

Running head: Humanoid robots become human-like partners

When humanoid robots become human-like interaction partners:  
co-representation of robotic actions

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## Abstract

In human-human interactions co-representing a partner's actions is crucial to successfully adjust and coordinate actions with others. Current research suggests that action co-representation is restricted to interactions between human agents facilitating social interaction with conspecifics. In the present study, we investigated whether action co-representation, as measured by the Social Simon Effect (SSE), is present when we share a task with a real humanoid robot. Further, we tested if the believed humanness of the robot's functional principle modulates the extent to which robotic actions are co-represented. We described the robot to participants either as functioning in a biologically inspired human-like way or in a purely deterministic machine-like manner. The SSE was present in the human-like, but not in the machine-like robot condition. The present findings suggest that humans co-represent the actions of non-biological robotic agents when they start to attribute human-like cognitive processes to the robot. Our findings provide novel evidence for top-down modulation effects on action co-representation in human-robot interaction situations.

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## Introduction

As humans we have much experience in sharing tasks with other humans. Due to the recent fast technical development, interactions with robotic agents will increase in daily life in areas such as health care, education or entertainment. However, little is known about the cognitive processes involved in real world joint action between humans and robotic interaction partners.

In human-human interaction one crucial aspect for successful action coordination with a partner is the formation of mental representations of a partner's actions (Sebanz, Bekkering, & Knoblich, 2006). The cognitive representation of other's actions during dyadic interactions has recently been investigated with different joint action paradigms (Atmaca, Sebanz, & Knoblich, 2011; Atmaca, Sebanz, Prinz, & Knoblich, 2008; Lam & Chua, 2010) with the most prominent of them being the *Social Simon Task*. In the *Social Simon Task* a standard *Simon Task* is divided between two individuals sharing the task. In a standard *Simon Task*, one of two possible stimuli (e.g., square and diamond) is displayed either on the left or the right side of a monitor to a single participant. The participant performs spatially defined manual responses to non-spatial stimulus attributes (e.g., right button press for diamond, left for square). Responses are faster when stimulus and response are spatially compatible (facilitation) than when they are spatially incompatible (interference). The difference in reaction times between spatially compatible and incompatible conditions is called the *Simon Effect* (Simon & Rudell, 1967). The *Simon Effect* is absent when the participant has to respond to only one of the two stimuli disregarding the other (*Individual Go/Nogo Task*). When two participants share the *Simon task*, so that one participant responds to only one stimulus (e.g., square) and the other participant responds to the other stimulus (diamond), a *Simon*

Effect is reintroduced, which is called the *Social Simon Effect* or SSE (Hommel, Colzato, & van den Wildenberg, 2009; Liepelt, Wenke, Fischer, & Prinz, 2011; Sebanz, Knoblich, Prinz, & Wascher, 2006). Although each participant has the same task as in an individual go/nogo situation, partnering the two individuals in a shared task setting reinstates the Simon Effect in each of them. The SSE is regarded as a measure of action co-representation, i.e. both participants cognitively represent the action and/or task of the partner as if each one was in charge of the full, undivided task (Sebanz, Knoblich, & Prinz, 2003; Sebanz, Knoblich, & Prinz, 2005). Recently, Wenke and colleagues proposed, that the content of co-representation is the representation of whether and when the co-actor has to respond (Wenke et al., 2011). The co-actor's response might represent a salient event, that provides an alternative for the actor's own response. Like this, a reference frame for a spatial coding of responses might be induced (Dolk et al., 2011; Guagnano, Rusconi, & Umiltà, 2010), leading to response facilitation in compatible trials and response interference in incompatible trials.

Most research on action co-representation suggests that the shared representational system is primarily tuned to other humans (Kilner, Pauligan, & Blakemore, 2003; Tsai, Kuo, Hung, & Tzeng, 2008). For example, Tsai and Brass (2007) replaced the human interaction partner in a Social Simon Task with a video of either a human hand or a wooden hand. They found a significant SSE in the human hand condition, but not in the wooden hand condition. However, this study and most other studies investigating biological tuning of the shared representational system used rather virtual and unreal interaction situations, in which participants observed or interacted with videos or simple pictures of artificial agents. Based on the assumption that interacting with an agent in real-time is fundamentally different compared to

passively observing action videos (Schilbach et al., 2006), we think that it may be premature to draw definite conclusions regarding the nature of shared representations for non-biological agents. More real world interaction situations need to be tested to fully understand the mechanisms underlying dyadic human-robot interactions.

Moreover, recent studies suggest that the shared representational system is affected by the intentionality attributed to an agent (Atmaca et al., 2011; Liepelt, von Cramon, & Brass, 2008), independent of whether the agent is human or non-human in its nature (Liepelt & Brass, 2010; Müller et al., 2011a; Stanley, Gowen, & Miall, 2007).

In the present study, we tested if humans do co-represent actions of a humanoid robot in a real world interaction situation. Further, we investigated if the magnitude of action co-representation can be modulated by the intentionality attributed to a robotic interaction partner. All participants performed a Social Simon Task together with a humanoid robot under perceptually identical conditions, but prior to the task, we manipulated the participant's belief about the functional principle of the robot. The robot was either described as functioning in a biologically inspired, autonomous way (*human-like robot condition*) or in a purely deterministic way (*machine-like robot condition*).

If action co-representation is sensitive to the intentionality attributed to an agent, we expected to find a larger SSE in the human-like robot condition compared to the machine-like robot condition. If, however, action co-representation is not sensitive to the intentionality attributed to a robot, we expected to find no difference in the SSE between the two conditions. If action co-representation is restricted to biological agents only, we expected to find no SSE in either condition.

## Method

### Participants

Forty-eight students from technical studies and humanities of the University Jaume I participated in the experiment. Twenty-four were randomly assigned to the human-like robot condition (12 men,  $M_{\text{age}}=19.13$  years,  $SD_{\text{age}}=4.24$  years), and twenty-four were randomly assigned to the machine-like robot condition (12 men,  $M_{\text{age}}=20.38$  years,  $SD_{\text{age}}=4.31$  years). Each participant received €10 for participation. Participants gave their informed consent to participate in the study, which was conducted in accordance with the ethical standards laid down in the 1975 Declaration of Helsinki.

### Apparatus

The experimental program was controlled by a Laptop attached to a 16-inch CRT monitor. The viewing distance was 60 cm. Responses were recorded with two keyboards placed on a table next to each other (Figure 1). The right command key located in the center of each keyboard served as response key.

The robot *Tombatossals*, a humanoid torso with a pan/tilt/vergence anthropomorphic head, eyes-cameras, arms, and a three-finger, four-degrees-of-freedom *Barrett Hand* (left hand) (Chinellato, Antonelli, Grzyb, & del Pobil, 2011) served as the co-actor in a Social Simon Task (Figure 1).

--- Figure 1 ---

### Stimuli and Procedure

Each trial began with the presentation of a fixation point (white dot,  $0.4^\circ \times 0.4^\circ$ ) in the center of a black screen for 250 ms. Then, either a white square or a diamond ( $1.9^\circ \times 1.9^\circ$ ) appeared  $8.0^\circ$  left or right of the fixation point for 250 ms. Stimulus types and placements were randomly interleaved. Responses had to be given

within 1800 ms. Afterwards visual feedback about the accuracy of the response was provided for 300 ms: The fixation dot turned green in case of correct responses, and red in case of an error. After a constant inter-trial interval of 1850 ms the next trial started. The experiment consisted of 512 trials separated by short breaks after every 128 trials.

The participant (left side) responded as fast and as accurately as possible whenever the square was presented by pressing the left response key with the index finger of his/her right hand. The robot (right side) responded to the diamond by pressing the right response key with the rightmost finger of its left hand (“index” finger). The finger was held slightly above the keyboard, and moved down to press the key when a trigger signal was received. The two joints of the finger moved simultaneously while the rest of the hand as well as the robot’s body posture was kept completely still throughout the whole experiment (Figure 1, Supplement 1).

We manipulated the participant’s belief about the robot’s functional principle between the human-like robot condition and the machine-like robot condition. In the human-like robot condition, the robot was described as an active and intelligent agent. Participants were informed that the robot was able to perceive stimuli with its own eyes (cameras), to actively explore its environment, and to autonomously respond on the basis of a biologically inspired neural network. In the machine-like robot condition, the robot was described as a passive and purely deterministic agent. Participants were informed that the robot was a mechatronic device that was completely controlled by the commands of a computer program, thus passively executing external motor commands. The information about the robot was given to participants as a written text. Text length was roughly matched between both conditions. After participants had read the instructions, a master student (and not the

experimenter) read the instructions out aloud in a standardized way with no special emphasis on either condition.

In order to provide a human-like behaviour by the robot and allow a comparison with data from human-human interaction experiments the robot was controlled by an operator hidden from the view of the participant. The stimulus program generated a tone, in trials in which the robot was supposed to respond, which was presented to the operator via headphones. When hearing the tone, the operator pressed a keyboard button to trigger the finger movement of the robot, which was controlled by the robot's software. Therefore, reaction times were roughly matched to those of a typical human interaction partner (mean reaction time: 371 ms). The stimulus program included a certain percentage of random errors (1.6% of trials) so that the robots rate of correct responses was also comparable to that of a human interaction partner. The robot behavior, the visual stimulation, and the task were identical in both (human-like and machine-like) conditions. Debriefing after the experiment showed that no participant was aware that an external operator controlled the robot's behavior.

## **Results**

### **Response time analysis**

The median response times (RTs) per participant for correct responses were calculated and entered into an analysis of variance (ANOVA) for repeated measures with compatibility (compatible vs. incompatible) as a within-subject factor and belief (human-like robot vs. machine-like robot) as a between-subject factor. The SSE was measured by subtracting RTs for compatible trials from RTs for incompatible trials. Subjects with a difference score of 2.5 SD below or above the group mean had to be



excluded from analysis (Müller et al., 2011b), which resulted in the exclusion of one subject. Prior to statistical RT analysis, all error trials (2.5%) were excluded. Because of the low number of error rates, which reflects the relative ease of a simple stimulus discrimination task, error rates were not analyzed further.

We found a significant main effect of compatibility,  $F(1,45) = 9.39, p = .004$ , partial  $\eta^2 = .17$ , indicating shorter RTs in compatible (337 ms) compared to incompatible trials (341 ms), confirming the presence of an overall SSE. A significant interaction between compatibility and belief,  $F(1,45) = 4.95, p = .03$ , partial  $\eta^2 = .10$ , indicated that the SSE was significantly larger in the human-like robot condition (8 ms),  $F(1,23) = 10.48, p = .004$ , partial  $\eta^2 = .31$ , compared to the machine-like robot condition (1 ms),  $F(1,22) = .56, p = .46$ , partial  $\eta^2 = .03$  (Figure 2). There was no significant main effect of belief,  $F(1,45) = 1.07, p = .31$ , partial  $\eta^2 = .02$ .

--- Figure 2 ---

### **Belief manipulation check**

To test whether the belief manipulation was successful, participants were asked to rate statements regarding the perceived intentionality of the robot's actions at the end of the experiment. The items were "The robot acted intentionally" and "The robot decided actively when to respond to a stimulus", which had to be rated on a five-point Likert Scale (0='strongly disagree', 4='strongly agree'). We calculated the average score of both items, as they seemed to measure the same construct (Cronbach's Alpha=.79). Participants in the human-like robot condition showed a significantly higher rating score than participants in the machine-like robot condition ( $M_{\text{human-like}}=2.32, M_{\text{machine-like}}=1.25, p < .01$ ) providing evidence that the belief manipulation was efficient.

## Discussion

Using a Social Simon Task that was shared between a human and a humanoid robot, we tested whether action co-representation as measured by the SSE does occur in a real world interaction situation with a robotic agent. Further, we tested if the amount of action co-representation can be modulated by the believed humanness of the robot's functional principle. We found a reliable and robust SSE, when the robot was described as functioning in a biologically inspired human-like way. When the robot was described as a purely deterministic machine-like agent the SSE was completely abolished. Critically, the SSE in the human-like robot condition was significantly larger than the SSE in the machine-like robot condition as indicated by a significant interaction of compatibility and belief. Even if the size of the SSE was relatively modest when interacting with a humanoid robot, it is comparable to that of other studies on the SSE measuring human-human interaction (e.g., Guagnano et al., 2010, Experiment 1: 7 ms; Liepelt et al., 2011: 9 ms; Sebanz et al., 2003, Experiment 1: 11 ms, Experiment 2: 8 ms).

These findings suggest that the human shared representational system is not solely tuned to biological agents. Action co-representation can occur in a real world interaction situation with a non-biological robotic agent. Further, our results suggest an essential role of top-down belief processes on action co-representation, and provide evidence for differences in action co-representation within the class of artificial agents depending on their assumed functional principle. In order to co-represent the actions of an artificial agent, it seems to be crucial to perceive the agent as functioning in a human-like or biologically inspired way.

A recent development in robotics is to produce artificial agents that look more and more human-like in order to facilitate interactions with humans (Kanda,

Miyashita, Osada, Haikawa, & Ishiguro, 2008; MacDorman & Ishiguro, 2006). The humanoid robot we used in our study had a rather non-human physical appearance. Nevertheless, we found evidence for action co-representation when participants attributed human-like cognitive processes to the robot. This suggests a critical role of top-down belief processes (Liepelt & Brass, 2010; Stanley et al., 2007), which may have been underestimated in previous research on biological tuning of the shared representational system, as well as in social robotics. When constructing a technical system that is able to interact with humans, one should not only consider a biologically inspired implementation of the form (head and body shape), or the motion (movement kinematics). One should also be aware of the observer's beliefs about a robot's functional principle, which may or may not match its actual functional principle. This is not to say that human-like physical appearance should not matter for action co-representation. One important direction for future research on human-robot interaction is how belief, form and movement kinematics may interact in affecting the amount of action co-representation.

Taken together, our results suggest that action co-representation is not exclusively tuned to biological agents. Action co-representation can also occur for real robotic agents, when one believes that the robot functions in a biologically inspired, human-like way, suggesting a vital role of top-down belief processes in human-robot interactions.

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**Figure Captions**

*Figure 1.* Experimental setup: *Social Simon Task* shared between a human and a humanoid robot.

*Figure 2.* Mean response times for compatible (light grey) and incompatible (dark grey) trials for the *human-like robot condition* (left) and the *machine-like robot condition* (right). Error bars represent standard errors of the mean differences. \*\*:  $p < .01$ , n.s.:  $p > .05$ .



*Figure 1*

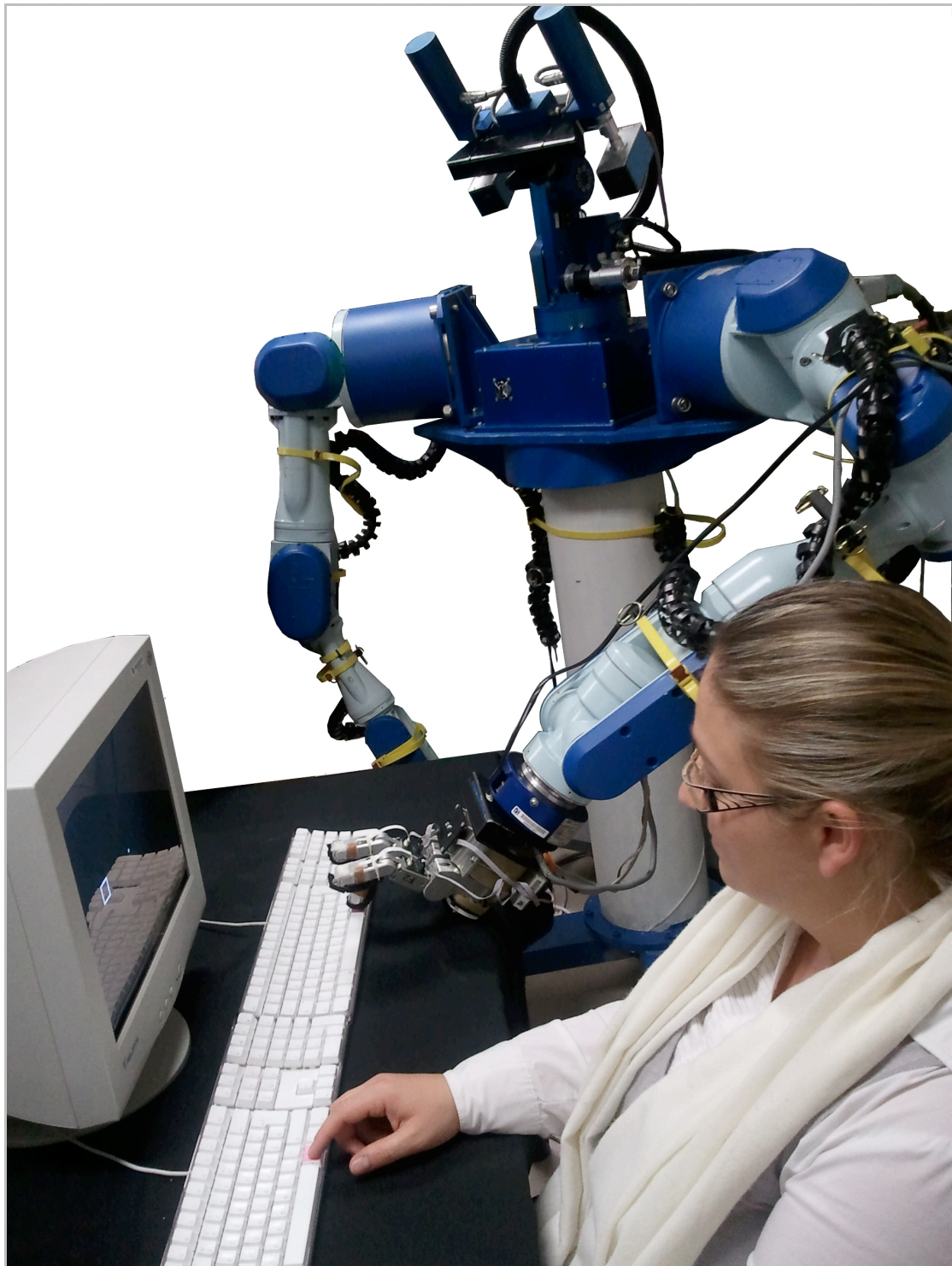


Figure 2

