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Non-anthropomorphic robots as social entities on a neurophysiological level[☆]

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ABSTRACT

The mirror-neuron-system (MNS) is involved in the perception of actions of humans and anthropomorphic robots. The current study investigates whether social interaction with a non-anthropomorphic robot is sufficient for a response of the MNS.

Fifty-seven participants observed movements of a vacuum cleaning robot before and after it was handled by its owner. The robot was either humanized, being treated aggressively ($n = 30$), or it was treated as an object ($n = 27$). Electroencephalographic mu-activity is used as an index of MNS activity, because both are inversely correlated. Activity within the 8–13 Hz band was measured at central (mu-activity) and occipital (alpha-activity) electrodes. Further, the level of aggressiveness displayed by the robot's owner, and the participants' compassion were rated on visual analog scales.

Mu-activity showed medium-sized correlations with rated aggressiveness and compassion: The more aggressive the action towards the robot was perceived ($r = -.379$, $p = .004$), and the more compassion was felt for the robot ($r = -.339$, $p = .010$), the less pronounced mu-activity was at electrode C3 in response to the robot's movement.

Thus social interaction with a non-anthropomorphic robot might establish the robot as a social entity and is sufficient to activate the human MNS.

1. Introduction

Anecdotal reports indicate that consumers name and attribute personalities to their cleaning robots, despite robots being inanimate objects ("My Roomba is Rambo", Sung, Guo, Grinter, & Christensen, 2007). Current research suggests that social identity of an object can be established through social actions towards the object. A recent study suggests that mind is attributed to robots when a human performs harmful actions towards the robot. As the harmful actions of the human are regarded as social, the targets of the action are regarded as social too and therefore also the counterparts (Ward, Olsen, & Wegner, 2013). As a consequence, social identity is ascribed to the robot. Similarly, the observation of violent behavior against a human and a zoomorphic robot (dinosaur) activates comparable brain regions associated with emotional distress (Rosenthal-von der Pütten et al., 2014). However, it remains open whether social actions towards a non-anthropomorphic/non-zoomorphic robot are sufficient to establish the robot as a social entity.

Oberman, McCleery, Ramachandran, and Pineda (2007) proposed the activation of the human mirror-neuron-system as a 'neurophysiological Turing Test' (testing a machine's ability to be indistinguishable from an animate being) for the evaluation of robot movements. Phylogenetic theories propose that the mirror neuron system evolved through natural selection, supporting socio-cognitive processes (e.g. Bonini & Ferrari, 2011; Rizzolatti & Sinigaglia, 2010). The mirror neuron system is not only thought to map observed motor actions to one's own motor system, but also to code the goal of an action and therefore facilitates action understanding (Rizzolatti & Sinigaglia, 2010). Several studies show that the mirror neuron system is activated by the perception of movements of anthropomorphic robots (e.g. Gazzola, Rizzolatti, Wicker, & Keysers, 2007; Oberman et al., 2007; Urgen, Plank, Ishiguro, Poizner, & Saygin, 2013).

In order to explore whether aggressive behavior against a non-

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anthropomorphic robot can alter the activity of the mirror-neuron-system, the methods of Hoenen, Schain, and Pause (2013) were adopted. The authors showed that the response of the human mirror neuron system to observed actions is stronger when the participants are primed with a sad story about the observed actor.

Here it is tested, whether emotional priming (by means of aggressive behavior towards the robot) leads to a stronger activity of the mirror neuron system in response to movements of a robot. A robotic vacuum cleaner was chosen, since this type of robot in itself should not elicit activity of the mirror neuron system, because it lacks an anthropomorphic/zoomorphic shape, biological kinematics, and produces meaningless movements (e.g. Gazzola et al., 2007; Krach et al., 2008). Electroencephalographic mu-activity was used to quantify the activity of the human mirror neuron system. Mu-activity, oscillations in the 8–13 Hz range, measured at central electrodes (Pineda, 2005) is inversely correlated with the activity of the mirror neuron system (Arnstein, Cui, Keysers, Maurits, & Gazzola, 2011) and can be modulated by social processes like empathy, and personal involvement (Hoenen et al., 2013; Perry, Stein, & Bentin, 2011).

It is hypothesized, that mu-activity during observation of robot movement is less pronounced, the more aggressive the situation was perceived and the more compassion was felt for the robot. Alpha-activity (range: 8–13 Hz) above occipital areas was used to control for effects of attentional processes (Woodruff, Daut, Brower, & Bragg, 2011).

2. Method

2.1. Participants

A total of 64 right-handed (assessed using Annett, 1967) volunteers participated in the experiment. All participants reported to be healthy, and free of neurological or psychiatric conditions. Due to recording problems ($n = 2$) and strong motor activity during EEG-recording ($n = 1$) three participants were excluded. Furthermore, two participants were excluded because they rated the aggressive interaction as not aggressive (>3 *SD* below group mean) and two participants were excluded, because they showed an error rate of more than 25% in a task controlling for attention (see 2.3).

Participants were randomly assigned to the two experimental conditions. The final sample consisted of 23 females and 7 males ($n = 30$) in the aggression condition and 19 females and 8 males ($n = 27$) in the control condition. Participants had a mean age of 23.2 years ($SD = 4.4$; range: 19–37) and age did not differ between groups ($p > .500$). Groups did not differ regarding their empathic abilities (see Table 1). Two participants in the aggression group and three participants in the control group reported to have experience with vacuum cleaning robots.

All participants gave written informed consent and were compensated with course credit or € 12. The experiment was approved by the ethics committee of the Faculty of Mathematics and Natural Sciences of the Heinrich-Heine-University Düsseldorf.

Table 1
Comparison of participant's empathic abilities between experimental conditions.

	Control condition	Aggressive condition		
SPQ scale	*M* (*SD*)	*M* (*SD*)	*t*(55)	*p*
Fantasy	14.7 (2.6)	13.8 (3.0)	1.27	.210
Empathic Concern	15.2 (2.6)	14.7 (2.3)	0.69	.491
Perspective Taking	13.5 (3.4)	14.8 (2.7)	1.62	.110
Personal Distress	11.4 (3.0)	11.2 (2.9)	0.31	.757

Note: SPQ = Saarbrueck Personality Questionnaire.

2.2. Materials

The stimuli consisted of self-made video-clips (duration 3:49 min, 50 frames/s, resolution 1440 × 1080 pixel, XVID-Codec), showing a moving remote controlled robotic vacuum cleaner (Roomba, 531, iRobot Corp., MA), shown from bird's eye view (see Fig. 1). The video starts by showing the robot in a stationary position in the center of the screen. The owner then enters the frame, switches the robot on and then leaves the frame. The robot then moves on a predefined trajectory and stops in the middle of the screen (duration: 90 s; pre-interaction). Then, the owner enters again, inspects and repairs the robot, and places it in the center of the screen (duration: 27 s; interaction). The robot is switched on again and the owner leaves. Afterwards, the robot begins moving, following the same predefined trajectory as before (duration: 90 s; post-interaction).

For both the control and the aggression condition, the same visual material was used. Only the audio track during the action towards the robot was altered between conditions. In the control condition, the owner wondered why the robot was not working and evaluated possible errors. In the aggression condition, the owner verbally harassed the robot because it stopped working, addressing it like a human. Only the body but not head or face of the owner were visible.

As baseline, a self-made video-clip (duration: 90 s, 50 frames/s, resolution 1440 × 1080 pixel, XVID-Codec) was used, showing a circle moving on a trajectory matching the movement of the robot. Diameter and color of the circle and color of the background were matched to the average color and diameter of the robot and its background.

The robot was introduced with pictures, showing the robot cleaning an apartment and a short text explaining that the robot acts autonomously.

The videos were presented on a 20 inch TFT monitor (resolution: 1680 × 1050 pixel; model: AL 2023W; Acer Inc., Taiwan) at a distance of 75 cm to the participant's eyes. Audio was presented via in-ear headphones (model: Er-4P; Etymotic Research Inc., IL). Presentation 16 (Neurobehavioral Systems Inc., CA) was used to control the presentation of the stimuli.

Aggressiveness and realism of the human–robot interaction and compassion felt for the robot were rated on computer-based visual analog scales (length 18.5 cm; 0 = *not at all*, 100 = *very much*). Additionally, participants completed the *Saarbrueck Personality Questionnaire on Empathy* (SPQ, a German adaptation of the Interpersonal Reactivity Index; Davis, 1983; Paulus, 2009), a self-report of empathic abilities.

2.3. Procedure

Prior to the EEG-recording, the participants were instructed to relax, and to blink and move as little as possible in order to minimize artifacts. Then, participants were asked to watch the video depicting the circle (baseline). In order to ensure that participants attended to the circle, they were asked to silently count the number of directional shifts performed by the circle, and to indicate the number of shifts after the video stopped. Then participants read the introduction of the robot and then watched the video of the robot. Again, participants were asked to count the number of directional shifts. Afterwards, participants evaluated the interaction (aggressiveness, realism, compassion) and filled in the SPF. The sequence of the experiment is depicted in Fig. 1.

2.4. EEG recording and analysis

EEG was recorded from 22 Ag/AgCl sintered electrodes