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Imagine how to behave: the influence of imagined contact on human–robot interaction

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Imagined contact (IC), that is, mentally simulating an interaction with an outgroup member, reduces negative attitudes towards outgroup members, increases contact intentions, and reduces intergroup anxiety in human–human intergroup context. Our experiment tested the effectiveness of IC with a robot to improve human–robot interaction (HRI). Social psychological literature suggested that IC provides a behavioural script for an interaction. Hence, an imagined scenario similar to a real contact scenario should be more effective in eliciting the aforementioned positive effects. We therefore examined the effect of similarity between IC with a robot and the following actual HRI on interaction perception, and behaviours towards the robot. High similarity was expected to lead to a more positive perception of HRI and more positive interaction behaviour towards the robot (e.g. more social behaviour). Results showed that perceived HRI quality was evaluated more positively and participants displayed more social behaviour towards the robot when the imagined task resembled the HRI that followed, compared to when it did not resemble the subsequent HRI. When controlling for covariates, the effects on number of social behaviours and perceived interaction quality remained significant, however, there was no effect on the total amount of time spent producing social behaviours.

This article is part of the theme issue 'From social brains to social robots: applying neurocognitive insights to human–robot interaction'.

1. Introduction and related work

Even though robots potentially offer a wide range of assistive functions to support humans (e.g. at the workplace, in rehabilitation, in schools, and within the home), many people react with anxiety and fear towards them (e.g. [1,2]). This may have a negative effect on behavioural responses during human–robot interaction (HRI), for example, by making people more reluctant to communicate with robots [1,2]. The influence of negative attitudes and robot anxiety was also observed in specific fields of deployment: for instance, negative attitudes towards robots have a negative impact on the willingness to learn with an educational robot [3] and on the willingness to communicate with robots in general [4,5]. Thus, as negative attitudes towards and fear of robots influence behaviour towards robots, the present study focused on behaviour towards robots in HRI while controlling for effects of robot-related attitudes.

In psychology, two approaches to measure attitudes are prominent: attitudes can be measured directly via self-reports, or indirectly, e.g., via reaction times. However, self-report measures might be biased by self-presentation and social desirability issues, that is, the desire to give a good impression or to solve a given task in the supposedly correct or acceptable way [6]. Indirect attitude measures serve as a solution for these problems: they are much less likely to be biased, as participants are not directly asked for their attitudes [7,8]. One further advantage of using indirect attitude measures concerns the relationship between attitudes and different aspects of behaviour. It has been shown that implicit attitudes influence automatic behaviour to a greater extent than explicit attitudes,

whereas explicit attitudes influence deliberate behaviour to a greater extent than implicit attitudes (e.g. [9,10]). However, despite the many good reasons for using both direct and indirect attitude measures in the context of social robotics, indirect attitude measures have been scarcely administered in this area of research (for exceptions, see [11] and [12]). To control for influences of both implicit and explicit attitudes towards robots on interaction behaviour, we included both types of measurement as covariates in this study. However, our core research interest was focused on how to change interaction behaviour in HRI by using imagined contact (IC), in order to affect HRI positively.

To tackle this issue, we turned to social psychological intergroup literature which suggests IC as a possible solution.

IC has been defined as the 'mental simulation of a social interaction with a member or members of an outgroup category' [13, p. 234]. It represents an effective intervention to improve attitudes towards social outgroups [14,15]. Furthermore, IC increases the willingness to interact with outgroup members, reduces intergroup anxiety [15,16], and, on the behavioural level, improves approach behaviour towards outgroup members [17]. Miles and Crisp [18] have conducted a meta-analysis with more than 70 studies that documented these beneficial effects of IC. Therefore, IC might also bear the potential to improve robot-related evaluations and behaviour in HRI. Only few previous studies have tested IC in the context of social robots with regards to attitudes and the respective findings presented a rather mixed picture (e.g. [19–21]): for example, Kuchenbrandt and Eyssel have demonstrated that independent of content of the imagination, IC with a robot improved robot-related attitudes [19]. In turn, results by Wullenkord and Eyssel [20] have shown that IC with a robot did not change robot-related attitudes significantly. However, more recently, Wullenkord *et al.* have found that imagined robot contact was effective in reducing negative emotions towards a robot, but once more, IC did not change robot-related attitudes [21]. Considering these mixed results, it remains unclear which psychological processes are responsible for the efficacy of IC. Furthermore, the previous studies did not investigate the impact of IC on real interactions between humans and social robots. Thus, it has not been tested yet whether IC would improve HRI quality by changing how people experience HRI and how they actually behave towards a robot.

Previous research has postulated that IC would provide a 'behavioural script' for contact situations (e.g. [22–24]). The idea of behavioural scripts was based on script theory by Abelson [25,26]. A script is defined as 'a schematic conception [. . .] that guides our understanding of the situation and our behaviour in it by preparing us for the next scenes' [22, p. 294]. If indeed, IC would provide a behavioural script for the imagined situation, it should positively influence both verbal and nonverbal behaviour exerted during HRI and perceived HRI quality. A 'script', giving participants a schematic idea of what to expect within an interaction with a robot, should then guide the participants behaviour during the actual HRI, providing a repertoire of interaction behaviours, and making them feel more at ease with the interaction in general. Its positive effects should be stronger as a function of how applicable the script is for the given situation. We thus assumed that the similarity between the IC and the real contact situation would be crucial to obtain positive effects of IC on HRI and perceived HRI quality. Therefore, our experimental hypotheses were as follows: first, an IC task that was highly similar to a subsequent HRI situation should result in a more positive rating of the interaction compared to an IC situation that was low in similarity to the subsequent HRI (H1); second, imagining contact that was highly similar to the following HRI should lead to more positive (verbal and nonverbal) interaction behaviour towards the robot compared to an imagined situation that was marked by low similarity (H2).

2. Method

(a) Design and sample

The experiment was designed as a between-subjects design that manipulated similarity (low versus high) between the IC and the subsequent actual interaction with a robot. Participants were recruited using flyers and face-to-face recruitment on a German university campus. They were randomly assigned to the experimental conditions, with gender being counterbalanced. A power analysis with G*Power with an estimated medium-sized effect ($d = 0.5$) showed that 176 participants would be necessary to have 95% statistical power. Unfortunately, owing to the complex and time-consuming nature of the study, as well as the extensive preparation of the video data for analyses, such a high number was beyond scope. For the experiment, we thus collected data from 20 males and 20 females ranging in age between 19 and 40 years ($M = 23.78$, s.d. $= 4.52$). Outlier analysis of the variables used in the study showed no need to exclude any participants. Thirty people were German native speakers, while 10 had reported other mother tongues. Sixteen participants indicated that they had already participated in different social robotics studies, whereas 24 individuals did not report prior robot experience.

(b) Procedure

The double-blind study was approved by the Bielefeld University Ethics Board. Double blind means that participants did not know which condition they were assigned to and the experimenter did not know which condition he/she assigned the participants to, either. In the beginning of the experiment, participants gave informed consent to participation and video recording of their interaction with the robot. They were told that the study would test the impact of their imagination on subsequent HRI and their attitudes. Afterwards, they were seated in front of a laptop and read a short description of service robots as some of the attitude measures referred to service robots. This was followed by the imagination task. After the imagination, they filled out the dependent attitude measures and started the interaction with the robot NAO. Then participants evaluated the interaction and gave their demographic information. Upon leaving the laboratory, participants were debriefed in written form, they were reimbursed with course credit or € 3 and a chocolate bar.

(c) Independent variable: imagined contact

We experimentally manipulated the similarity of the IC and the subsequent HRI, resulting in two scenarios that were either low or high in similarity compared to the successively scheduled HRI with the robot NAO. In the high similarity condition, the imagination task was formulated to mirror the HRI with NAO. Accordingly, participants were instructed as follows: 'imagine you would play a memory game with the NAO robot, which is seated in front of you. You uncover your cards and, taking turns, it instructs you to uncover cards on its behalf. When all pairs are found, the game is over, and the robot asks you if you would like to play another round.' In the low similarity condition, the imagination consisted of a standard scenario that has already

been used in previous experiments by [27]. It depicted the NAO as an assistant at home. It was chosen as the control scenario because previous research has shown that it did not evoke different emotions or led to a different imagination quality compared to the other scenarios used by [27]. Instructions read as follows: 'imagine you had a NAO robot at your home. We are interested in how NAO could help and support you. Imagine for example that the NAO helps and supports you with tasks, that you talk to each other etc.'

Previous research by Wullenkord and Eyssel [20] has shown that the amount of detail in an imagination scenario did not influence the effects of IC on robot attitudes. In their study, the authors used a restaurant scenario that was described either with a low versus high amount of detail. In the 'high detail condition', the interaction with the robot was described meticulously, including the course of the interaction from start to finish, what was discussed during interaction, and a description of the robot's behaviour. In the 'low detail condition', the interaction was described in general terms, referring to the fact that the participant and the robot would engage in a short and pleasant interaction. As in the present study, the amount of details presented was vastly different, and the scenarios used by [20] were pretested extensively to make sure that participants indeed experienced a different amount of detail in the different conditions. Accordingly, even though the scenario in the low similarity condition in the present study appeared less detailed compared to the scenario in the high similarity condition, the difference in amount of details should not influence the results regarding HRI, but the results should be because of the differences in similarity. Participants were instructed to imagine the task for 90 s with their eyes closed as closing the eyes during imagination enhances the IC effect [28]. The duration was set to 90 s as previous experiments showed that the time was sufficient to read the instructions and imagine the task in detail. Furthermore, participants started to ignore the instructions and looked around the room when imagination time was longer. After 90 s, an audio signal indicated that the imagination task was finished, and participants proceeded with the robot interaction task.

(d) Human–robot interaction with NAO

NAO is a humanoid robot by SoftBank Robotics. It is 57.4 cm tall and weights 5.2 kg. NAO has 25 degrees of freedom and is equipped with tactile sensors, directive microphones, high definition cameras, loudspeakers as well as infrared sensors.

To realize an HRI scenario, participants played a memory game with the NAO robot. They were seated in front of NAO, the game was explained in detail, and participants had the opportunity to get instructed several times if needed. The complete interaction was videotaped. Participants were told that they would take turns turning cards for themselves and on behalf of the robot. The rationale behind this procedure was simply based on the fact that NAO's hands are not suitable for picking up cards from the table and for turning them around. The robot would therefore explain to participants that its arms were too short to pick up the cards. It instructed them in each turn which cards they were supposed to turn (e.g. 'please turn the left card in the second row.'). To keep the trials as similar as possible, the cards would be distributed as shown in figure 1 for every trial.

The NAO robot was operated by a trained experimenter via Wizard-of-Oz, meaning the robot appeared as if he would function autonomously and the participants did not know that the experimenter in fact controlled the robot. The experimenter would sit behind a partition panel during the interaction task. A webcam made sure that the experimenter could see what the participants were doing. The different behavioural response options were pre-programmed in CHOREGRAPHE and the

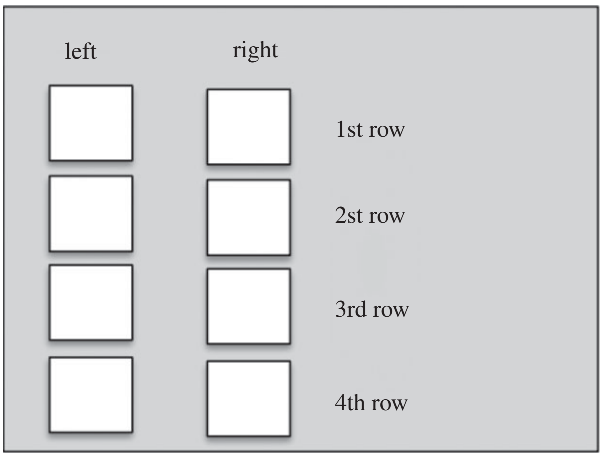

Figure 1. Work space of the memory game task.

experimenter chose robot behaviour that was suitable for the given situation. The behaviour to choose from included verbal explanations about the memory game itself, instructions regarding which card to uncover next, the robots' reactions upon winning or losing a round, and inquiries as to whether participants wanted to play another round. To make sure that unexpected participant behaviour (e.g. asking questions that are beyond NAOs response options) would not require the termination of the experimental session, 'emergency behaviours' were included in NAO's response repertoire. For example, NAO would say that it did not understand the participant and wanted to continue playing, or that it did not understand and accordingly, NAO asked the participant to call the experimenter. Furthermore, the experimenter had the possibility to react to cheating by having the robot ask the participant to stick to the rules. However, this was not needed during the experiment as all participants played in a fair manner. The game lasted for a maximum of four rounds. To make the rounds shorter and to provide participants with the opportunity to play multiple rounds, only eight cards were included in the game, resulting in four pairs, as seen in figure 1. A round ended when all pairs were found and could result in either the participant winning, NAO winning, or a draw. After each round, NAO asked if participants wanted to play another round until the maximum of four rounds was reached. Then, NAO told participants that the interaction was over, and that the experimenter would tell them how to proceed.

(e) Video coding

The interaction between the participant and the robot was video-recorded. Participants were aware of the video recordings and consented before the start of the experiment. The video data were coded according to a scheme which was developed based on two taxonomies of behaviour. First, Mehrabian [29] has introduced a taxonomy of verbal and nonverbal behaviours which are associated with attitudes and reactivity towards an interaction partner [29]. It includes behaviours such as facial expressions (e.g. smiles), gestures (e.g. nodding, head shakes), touch of one's own body, eye contact, body signs of comfort and relaxation as well as verbal utterances. Complementing this taxonomy, we referred to Patterson's work [30]. This encompassed a taxonomy of nonverbal behaviours, including distance, gaze, touch, posture, movements, self- and object manipulation, pupil reactions, and several other categories. Taken together, these two taxonomies formed the theoretical basis for the video coding scheme to analyse our qualitative data. To build a baseline, four randomly selected videos of the interaction with the NAO robot were inspected by two research assistants as well as two research interns from our laboratory. They compared the taxonomies suggested in the

literature with the behaviours that were displayed during the memory card game. This was relevant to reduce the taxonomies to categories relevant for the given video data. In some cases, several different behaviours were summarized under a category, for example social behaviour towards the NAO encompassed behaviours such as nodding or frowning. This initial coding scheme was then used to train our annotator, another research intern from the laboratory, and to code two more videos. Subsequently, the coding scheme was adapted and refined according to his remarks. The behaviour was coded by the annotator based on this final coding scheme using ELAN (Max Planck Institute for Psycholinguistics). The data were then pre-processed by an algorithm that counted the number of annotated behaviours, and computed the mean duration of each behaviour and of the behaviour overall.

(f) Dependent measures

Dependent measures were assessed using a questionnaire that included items on perceived interaction quality as well as participants' interaction behaviour during HRI. Interaction quality of the memory game task [27] was measured with items like: 'I would have liked to play with the NAO for longer.' or 'I would have preferred to play with a human.' Responses were given on seven-point Likert scales, with 1 indicating low self-reported interaction quality and 7, indicating high perceived interaction quality.

Regarding behaviour assessment during HRI with NAO, we used a coding scheme that encompassed nine categories to evaluate participants' interaction behaviour. Firstly, the duration and number of verbal utterances towards the robot were measured. Secondly, passivity during the game was evaluated. This category referred to the number of times the experimenter had to instruct the participant to proceed with the game. Furthermore, perceived wellbeing of the participant during the interaction was coded, operationalized by the participant showing signs of discomfort, for example, folding the arms, turning away from the robot, creating distance by moving away from the table, etc. Additionally, number and duration of smiles towards the robot were coded as well as eye contact with the robot. Finally, the number of rounds won by the participant, and social behaviour towards the robot were measured, which was operationalized as nonverbal communication behaviour like nodding and frowning.

(g) Covariates

Several covariates were included in the design of the present experiment to control for their impact on the experimental results. We aimed to make sure that potential changes in perceived interaction quality and interaction behaviour were owing to the similarity between imagination task and the interaction scenario with NAO, and not owing to changes in robot-related attitudes or differences in imagination quality. Therefore, we analysed the results with as well as without controlling for effects of these covariates. Participants reported perceived clarity and vividness of their imagination (e.g. 'the imagination task was difficult for me.'). Furthermore, we captured their emotions during the imagination (e.g. 'if you were in the situation you imagined, how irritated would you be?'). We also controlled for robot-related attitudes using the Negative Attitudes towards Robots Scale (NARS) [31] and the Robot Anxiety Scale (RAS) [32], we assessed their liking and acceptance of service robots [33], as well as contact intentions and willingness to interact with robots [34].

Additionally, we included an indirect attitude measure to assess the relative preference of humans over robots. In this regard, participants completed the implicit association test (IAT) [35], a reaction time measure which captures the strength of associations between concepts. Finally, prior robot experience and

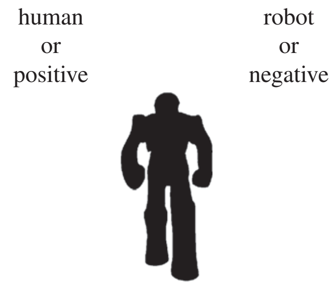

Figure 2. Screenshot from the IAT task.

demographic information (e.g. gender, nationality etc.) were measured to control for these variables.

(h) Implicit association test

The IAT is an indirect attitude measure developed by Greenwald *et al.* which uses reaction times to assess the preference of one concept over another [35]. More specifically, in the case of this study, the IAT captured the relative preference for humans over robots. Our stimuli consisted of positive and negative words such as 'joy', 'wonderful', and 'death' or 'disgusting' and pictures. The stimuli consisted of black silhouettes of human beings and robots, taken from [36]. Participants were instructed to categorize these stimuli via button press. In the beginning, practice trials were implemented to make sure that participants were familiar with the procedure. The task in the first block of test trials was to categorize positive words and human pictures on one button (the 'X' key) and negative words and robot pictures on another button (the 'M' key). Afterwards, the order was reversed and accordingly, participants had to categorize positive words and robot pictures on one key, and negative words and human pictures on the other key. Again, we implemented some practice trials in the beginning to train participants. Figure 2 shows a screenshot from the IAT task.

(i) Implicit association test scoring

To prepare the IAT data for analyses, a *D* score was computed using the *D*-algorithm by [37]. The *D* score reflects a relationship between the reaction times in 'consistent' trials (i.e. trials in which human pictures were paired with positive words and robot pictures with were paired with negative words), and the reaction times in 'inconsistent' trials (i.e. the trials in which human pictures were paired with negative words and robot pictures were paired with positive words, respectively). If this score is significantly different from zero, this means that participants showed a preference of one concept over the other. In the context of our experiment, this would imply that participants preferred humans over robots. If the score is not different from zero, both concepts are evaluated equally positive or negative, respectively.

3. Results

(a) Preliminary analyses

To gain insights into the psychometric characteristics of the measures used in the present research, mean values and reliabilities were computed (table 1). All reliabilities ranged from acceptable to good, respectively, with $\alpha = 0.72$ for liking and $\alpha = 0.89$ for contact intentions. Intraclass-correlations (ICCs), which in this case represent the interrater reliabilities for the behavioural measures obtained through the video analysis, ranged from ICC $= 0.72$ for the duration of smiles shown by the participants, to ICC $= 0.84$ for perceived wellbeing of the participants, which was acceptable as well.

Table 1. Means, standard deviations and reliabilities of the dependent measures and covariates. (Note. Duration behaviours in ms. Verbal, verbal utterances; social, social behaviours. Covariates are displayed in italic font.)

scale	*M*	s.d.	Cronbach's α	intraclass-correlation
willingness to interact	4.89	0.94	0.75	—
RAS	3.41	0.94	0.84	—
NARS	3.46	0.97	0.81	—
contact intentions	4.69	1.26	0.89	—
liking	4.47	1.06	0.72	—
acceptance	2.76	1.05	0.84	—
IAT	0.44	0.37	0.77	—
interaction quality	5.37	1.09	0.81	—
$\text{duration}_{\text{verbal}}$	15384.15	17752.51	—	0.75
$\text{number}_{\text{verbal}}$	16.25	14.90	—	0.75
$\text{duration}_{\text{smiles}}$	50614.15	40593.64	—	0.75
$\text{number}_{\text{smiles}}$	13.95	8.93	—	0.72
passivity	2.95	9.18	—	0.80
rounds won	0.15	0.43	—	1.0
wellbeing	5.20	1.22	—	0.84
eye contact	4.13	0.79	—	0.71
$\text{duration}_{\text{social}}$	26558.75	17608.84	—	0.76
$\text{number}_{\text{social}}$	18.85	9.60	—	0.77

(b) Main analyses

We were interested in the effects of IC on HRI. More specifically, our experiment was designed to examine the effect of the similarity between an IC task (low versus high) on a subsequent HRI. We predicted that given high similarity between IC and HRI, participants would rate the HRI more positively compared to low similarity between IC and HRI (H1). Secondly, high similarity between IC and HRI would lead to more positive (verbal and nonverbal) interaction behaviour, compared to low similarity between IC and HRI (H2).

(c) Analyses without covariates

To test hypothesis 1, a *t*-test was computed using the similarity of the imagination (low versus high) as the independent variable, and the perceived interaction quality as the dependent variable. There was a significant effect of similarity on perceived interaction quality, $t_{38} = 2.24$, $p = 0.03$, $d = 0.72$. Participants who had imagined a situation that was highly similar to the subsequent HRI, rated the interaction more positively ($M = 5.73$, s.d. = 1.11) than participants who had imagined a task low in similarity ($M = 5.00$, s.d. = 0.95). Figure 3 illustrates these findings.

A second *t*-test was conducted to test hypothesis 2, which predicted that high similarity of imagination and HRI would lead to more positive behaviour during HRI, Again, the similarity between IC and the interaction was used as the independent variable and the behavioural measures were used as dependent variables. The *t*-test showed a significant and large effect of similarity on number of social behaviours towards NAO ($t_{38} = -2.37$, $p = 0.02$, $d = 0.75$). That is, participants who had imagined a scenario that was high in similarity to the actual HRI showed more social behaviours ($M = 22.25$,

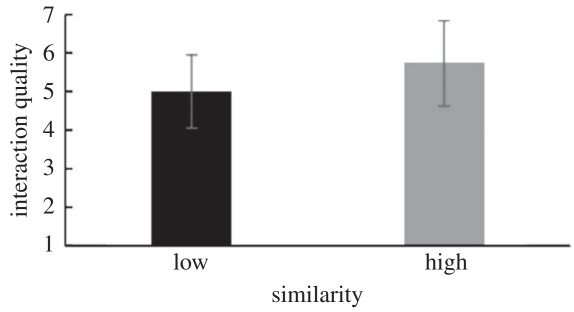

Figure 3. Perceived interaction quality as a function of similarity between IC and HRI.

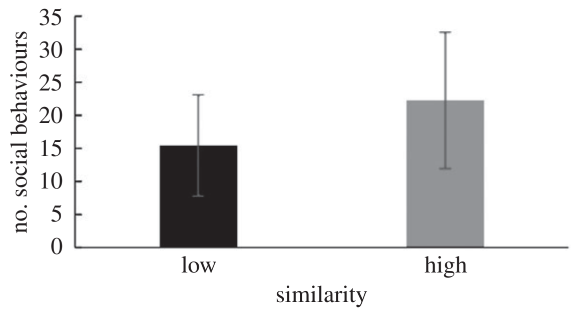

Figure 4. Number of social behaviours as a function of similarity between IC and HRI.

s.d. = 10.31) than participants who imagined a scenario low in similarity to the actual HRI ($M = 15.45$, s.d. = 7.66). The effect is displayed in figure 4. A marginally significant effect of similarity was obtained for duration of social behaviours towards NAO, $t_{38} = -1.74$, $p = 0.09$, $d = 0.55$. Participants in the high similarity condition showed a longer duration of

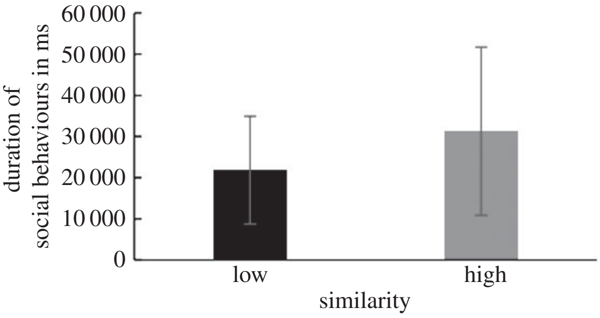

Figure 5. Duration of social behaviours as a function of similarity between IC and HRI.

social behaviours ($M = 31291.15$, s.d. $= 20443.41$) than in the condition with low similarity ($M = 21826.35$, s.d. $= 13091.24$). Figure 5 shows these results. They support hypothesis 2 regarding nonverbal interaction behaviour. The part of hypothesis 2 predicting differences in verbal interaction behaviour could not be supported.

(d) Analyses with covariates

To make sure that our results were in fact owing to our experimental manipulation rather than biased by covariates, we decided to conduct an additional analysis of covariance (ANCOVA). According to the principle of parsimony [38], covariates that do not significantly influence the dependent measures in the first place are eliminated from the ANCOVA. The IAT *D*-score differed significantly from 0 ($M = 0.44$, s.d. $= 0.37$, $p < 0.001$), indicating that, in line with our prediction, the reaction times revealed an implicit preference for humans over robots. However, the IAT did not serve as a significant covariate and was therefore removed from the ANCOVA. Thus, the following covariates remained in the analysis: nationality, robot experience, gender, imagination quality, and emotions during the imagination. We computed the ANCOVA including condition as an independent variable and interaction behaviour as well as perceived interaction quality as dependent variables and controlled for the aforementioned covariates. Results revealed an effect of similarity on perceived interaction quality ($F_{1,33} = 5.85$, $p = 0.02$, partial $\eta^2 = 0.15$) and on number of social behaviours ($F_{1,33} = 7.25$, $p = 0.01$, partial $\eta^2 = 0.18$). As before, participants who imagined a situation similar to the subsequent HRI reported a higher perceived interaction quality ($M = 5.75$, s.d. $= 0.98$) and a higher number of social behaviours ($M = 22.51$, s.d. $=$ 8.46) than participants who imagined a situation low in similarity to the HRI situation ($M = 5.0$, s.d. $= 0.98$ for perceived interaction quality and $M = 15.19$, s.d. $= 8.46$ for number of social behaviours, respectively). No other significant effects of similarity were obtained.

4. Discussion

The widespread deployment of robots in various societal contexts may be hindered by fears and anxiety related to robots, among other factors. Previous research was inspired by social psychology and has tackled this issue by trying to improve negative robot attitudes and to reduce robot anxiety by implementing IC. IC represents an experimental paradigm that effectively reduces intergroup prejudice between humans (see, e.g. [13–16,19–21]). Using this paradigm to improve attitudes towards robots yielded mixed results. That is, whereas some findings speak to its effectiveness in improving robot attitudes and emotions towards robots [20], other results fail to replicate the beneficial effects [21].

The present experiment thus aimed to address the question of whether IC might be useful to improve actual HRI, which goes beyond previous research which has focused solely on attitudes towards robots or mere self-reports regarding HRI behaviour. Accordingly, we explored the effects of IC on the perception of and behaviour during actual HRI. This idea rested on the assumption that IC would provide a behavioural script for HRI (e.g. [22–24]). We reasoned that the imagination of human–robot contact that is marked by high similarity to subsequent actual HRI would (i) positively affect perceived HRI quality and would (ii) positively impact behaviour during HRI with NAO compared to an imagination that was low in similarity to the actual HRI scenario.

Indeed, our experimental results give interesting insights into the influence of IC on HRI, showing that perceived HRI quality and HRI behaviour are positively affected by IC, documenting the positive effect of IC in the realm of social robots. Our findings are in line with our hypotheses, providing evidence for the fact that participants who imagined a situation that was highly similar to the real HRI situation they experienced later, rated the interaction more positively, and showed a higher number of social behaviours towards the NAO robot during the interaction.

The multi-method approach we used is one of the major strengths of the study: we incorporated behavioural data from the interaction situation, self-report measures, and an indirect attitude measure. Therefore, our results include both qualitative and quantitative data—enabling a multifaceted analysis of actual behaviour, self-reports, and reaction time data to gain insights into the psychological processes involved. Arguably, the IAT falls victim to the typical methodological issues of indirect attitude measures in general, e.g. a relatively lower reliability in comparison to direct measures [39]. At the same time, the psychometric properties of an IAT outperform many other indirect attitude measures (see [40] for a detailed overview over the validity of the IAT). Follow-up studies should include even more indirect attitude measures as dependent variables to investigate these in the context of social robotics further.

Moreover, studies that include real-time HRIs often lack statistical power owing to small sample sizes. This was not the case in the present research, as *a posteriori* power analyses conducted with G*power confirmed that our sample was big enough even for small effects to reach significance. That means, in our case, statistical power was sufficient.

In addition to these methodological strengths, our experiment goes beyond the results of previous IC research in HRI in terms of scope (e.g. [19–21]): Our data show that IC improves the perceived quality of HRI and behaviour during HRI if users imagine contact with a robot prior to real contact with NAO, highlighting the key role of similarity between imagination and reality. Previous research on the effectiveness of IC in the context of social robotics has administered scenarios which usually featured an unspecific interaction with a robot without further detailing the context. Indeed, it might be advantageous to have a 'one-fits-all' generic IC scenario at hand that would be applicable and generalizable to a variety of users and contexts. However, the mixed results from previous research document the difficulty of identifying an optimal solution of this kind (e.g. [19–21,27]). So far, it has not yet been shown that IC

reliably and reproducibly improved robot-related evaluations. The present study goes beyond these results by providing evidence for the need to specifically tailor the IC situation to the given context of the HRI. Further research should explore the degree of similarity necessary to evoke effects on behaviour during HRI and HRI perception.

With regards to determining the required minimal similarity between imagined and actual contact, we suggest several possibilities. On the one hand, it could be possible that an IC scenario has to exactly mirror the subsequent task to evoke the positive effects we found. On the other hand, it might be sufficient to only mirror the context of the HRI (e.g. the environment being a school), without the need for exactly mirroring the subsequent HRI. If this applies, one general, rather unspecific scenario for robots in a school setting would be sufficient to improve HRI in this context without the necessity to tailor IC scenarios for every possible HRI task that could occur within the school context. For example, such a more universal scenario could read: 'Imagine there was a robot to assist you while you are at school. We are interested in how the robot could help and support you. Imagine for example, that the robot helps and supports you with your tasks, that you talk to each other etc.'. The idea of having one scenario for several potential interactions in one context, for example the school context, is supported by the results of [41] who found that the positive effects of mentally simulating an activity transfers to other, similar activities.

Clearly, the present research has set the stage for several follow-up studies. The present research did not assess the effect of the IC scenarios on robot attitudes, but rather concentrated on the effect on HRI and perceived HRI quality. Future studies should assess the effects of similarity of IC and HRI on robot-related attitudes as well, replicating previous research. In addition, even though our power analysis showed sufficient power to detect small effect sizes, an *a priori* power analysis revealed that a larger sample size encompassing 176 participants would have been optimal in terms of statistical power. Since the study design and set-up was complex, so was the analysis of the video data. Therefore, at the time of data collection, recruiting a larger sample of participants was not feasible. It is plausible that a replication study with more participants might yield even stronger results than those obtained in the present research. Furthermore, it might be advisable to include a baseline control condition without IC to gain better insights into the perception of the interaction and interaction patterns in HRI *per se*. That is, future studies should add one condition in which participants do not imagine contact of any kind, neither high nor low in similarity to the following actual HRI. Such a baseline control condition would allow insights into the perception of the mere HRI itself without the influences of the previous experimental treatment. With regards to the implementation of the experimental conditions in the present research, it might be that these might have evoked different expectations regarding the robot's capabilities. Even though NARS, RAS, contact intentions, the willingness to interact, acceptance and liking of the robot were no relevant covariates, it cannot be ruled out completely that differences in participants' expectations regarding the robot's capabilities might have affected the present results. That is, such expectations might not have been met, particularly in the low similarity condition. Therefore, we recommend assessing perceived robot capabilities to control for inter-individual differences in participants' expectations.

Additionally, the amount of details implemented in our scenarios may represent a critical issue. This is because one might argue that the scenario low in similarity included fewer details. This, in turn, might have decreased the level of elaboration, thereby biasing the results. However, as previously mentioned, the results in [20] have shown that the amount of detail in the scenarios did not have an impact on the experimental outcomes. Additionally, in the present research, we had assessed vividness and clarity of the imagination, which should be affected by a different amount of elaboration of the imagination task. In fact, imagination quality turned out a significant covariate and we controlled for it in the analysis of covariance. The effects of similarity on number of social behaviours as well as on the perceived quality of the interaction were also statistically significant in the ANCOVA.

Also, statistically significant effects were obtained only for two of the behavioural measures that we had implemented in our design—social behaviour, in particular. Social behaviour was operationalized as nonverbal communication behaviour like nodding and frowning. At the same time, however, the IC task did not change the amount of verbal utterances towards the robot, or the amount of eye contact, for example. There are several potential reasons for this outcome. One reason could be that the robot interaction task was highly structured. Therefore, participants might not have felt the need to communicate with the robot and thus, might mainly have focused on the task at hand, the memory game. It would be interesting to replicate the findings using a different HRI task which would encompass more mutual interaction between the robot and participants.

Another important issue for future research concerns the context of HRI itself. Participants were asked to play a memory game with the robot. However, this game context does not allow generalization to everyday scenarios, like the afore mentioned school context, for example. Furthermore, a participant can simply lose the memory game. This trivial fact could elicit frustration in the participants. Even though we tried to let the participants win the first game of any round to allow for a start with a positive experience (which was successful most of the time), we suggest measuring positive and negative affect, including frustration after the memory game task to control for such aspects. Moreover, it might be recommendable to keep the number of rounds constant. We made it variable to use it as a dependent measure for the HRI situation, assuming that participants who like to interact with NAO would play more rounds. However, this is not what we actually observed. Thus, the fact that participants varied in the number of rounds played, extended or shortened the HRI accordingly—an issue that should be avoided in follow-up experiments.

Furthermore, the duration of the HRI scenario in our experiment has to be discussed. Participants had the opportunity to play up to four rounds of memory with the robot. This would result in an interaction of medium length (approx. up to 8 min). Realistic interactions with social robots in the future will be either much shorter (e.g. paying my groceries to a robot cashier or asking for directions) or much longer, involving repeated interactions (e.g. cooperating with a robot in the work context). Consequently, further studies should consider the length of the HRI as a key factor, potentially even realizing repeated interactions over time. Finally, future studies should go beyond the present work regarding the imagination task by explicitly asking participants about their behavioural script. This would more directly test our tacit assumption that the

formation of a behavioural script represents a psychological mechanism underlying the positive effects of similarity in IC. We assumed that a script would facilitate HRI by offering participants a predefined repertoire of behaviours and responses for the HRI situation, thus providing them with different behaviour alternatives to choose from. To test this assumption, participants could be asked to freely generate possible behaviours within the broad general context of the upcoming HRI situation before the interaction takes place, without presenting an IC scenario. If those participants whose generated scripts matched the HRI more closely would show similar benefits to the participants in our condition high in similarity to the subsequent HRI, it could be seen as more evidence for our behavioural script hypothesis. It could also be interesting to investigate the impact of different approaches to train participants for subsequent contact with a robot. That is, IC could be compared with mental training, a prominent approach in sports psychology (see e.g. [42] for a meta-analysis or a video of an interaction could be presented instead (e.g. [43])).

5. Conclusion

The present experimental data speak to the effectiveness of IC in the context of social robotics, extending the evidence to a nonhuman 'outgroup'. Owing to our multi-method approach, the findings go beyond previous research [19–21] and provide insights into participants' perception and behaviour during actual HRI. The results imply that it is beneficial to tailor the IC scenario to the HRI situation and, by that, give a possible explanation for the fact that previous studies had rather mixed results with regards to the effectiveness of IC in the context of social robotics. Furthermore, the results have important implications for future research. First, further research has to identify the ideal fit between IC and actual human–robot contact for maximal IC effectiveness. Second, our results support the assumption that IC offers a behavioural script to guide the performance in an interaction situation, which should be examined in more detail. Above and beyond, the experimental paradigm of the memory card game with the robot NAO serves as a fruitful basis for various follow-up studies to further clarify the boundary conditions for IC effects in HRI. Finally, we hope to inspire more experimental research using multi-method approaches to study social psychological phenomena in the context of social robots and HRI.

Ethics. Our study was approved by the Bielefeld University Ethics Board (ethics application number EUB-2015-115).

Data accessibility. All analyses were done with IBM SPSS Statistics v. 21. Video coding was done using the freeware tool ELAN v. 5.2 for Windows (Max Planck Institute for Psycholinguistics). The datasets supporting this article have been uploaded in the electronic supplementary material.

Authors' contributions. The first and second authors of this manuscript conceptualized the study in cooperation. The first author collected and analysed the data, as well as drafted the article. The first and second authors revised the article in cooperation. The second author gave final approval of the version to be published.

Competing interests. We declare we have no competing interests.

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