A Controllable and Repeatable Method to Study Perceptual and Motor Adaptation in Human-Robot Interaction

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ABSTRACT

Human perception and motion are continuously influenced by prior experience. However, when humans have to share the same space and time, different previous experience could lead towards opposite percepts and actions, consequently failing in coordination. This study presents a novel experimental setup that aims at exploring the interplay between human perceptual mechanisms and motor strategies during human-robot interaction. To achieve this goal, we developed a complex system to enable the realization of an interactive perceptual task, where the participant has to perceive and estimate temporal durations together with iCub, with the goal of coordinating with the robotic partner. Results show that the experimental setup continuously monitor how participants implement their perceptual and motor behavior during the interaction with a controllable interacting agent. Therefore, it will be possible to produce quantitative models describing the interplay between perceptual and motor adaptation during an interaction.

CCS CONCEPTS

• Human-centered computing

KEYWORDS

Human-robot interaction; adaptation; perception; kinematics

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1 INTRODUCTION

Every day humans spontaneously succeed in coordinating with others in daily routine, free time and work, often without the need of explicit communication. Most of the time humans unconsciously adapt their behavior in social interactive settings: if we just think about passers-by in crowded streets, they commonly adjust their walk in order not to bump into others [1]. Although this adaptive behavior seems to be automatic for human beings, the naturalness of human social skills has not been fully transferred in robots yet [2]. It would be extremely important to develop a new quantitative model that is able to describe human adaptation in interaction, investigating how humans manage to coordinate efficiently in every day joint activities.

Our study starts from the observation that prior experiences continuously shape and influence human perception and actions. Humans are repeatedly exposed to sensory stimuli, hailing from the surrounding environment. To handle with sensory uncertainty, human perception takes into account not only the current information, but also the sensory history related to this stimulus [3, 4]. We refer to this phenomenon as central tendency [5], which can be modeled through Bayesian techniques [6, 7, 8, 9]. Thanks to central tendency, the magnitude of the total error is reduced and, therefore, the reliability of the percept is increased [10]. To augment the dependability of a set of repeated actions, humans apply this strategy also for actions [11, 12, 13]. Indeed, movements are influenced by their motor history and, therefore, the duration of the task can affect the anterograde inferences in the correspondent actions [14]. However, strategies relying on personal experience do not seem to be the best one to apply when humans have to coordinate efficiently with other agents, who are characterized by different previous experiences [15]. In this regard, a recent study provides some insights in the context of an interaction with a humanoid robot: in interactive contexts, people tend to rely on their current percept, trying to neglect their sensory prior experience [16]. In this work, we aim at studying how human perception and motion can weigh differently their prior experiences either in

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individual or interactive settings. To have a comprehensive description of the process, we investigate the relation between these two components of human behavior, namely perception and action, depending on the context (individual or social). To achieve this goal, we developed a perceptual task, in which a participant estimates the temporal duration of visual stimuli and reproduce it by moving a wooden stick from a resting position until they hit a rubber pad (as a drummer keeping their tempo). In some phases of the task, the participant has to apply an efficient perceptual and motor adaptive strategy to align their responses to those of a robot, which is controlled to perform the task. The initial phase of this study consisted in creating an innovative setup, characterized by precision and synchrony among all the devices and the interacting agents involved. To realize a controllable and repeatable interactive context, we characterized a humanoid robot iCub [17], with its own perceptual and motor models: thanks to the architecture of the setup, behavior of the participant and the robot are monitored during each temporal instant of their interaction, both in terms of perception and motion.

This study provides a new experimental methodology, which allows a controllable and repeatable human-robot interaction to investigate adaptive perceptual and motor mechanisms in human beings. Thanks to this setup, it will be possible to investigate how human beings adapt to an artificial agent, characterized by different prior experience, and verify if they implement mechanisms of motor adaptation in order to align better with its perceptual responses. Therefore, the acquisition of quantitative measures related to perception and kinematics will lead towards the development of a model, which describes human adaptive behavior in a precise manner. Indeed, the long-term goal of this research consists in transferring bio-inspired model of adaptation and, consequently, developing novel adaptive robots, able to predict humans' perceptual and motor behavioral peculiarities: therefore, these artificial embodied agents could tailor their action in order to assist person with neurocognitive distortions in the biomedical fields (e.g., rehabilitation, assistance) or to optimize the working flow in industrial settings [2, 18].

2 MATERIALS AND METHODS

2.1 Experimental Setup and Paradigm

To investigate the modulation of perception and kinematics in individual and interactive settings, we developed a novel experimental paradigm. Participants are located in front of a rectangular-shaped table, on which two strips of LEDs lay respectively at a distance of 23 cm from the edge near the participant and the one near the robot. Using Optotrak motion capture system, participants' kinematics is tracked at a frequency of 100 Hz: markers are attached to participants' right arm, precisely on the shoulder, elbow, wrist and two points of the metacarpal bones of the hand. Participants' perceptual responses are detected by a piezoelectric sensor, which is enveloped in a rubber pad.

During the task, two consecutive flashes are provided on the first strip of white LEDs. These two visual stimuli are separated by a temporal duration, randomly chosen in the interval from 1.0 s to 4.0 s, with a step of 0.375 s. Participants have to perceive the shown temporal duration and reproduce their estimate, moving a wooden stick from a resting position until they hit a rubber pad. Participants' estimate is computed as the temporal distance between the appearance of the second lightening and participants' hit on the rubber pad. The appearance of a third flash on the first strip of LEDs signals the end of participants' movement. The experimental paradigm is composed of two different conditions: Individual and Social. These sessions are characterized by the same perceptual task, but they differ from participants' goal.

a) Individual (IND): participants have to reproduce the temporal duration in the most accurate way;
b) Social (SOC): participants executed the task together with iCub, a humanoid robot. Their aim is to align their perceptual responses to the one of the robot. To achieve this result, participants have the possibility of visualizing the movement of the robot during the task (Figure 1). Moreover, the perceptual responses of the robot are shown through a flash on the second strip of green LEDs (Figure 2);

Participants address the previous conditions always in the same order: Individual and then Social, each one composed of 54 trials.

Figure 1. Experimental setup. A controlled and repeatable interactive setup was created. Both the participant and iCub are positioned in front of a rectangular-shaped table with two strips of LEDs. They both hold a wooden stick in order to hit the rubber pad to register their temporal estimate. Markers are attached to their arms to track their kinematics.

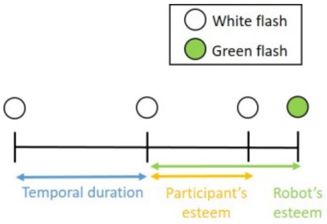

Figure 2. Temporal sequence of LEDs during each trial of the experiment. To present temporal durations, two consecutive flashes are presented through the strip of white LEDs. When the participant or the robot hits the pad to record their esteem, respectively a white or green flash of feedback appears.

2.2 iCub's Perceptual and Kinematic Behavior

Despite their different previous experience, humans manage to implement their perceptual and motor mechanisms of adaptation when they coordinate with another agent. To explore the process of adaptation during an interaction, we decided to endow the robot with a perceptual and motor behavior characterized by a prior experience that would be different from that of the participant. To achieve these goals, we carried out two modified versions of our experimental paradigm.

2.2.1 Modeling iCub's Perceptual Responses

We carried out a first experiment where 10 participants took part in a version of the experiment composed only by the IND condition. This time, longer temporal durations were presented in the range from 4.0 s to 7.0 s, with a step of 0.375 s. Applying linear regression on the mean of participants' temporal responses, we simulated the perceptual feedback of the robot in the interval of shorter durations from 1.0 s to 4.0 s. In this way, we obtained 9 responses of the robot, each one associated to a specific temporal stimulus in the new experimental paradigm. These responses simulate those of an agent with a different prior experience, which is characterized by longer stimuli.

2.2.2 Modeling iCub's Action

To characterize the motion of the robot, we carried out another experiment with 10 participants, composed of both IND and SOC conditions. However, differently from our final experiment, the robot was not present in the experimental room: therefore, participants had to align to its feedback, without seeing the action of the embodied agent. This experimental feature was meant to assess the natural adaptive motor processes implemented by participants. Results revealed that in the SOC condition participants delayed the onset of their pseudo-elliptical actions, maintaining unvaried the amplitude of the gesture from the setup table. Then we used these behavioral and kinematic results to design the robot's movement for our final interactive experiment. We designed 9 different bio-inspired actions, each one associated to the temporal duration of the perceptual task. To endow the robot with a bio-inspired and human-like motor behavior, each movement was characterized by an elliptical trajectory, executed with a velocity that follows the two-thirds power law [19]. To analyze if participants adapt their kinematics to their partner's movement to match its perceptual response during the interaction, we designed actions with the opposite kinematic variables: the amplitude of each gesture was set in the range from 15 to 35 cm. On the contrary, the onset of the movements was kept unvaried and, therefore, the action started 0.2 s after the lightening of the second flash in the perceptual task. To have control on the kinematic feedback of the robot, its joint positions were previously computed through inverse kinematics and, during the experiment, they assumed the same values for a specific action. In order to let the robot hit its rubber pad like participants, the joint configuration of the left arm was fixed and, therefore, the final position and orientation of the palm maintained unchanged its tridimensional coordinates. Thanks to this feature, we eliminate variability of the movement among trials and among participants, obtaining a controlled and repeatable interacting agent. During the creation of the movement of the robot, we wanted to keep a balanced trade-off between the number of samples in the elliptical trajectory and a specific timing related to the response feedback of the robot. This result allowed us to obtain smooth bio-inspired movements, whose corresponding end perfectly coincides with the hit of the robot on the rubber pad.

3 RESULTS

3.1 Testing Our Controllable and Repeatable Interactive Experimental Environment

3.1.1 Perceptual Results

To investigate how perceptual and motor reliance on prior experience is modulated during an interaction, the robot was characterized with a specific perceptual and motor behavior, which differ from the participants' ones. Figure 3 shows the linear regression applied to one participant's perceptual response means, compared to the perceptual behavior of the robot. We can see that the perceptual characterization of the robot was effective: the robot and the participant have a different prior experience, which influences their current percepts. Indeed, the green line, representing the mean trend of iCub's perceptual responses, is shifted towards longer reproduced durations, compared to that of the human interacting partner. Moreover, thanks to our setup, it is also possible to have a comparison among the different conditions of the experiments. Indeed, when participants execute the perceptual task with iCub, they shift their perceptual model towards the one of the robot (Figure 4). This outcome will allow us to study how our perceptual model weighs prior experience during an interaction with iCub, characterized by a different perceptual model.

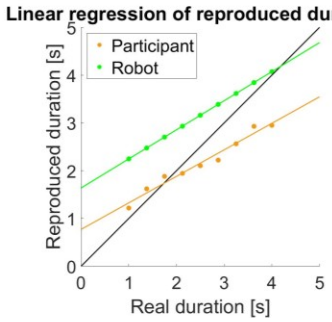

Figure 3. Linear regression of reproduced durations. One representative participant's mean responses in IND and the ones of the robot are plotted (respectively orange and green dots). Applying linear regression, it is possible to visualize the two different perceptual models, related to the participant and the robot. It is clear that the reproduced durations of the robot are longer than the participant's ones.

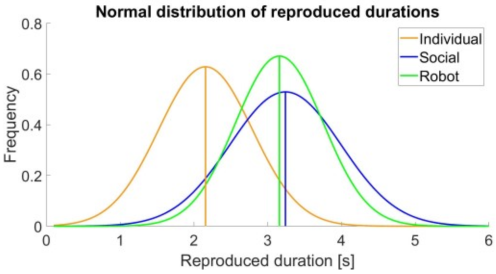

Figure 4. Normal distribution of reproduced durations. The orange and the blue curves show the distribution of a representative participant's perceptual responses, in IND and SOC conditions, while the green distribution represents iCub's perceptual model, characterized by a higher mean than the participant's one in IND.

3.1.2 Kinematic Results

Our final goal is not only limited to describe the variation of the reliance in human perception during interaction, but also to model the mutual relation between perceptual and motor adaptive mechanisms. For this reason, we characterized the interacting agent with a different motor behavior from the participant's one. Indeed, our goal consists in investigating if the visible action of the robot can help the participant in adapting better to its perceptual responses. Figure 5 shows the trajectory of one participant's right hand in IND session, while Figure 6 represents iCub's kinematics during the estimation of the same temporal duration, equal to 3.25 s. The comparison between Figure 5 and Figure 6 highlights the outcome of the motor manipulation of the robot: iCub's elliptical gesture assumes a higher amplitude (i.e., amplitude range: 15-35 cm) than the participants' one and fixes its onset 0.2 s after the lightening of the second flash. Therefore, the motor manipulation of the robot returns an embodied agent that varies the amplitude of its movement according to the presented stimulus. For longer temporal durations, the robot will execute a gesture with a higher amplitude. The setup will allow us to verify if during the interaction participants modulate its kinematics to align with iCub and whether motor adaptation processes mediate changes in human perception.

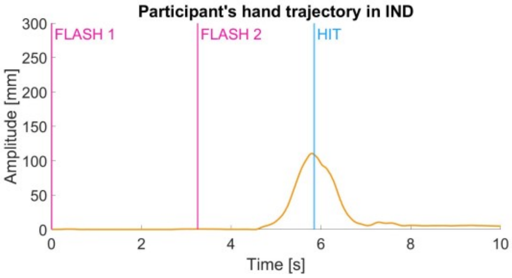

Figure 5. Participant's hand trajectory. This image represents the trajectory of one representative participant's hand in IND: the baseline refers to the resting position, while the maximum amplitude coincides with the hit (stimulus: 3.25 s). Thanks to this precise setup, kinematic data are related to the corresponding perceptual stimulus (distance between flash 1 and flash 2) and the response (hit).

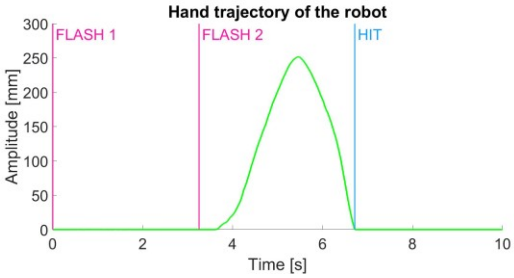

Figure 6. Hand trajectory of the robot. This figure represents hand trajectory of the robot, which moves its left arm from a resting position (baseline), until it hits the rubber pad at the same level. The robot assumes a maximum amplitude that is higher than the participant's one (stimulus: 3.25 s).

4 CONCLUSIONS

In this study we introduce a novel experimental setup that aims at investigating the perceptual and motor mechanisms underlying human-robot interaction and their mutual perceptual and motor adaptation. This methodology allows us to monitor the perceptual and kinematic behavior of a human participant at each instant of a joint interactive perceptual task. Indeed, the precision of the experimental setup was not only due to the synchronized communications between all the devices involved in the realization of the setup, but also to the strictly controlled characteristics of the robot, in terms of both perception and motion. As shown in the previous section (see 3 RESULTS), iCub's perception was biased by a different prior experience from that of the participants and modeled based on human-like perception skills. This aspect allows us to investigate how humans would adapt their perceptual model to align with the robot in the interactive task. At the same time, the different kinematic attitude of the robot gives us the possibility of investigating how humans leverage the visual feedback of the robot's actions to adapt their perception to their partner's one. This innovative methodology will lead us towards the development of a comprehensive model, which is able to describe how human perceptual and motor strategies use information on prior experience to succeed in the coordination with another agent. In future development, this quantitative model will be implemented in robots so that they will be able to adapt their perception and motion to collaborate more efficiently with humans. In this way, embodied artificial agents will manage to help people not only at home or work during their daily routine, but also in case of assistance or rehabilitation. To achieve this result, our setup will be exploited for future experimental paradigms, manipulating the perceptual and motor behavior of the robot and its social skills.

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