides, the length of wrist pathway is significantly longer for the robot condition compared to the box condition during the grabbing phase. Furthermore, the time at which maximum fingertips aperture is reached happens significantly earlier for the robot compared to the box. For these two last parameters, no significant difference was observed between the human and the robot conditions. These findings support the hypothesis that the participants modulate their movement kinematics quite similarly when the partner is a human and when the partner is a humanoid robot, as found in the "social conditions" in [2] and [9].

To summarize, compared to an inanimate object (box condition), interacting with a human or a humanoid robot agent affects the gesture kinematics as follows:

- Peak velocity is reached earlier during the grabbing and the dropping phase
- Peak aperture of the fingertips is reached earlier during the grabbing phase (although for the human vs box, we just observed a non-significant trend)
- The length of the wrist pathway is longer (although for the human vs box, we just observed a non-significant trend)

An interesting aspect is that participants were even more careful in planning the motor trajectories in the robot partner condition, kinematic modulations were more significant in this condition (Tab.I and Fig.2). One can notice in fact that, for the dropping phase, the maximum velocity amplitude is significantly lower for the robot partner condition compared to the human partner condition (see Fig.2). A possible explanation lies in the fact that the interaction with the robot induces uncertainty while the human and box conditions are more common, leading to a more careful and slower gesture during the interaction with Reachy.

The analysis of the Mind Perception Questionnaire seems to confirm this hypothesis. It shows that the parameter that was the most significantly affected by the robot and the human partner, i.e., the time to peak velocity, was correlated with the perception of the agency of the robot. This shows that participants attributing a lot of agency to the robot had a tendency to reach the peak velocity earlier, which can be interpreted as a pro-social behavior. Furthermore, this correlation was particularly strong for the Self-control and Planning items of the questionnaire. We hypothesize that the more the robot is perceived as an agent capable of acting and planning, the more the participant expects that the robot might move or take the object from their hand, which leads to a more careful gesture. One can argue that the significant kinematic modulations can be reduced if participant were familiar with the robot and its motor competences, which was not the case here.

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