Expressive handovers: neural and behavioral effects of different attitudes in humanoid actions

Fabio Vannucci
CONTACT Unit
Istituto Italiano di Tecnologia
Genova, Italy
fabio.vannucci@iit.it

Giuseppe Di Cesare
CONTACT unit
Istituto Italiano di Tecnologia
Genova, Italy
giuseppe.dicesare@unipr.it

Francesco Rea
Robotics, brain and cognitive science
Istituto Italiano di Tecnologia
Genova, Italy
francesco.rea@iit.it

Giulio Sandini
Robotics, brain and cognitive science
Istituto Italiano di Tecnologia
Genova, Italy
giulio.sandini@iit.it

Alessandra Sciutti
CONTACT unit
Istituto Italiano di Tecnologia
Genova, Italy
alessandra.sciutti@iit.it

***Abstract*—Interacting with others requires the ability to evaluate their attitudes based on how actions are performed. Even a simple everyday act as handing over an object acquires a different meaning if it is performed gently or harshly. This little difference can impact the whole evolution of a collaboration, as people tend to react aggressively to aggressive behaviors. Concerning human-robot interaction, it is important to be aware of the impact that robot motion features might have in the partner's interpretation of their actions. The challenge we address in this research is to endow the iCub humanoid robot with the capacity to communicate intuitively positive and negative attitudes in its own actions. The results of a series of fMRI and interactive studies showed that robotic passing actions performed with kind and aggressive attitudes (or vitality forms) have a significant impact not only on how the brain processes the observed robotic action, but also on the way the human partners act in response to it.**

Keywords—Vitality, Human-robot interaction, Biological motion, Neurophysiological bases.

Interaction between humans is very natural as we are experts in interpreting social communication even when it assumes different forms. Non-verbal communication for instance is extremely efficient and is achieved through small hints, involuntarily sent by our body and likewise interpreted by the observer's brain. These implicit signals, encoded in our way of moving, are the foundations of "emergent coordination"[1], one of the key features that make human interactions so effective by way of anticipation, synchronization and mutual adaptation [2]–[4]. Humanoid robots could largely benefit from the ability to send meaningful social signals embedded in their own motion. This would allow the human partners to anticipate properties of the robot action, which would otherwise not be easily detectable. Humans indeed are very good at predicting the goal of someone else's action[5], or at inferring the force they are using in handling an object or even the affective state of a partner, just from the observation of subtle properties of their motion (see [6] for a review).

Recent research found evidence that a humanoid robot exhibiting human-like behavior can trigger the same intuitive understanding occurring in human-human interaction. For instance, goal-oriented actions performed by a robot and a human actor could direct the attention of an observer towards the goal with a similar level of anticipation [7]. Another work demonstrated that an observer could deduce the weight of objects with the same accuracy when the lifting was performed by a human or by a robot [8]. Other examples include priming [9], [10] and even activation of the mirror-neurons system [11]. All the aforementioned literature confirms that a humanoid robot performing simple actions and replicating some regularities of human motion, can induce very similar intuitive understanding and very similar reactions in an human partner, as a person in the same circumstances would do.

Considering these results, we want to investigate the role of one specific feature of human motion, the so-called "vitaliy forms"[12]. Vitality forms represent the manner in which an action can be performed. Indeed, the same action can be carried out in different ways and acquire completely different meaning. For example, a passing action could be gentle or aggressive providing information about the affective states of the agent. The perception and the expression of these forms of action that communicate an inner state induce the activation of a small part of the brain, named dorso-central insula. Furthermore, the observation of gentle and rude actions influences the motor behavior of the observers [13], [14]. Humanoid robots might need to express vitality forms communicating different attitudes in several contexts. For example, an elderly care robot could display more "kind" behavior with slow and fluid motion while offering something, whereas in an emergency situation would be probably better an assertive robot, with the ability to communicate imperative commands and convince a person to quickly follow its instructions and take the object it is passing. The focus of our research is to endow a humanoid robot with the ability generate passing action expressing different attitudes and to assess whether these have an impact on the interaction. To address these issues, taking inspiration from the differences between human "rude" and "gentle" vitality forms, we generated passing gestures communicating aggressive or kind attitudes for an iCub robot. We then tested these stimuli by performing two fMRI and two interactive experiments.

The aim of the fMRI studies was to assess whether the observation of the iCub robot passing objects and mimicking human vitality forms produced the activation of the insula, similarly to what happens for human observation. In both studies, sixteen participants were required to pay attention either to video-clips showing a human actor offering an object in a gentle and rude way or to video-clips showing very similar actions generated by the iCub robot. In the first studies the attitude expressed by the robot passing action was modulated just by modifying the velocity of the motion (slow: gentle; fast: aggressive). The results showed that the observation of robot actions failed to activate to the same degree the dorso-central insula as the human actions (Fig. 1).

In the second study, we tried to improve the stimuli to better capture the movement properties associated to different vitality forms. To this aim, we recorded with an Optotrack motion capture system the kinematics of an actress while she was performing an offering gesture gently or rudely and we then retargeted these movements into the kinematic model of the iCub robot. The results of a second fMRI study using these novel stimuli showed that the observation of robotic actions endowed with human vitality forms produced an insular activity very similar to that obtained during the observation of human actions (Fig.1). These results confirm that the adoption of appropriate motion features in a passing action make it possible for the humanoid actions to be processed by the brain in a similar way as a human action.

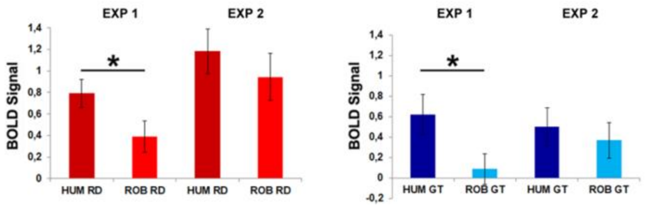

Figure 1. BOLD signal indicating the insula activity during the processing of actions performed by human actors and iCub robot in Exp.1 and Exp.2. The bar graphs indicate the comparisons between human and robot in gentle and rude conditions. Asterisk indicates the significant difference present in Exp. 1 (p<0.05). (RD = rude, GT = gentle).

To verify whether the iCub movements effectively conveied rude and gentle vitality in an actual interaction we performed an experiment in which the robot had to actually pass an object to participants[15]. The experimental setting is depicted in Fig 2. Ten participants sat comfortably in front of the robot with small headphones to hear verbal instructions, covered by hearing protectors to avoid experimental biases due to the noise of the moving motors. After iCub's action execution (passing the object) participants had to take a ball held by the robot at approximately 30 cm from their right hand. Between the participant and the robot, we placed a small table with marks indicating the starting position of the right hand and two different targets (yellow and orange) on which the ball had to be placed by the participant. The robot performed the passing action with two different vitality forms, rude and gentle, following the kinematics properties validated in the last fMRI study. The face of the robot was covered with a black piece of cloth held by two poles at the proper height, since the salience of the information had to be conveyed by the action alone. At the end of the experiment participants were asked how they would have described the robot behavior. All participants commented the rude stimuli using at least one of the words: "aggressive", "commanding", "angry", "rude", whereas the gentle stimuli were defined "kind", "calm", "relaxed", demonstrating that the subjective perception of the robot action was consistent with the designed vitality. Moreover, we found some minor modulations in the kinematics of the participants' response to the robot's action. These modifications though were not as strong as the ones observed in a similar human-human setting. In previous research, indeed, presenting videos of human expressing different vitality forms influenced significantly the observer's subsequent actions, which exhibited then the same vitality [14]. The effect occurred also when vitality in video was expressed not through an action, but only through the modulation of a voice expressing an aggressive or a gentle attitude. This indicates that the result was not guided just by motor contagion, but rather reflected a contagion of style.

To delve more in depth in this phenomenon we performed a new interactive experiment, where we added a condition in which the robot action was not performed in front of the participant ("Live") but was shown in video (replicating [12]). To focus on the communicative component of the passing action while keeping a perfect matching between the "Live" and the "Video" conditions, the robot did not hold the ball in its hand, but moved the hand toward it, as in a pointing. Ten participants performed the task in both conditions in two separate sessions. The results reported in Fig. 3 clearly show that the vitality of the robot action modulates the vitality of the participants' motion.

Figure 2. Snapshot of the experimental setup of the interactive task.

Participants' reaching actions become significantly faster and also their peak acceleration increases significantly when the robot behavior is aggressive. Even if there was no contact between the participant and the robot in both the video and live condition, the contagion was strong. The differences between "Video" and "Live" conditions indicate that the physical presence of the robot has an influence on the impact of the humanoid attitude on participant's behavior. Indeed, the effect is more evident in the "Video" condition. This might explain the reduced effect observed in our first experiment, which entailed only an actual interaction with the robot. These results confirm that the physical presence of the robot has a a different impact on certain aspects of the interaction, if compared with video-based scenarios, in line with previous literature [9], [16], [17].

Considering the results of this series of experiments, it emerges that a humanoid robot can effectively express different vitality forms in its passing actions. These are explicitly recognized by the human partners and have a significant influence on the interaction, changing the next actions performed by participants. In particular, they tend to match the style of the robot behavior, exhibiting more aggressive movements in response to aggressive robot attitudes. Hence, the way the transport phase of the handover is performed will not only impact on the "what", "where" and "when" the passage will happen[18], but will also inform "how" the whole interaction will evolve, both in terms of motion properties and in terms of subjective perception of the collaboration.

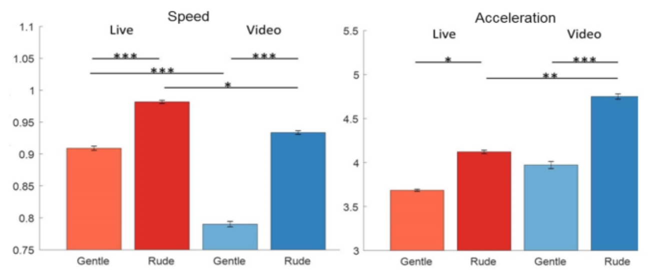

Figure 3. Average peak hand speed and peak hand acceleration for the reaching phase of the movement in response to the robot's action .The error bars represent standard error of the mean. The symbols indicate the level of significance of ANOVA followed by post-hoc analysis with Bonferroni correction: * p<0.05, ** p<0.01, *** p<0.001.

ACKNOWLEDGMENT

This work has been supported by a Starting Grant from the European Research Council (ERC) G.A. No 804388, wHiSPER

REFERECES

[1] G. Knoblich, S. Butterfill, and N. Sebanz, *Psychological Research on Joint Action: Theory and Data*, vol. 54. 2011.

[2] E. Bicho, L. Louro, and W. Erlhagen, “Integrating verbal and nonverbal communication in a dynamic neural field architecture for human-robot interaction,” *Front. Neurorobot.*, 2010.

[3] S. G. Khan, S. Bendoukha, and M. N. Mahyuddin, “Dynamic Control for Human-Humanoid Interaction,” in *Humanoid Robotics: A Reference*, 2017.

[4] M. N. Mahyuddin and G. Herrmann, “Cooperative robot manipulator control with human ‘pinning’ for robot assistive task execution,” in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 2013.

[5] J. R. Flanagan and R. S. Johansson, “Action plans used in action observation,” *Nature*, 2003.

[6] G. Sandini, A. Sciutti, and F. Rea, “Movement-Based Communication for Humanoid-Human Interaction,” in *Humanoid Robotics: A Reference*, 2017, pp. 1–29.

[7] J. D. Boucher *et al.*, “I reach faster when i see you look: Gaze effects in human-human and human-robot face-to-face cooperation,” *Front. Neurorobot.*, 2012.

[8] A. Sciutti, L. Patanè, F. Nori, and G. Sandini, “Understanding object weight from human and humanoid lifting actions,” *IEEE Trans. Auton. Ment. Dev.*, 2014.

[9] D. Eizicovits, Y. Edan, I. Tabak, and S. Levy-Tzedek, “Robotic gaming prototype for upper limb exercise: Effects of age and embodiment on user preferences and movement,” *Restor. Neurol. Neurosci.*, 2018.

[10] S. Kashi and S. Levy-Tzedek, “Smooth leader or sharp follower? Playing the mirror game with a robot,” *Restor. Neurol. Neurosci.*, 2018.

[11] V. Gazzola, G. Rizzolatti, B. Wicker, and C. Keysers, “The anthropomorphic brain: The mirror neuron system responds to human and robotic actions,” *Neuroimage*, 2007.

[12] D. Stern, *Forms of vitality: Exploring dynamic experience in psychology, the arts, psychotherapy, and development*, 2010th ed. Oxford University Press.

[13] G. Di Cesare, M. Marchi, A. Errante, F. Fasano, and G. Rizzolatti, “Mirroring the social aspects of speech and actions: The role of the Insula,” *Cereb. Cortex*, 2018.

[14] G. Di Cesare, E. De Stefani, M. Gentilucci, and D. De Marco, “Vitality Forms Expressed by Others Modulate Our Own Motor Response: A Kinematic Study,” *Front. Hum. Neurosci.*, 2017.

[15] F. Vannucci, G. Di Cesare, F. Rea, G. Sandini, and A. Sciutti, “A Robot with Style: Can Robotic Attitudes Influence Human Actions?,” *IEEE-RAS Int. Conf. Humanoid Robot.*, vol. 2018-Novem, pp. 952–957, 2019.

[16] J. Li, “The benefit of being physically present: A survey of experimental works comparing copresent robots, telepresent robots and virtual agents,” *Int. J. Hum. Comput. Stud.*, 2015.

[17] S. Levy-Tzedek, S. Berman, Y. Stiefel, E. Sharlin, J. Young, and D. Rea, “Robotic Mirror Game for movement rehabilitation,” in *International Conference on Virtual Rehabilitation, ICVR*, 2017.

[18] K. W. Strabala *et al.*, “Towards Seamless Human-Robot Handovers,” *J. Human-Robot Interact.*, 2013.