Journal of Experimental Psychology:
Human Perception and Performance
2012, Vol. 38, No. 5, 1073–1077

0096-1523/12/$12.00 DOI: 10.1037/a0029493

OBSERVATION

When Humanoid Robots Become Human-Like Interaction Partners: Corepresentation of Robotic Actions

Anna Stenzel
University of Muenster

Eris Chinellato
Imperial College London and Jaume I University

Maria A. Tirado Bou
Jaume I University

Ángel P. del Pobil
Jaume I University and Sungkyunkwan University

Markus Lappe and Roman Liepelt
University of Muenster

In human–human interactions, corepresenting a partner's actions is crucial to successfully adjust and coordinate actions with others. Current research suggests that action corepresentation is restricted to interactions between human agents facilitating social interaction with conspecifics. In this study, we investigated whether action corepresentation, as measured by the social Simon effect (SSE), is present when we share a task with a real humanoid robot. Further, we tested whether the believed humanness of the robot's functional principle modulates the extent to which robotic actions are corepresented. 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. These findings suggest that humans corepresent the actions of nonbiological 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 corepresentation in human–robot interaction situations.

Keywords: social Simon effect, joint action, human–robot interaction

Supplemental materials: http://dx.doi.org/10.1037/a0029493.supp

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 nonspatial 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 response times (RTs) between spatially compatible and incompatible conditions is called the *Simon effect* (Simon & Rudell, 1967). The

This article was published Online First August 6, 2012.

Anna Stenzel, Markus Lappe, and Roman Liepelt, University of Muenster, Institute for Psychology, Muenster, Germany; Eris Chinellato, Imperial College London, Department of Electrical and Electronic Engineering, London, United Kingdom, and Jaume I University, Robotic Intelligence Laboratory, Castellón de la Plana, Spain; Maria A. Tirado Bou, Jaume I University, Robotic Intelligence Laboratory, Castellón de la Plana, Spain; Ángel P. del Pobil, Jaume I University, Robotic Intelligence Laboratory, Castellón de la Plana, Spain, and Sungkyunkwan University, Department of Interaction Science, Seoul, South Korea.

This research was supported by the European Commission Project FP7-ICT-217077-Eyeshots, the German Research Foundation project DFG LI 2115/1-1, and by World Class University program through the National Research Foundation of Korea funded by the Ministry of Education, Science and Technology Grant R31-2008-000-10062-0.

Correspondence concerning this article should be addressed to Roman Liepelt, University of Münster, Institute for Psychology, Fliednerstraße 21, 48149 Münster, Germany. E-mail: roman.liepelt@uni-muenster.de

Simon effect is absent when the participant has to respond to only one of the two stimuli disregarding the other (individual go/no-go 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* (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/no-go 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 corepresentation; that is, both participants cognitively represent the action, task, or both, 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 et al. (2011) proposed, that the content of corepresentation is the representation of whether and when the coactor has to respond. The coactor's response might represent a salient event, which 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 corepresentation 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. On the basis of the assumption that interacting with an agent in real time is fundamentally different compared with 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 nonbiological 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 nonhuman in its nature (Liepelt & Brass, 2010; Müller, Brass, et al., 2011; Stanley, Gowen, & Miall, 2007).

In this study, we tested whether humans do corepresent actions of a humanoid robot in a real-world interaction situation. Further, we investigated whether the magnitude of action corepresentation 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 corepresentation is sensitive to the intentionality attributed to an agent, we expected to find a larger SSE in the human-like robot condition compared with the machine-like robot condition. If, however, action corepresentation 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 corepresentation 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 Jaume I University participated in the experiment. Twenty-four were randomly assigned to the human-like robot condition (12 men, *M* age = 19.92 years, *SD* age = 2.17 years), and 24 were randomly assigned to the machine-like robot condition (12 men, *M* age = 20.38 years, *SD* 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-in. CRT monitor. The viewing distance was 60 cm. Responses were recorded with two keyboards placed on a table next to each other (see 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) (Chinel-

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

lato, Antonelli, Grzyb, & del Pobil, 2011) served as the coactor in a social Simon task (see Figure 1).

Stimuli and Procedure

Each trial began with the presentation of a fixation point (white dot, 0.4° × 0.4°) in the center of a black screen for 250 ms. Then, either a white square or a diamond (1.9° × 1.9°) appeared 8.0° 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. Afterward, 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 intertrial 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 or 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 (see 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 behavior 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 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-subjects factor. The SSE was calculated by subtracting RTs for compatible trials from RTs for incompatible trials. Participants with a difference score of 2.5 *SD* below or above the group mean had to be excluded from analysis (Müller, Kuhn, et al., 2011), which resulted in the exclusion of one participant. 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 with 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 with the machine-like robot condition (1 ms), $F(1, 22) = 0.56$, $p = .46$, partial $\eta^2 = .03$ (see Figure 2). There was no significant main effect of belief, $F(1, 45) = 1.07$, $p = .31$, partial $\eta^2 = .02$.

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 5-point Likert scale, ranging from 0 (*strongly disagree*) to 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* human-like = 2.32, *M* machine-like = 1.25,

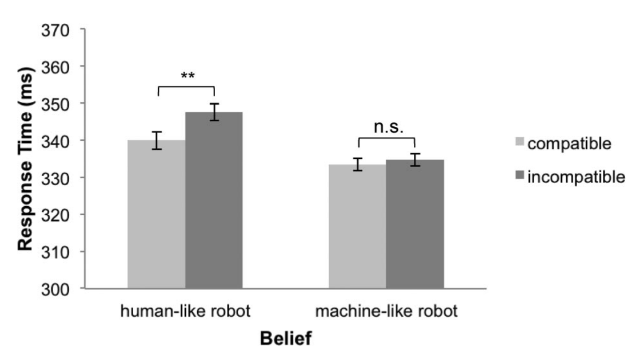

Figure 2. Mean response times for compatible (light gray) and incompatible (dark gray) trials for the human-like robot condition (left) and the machine-like robot condition (right). Error bars represent standard errors of the mean differences. ** $p < .01$. n.s. $p > .05$.

$p < .01$) 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 corepresentation as measured by the SSE does occur in a real-world interaction situation with a robotic agent. Further, we tested whether the amount of action corepresentation 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, and Experiment 2, 8 ms).

These findings suggest that the human shared representational system is not solely tuned to biological agents. Action corepresentation 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 corepresentation and provide evidence for differences in action corepresentation within the class of artificial agents depending on their assumed functional principle. In order to corepresent 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 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 nonhuman physical appearance. Nevertheless, we found evidence for action corepresentation 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 corepresentation. 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 corepresentation.

Taken together, our results suggest that action corepresentation is not exclusively tuned to biological agents. Action corepresentation 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.

References

Atmaca, S., Sebanz, N., & Knoblich, G. (2011). The joint flanker effect: Sharing tasks with real and imagined co-actors. *Experimental Brain Research, 211,* 371–385. doi:10.1007/s00221-011-2709-9

Atmaca, S., Sebanz, N., Prinz, W., & Knoblich, G. (2008). Action corepresentation: The joint SNARC effect. *Social Neuroscience, 3,* 410–420. doi:10.1080/17470910801900908

Chinellato, E., Antonelli, M., Grzyb, B. J., & del Pobil, A. P. (2011). Implicit sensorimotor mapping of the peripersonal space by gazing and reaching. *IEEE Transactions on Autonomous Mental Development, 3,* 43–53. doi:10.1109/TAMD.2011.2106781

Dolk, T., Hommel, B., Colzato, L. S., Schütz-Bosbach, S., Prinz, W., & Liepelt, R. (2011). How "social" is the social Simon effect? *Frontiers in Psychology, 2,* 84. doi:10.3389/fpsyg.2011.00084

Guagnano, D., Rusconi, E., & Umiltà, C. A. (2010). Sharing a task or sharing space? On the effect of the confederate in action coding in a detection task. *Cognition, 114,* 348–355. doi:10.1016/j.cognition.2009.10.008

Hommel, B., Colzato, L. S., & van den Wildenberg, W. P. M. (2009). How social are task representations? *Psychological Science, 20,* 794–798. doi:10.1111/j.1467-9280.2009.02367.x

Kanda, T., Miyashita, T., Osada, T., Haikawa, Y., & Ishiguro, H. (2008). Analysis of humanoid appearances in human-robot interaction. *IEEE Transactions on Robotics, 24,* 725–735. doi:10.1109/TRO.2008.921566

Kilner, J. M., Paulignan, Y., & Blakemore, S. J. (2003). An interference effect of observed biological movement on action. *Current Biology, 13,* 522–525. doi:10.1016/S0960-9822(03)00165-9

Lam, M. Y., & Chua, R. (2010). Influence of stimulus–response assignment on the joint-action correspondence effect. *Psychological Research, 74,* 476–480. doi:10.1007/s00426-009-0269-4

Liepelt, R., & Brass, M. (2010). Top-Down modulation of motor priming by belief about animacy. *Experimental Psychology, 57,* 221–227. doi:10.1027/1618-3169/a000028

Liepelt, R., von Cramon, D. Y., & Brass, M. (2008). What is matched in direct matching? Intention attribution modulates motor priming. *Journal of Experimental Psychology: Human Perception and Performance, 34,* 578–591. doi:10.1037/0096-1523.34.3.578

Liepelt, R., Wenke, D., Fischer, R., & Prinz, W. (2011). Trial-to-trial sequential dependencies in a social and non-social Simon task. *Psychological Research, 75,* 366–375. doi:10.1007/s00426-010-0314-3

MacDorman, K. F., & Ishiguro, H. (2006). The uncanny advantage of using androids in cognitive and social science research. *Interaction Studies, 7,* 297–337. doi:10.1075/is.7.3.03mac

Müller, B. C. N., Brass, M., Kühn, S., Tsai, C.-C., Nieuwboer, W., Dijksterhuis, A., & van Baaren, R. B. (2011). When Pinocchio acts like a human, a wooden hand becomes embodied. Action co-representation for non-biological agents. *Neuropsychologia, 49,* 1373–1377. doi:10.1016/j.neuropsychologia.2011.01.022

Müller, B. C. N., Kühn, S., van Baaren, R. B., Dotsch, R., Brass, M., & Dijksterhuis, A. (2011). Perspective taking eliminates differences in co-representation of out-group members' actions. *Experimental Brain Research, 211,* 423–428. doi:10.1007/s00221-011-2654-7

Schilbach, L., Wohlschlaeger, A. M., Kraemer, N. C., Newen, A., Shah, N. J., Fink, G. R., & Vogeley, K. (2006). Being with virtual others: Neural correlates of social interaction. *Neuropsychologia, 44,* 718–730. doi:10.1016/j.neuropsychologia.2005.07.017

Sebanz, N., Bekkering, H., & Knoblich, G. (2006). Joint action: Bodies and minds moving together. *Trends in Cognitive Sciences, 10,* 70–76. doi:10.1016/j.tics.2005.12.009

Sebanz, N., Knoblich, G., & Prinz, W. (2003). Representing others' actions: Just like one's own? *Cognition, 88,* B11–B21. doi:10.1016/S0010-0277(03)00043-X

Sebanz, N., Knoblich, G., & Prinz, W. (2005). How two share a task: Corepresenting stimulus-response mappings. *Journal of Experimental Psychology: Human Perception and Performance, 31,* 1234–1246. doi:10.1037/0096-1523.31.6.1234

Sebanz, N., Knoblich, G., Prinz, W., & Wascher, E. (2006). Twin peaks: An ERP study of action planning and control in coacting individuals. *Journal of Cognitive Neuroscience, 18,* 859–870. doi:10.1162/jocn.2006.18.5.859

Simon, J. R., & Rudell, A. P. (1967). Auditory S-R compatibility: The effect of an irrelevant cue on information processing. *Journal of Applied Psychology, 51,* 300–304. doi:10.1037/h0020586

Stanley, J., Gowen, E., & Miall, R. C. (2007). Effects of agency on movement interference during observation of a moving dot stimulus. *Journal of Experimental Psychology: Human Perception and Performance, 33,* 915–926. doi:10.1037/0096-1523.33.4.915

Tsai, C.-C., & Brass, M. (2007). Does the human motor system simulate Pinocchio's actions? *Psychological Science, 18,* 1058–1062. doi:10.1111/j.1467-9280.2007.02025.x

Tsai, C.-C., Kuo, W.-J., Hung, D. L., & Tzeng, O. J. L. (2008). Action co-representation is tuned to other humans. *Journal of Cognitive Neuroscience, 20,* 2015–2024. doi:10.1162/jocn.2008.20144

Wenke, D., Atmaca, S., Holländer, A., Liepelt, R., Baess, P., & Prinz, W. (2011). What is shared in joint action? Issues of co-representation, response conflict, and agent identification. *Review of Philosophy and Psychology, 2,* 147–172. doi:10.1007/s13164-011-0057-0

Received December 1, 2011
Revision received May 15, 2012
Accepted May 17, 2012 ■