It's in the eyes: The engaging role of mutual gaze in HRI

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Abstract

This paper reports a study where we examined how a humanoid robot was evaluated by users, dependent on established eye contact. In two experiments, we manipulated how the robot gazes, namely either by looking at the subjects' eyes (mutual gaze) or to a socially neutral position (neutral). Across the two experiments, we altered the level of predictiveness of the robot's gaze direction with respect to a subsequent target stimulus (in Exp.1 the direction was non-predictive, in Exp. 2 the gaze direction was counter-predictive). Results of subjective reports showed that participants were sensitive to eye contact. Moreover, participants were more engaged and ascribed higher intentionality to the robot in the mutual gaze condition relative to the neutral condition. This was independent of predictiveness of the gaze cue. Our results suggest that embodied humanoid robots can establish eye contact, which in turn has a positive impact on perceived socialness of the robot, and on the quality of human-robot interaction (HRI). Therefore, establishing mutual gaze should be considered in design of robot behaviors for social HRI.

Keywords

Mutual gaze, social human-robot interaction, social attention, iCub

1. Introduction

Robots are rapidly advancing technically, and they may increase their presence in our society in the near future. Robotic agents will assist humans in daily activities, i.e. by operating repetitive tasks, facilitating teaching, and supporting clinicians [1-5]. Moreover, robots will be a new form of social companions e.g. for elderly people [6-7]. For a smoother integration of robots in the complexity of human society, robots would require to attune to humans by responding to subtle social cues, coordinating with human actions, and adapting to human needs. In daily interactions, humans rely largely on non-verbal cues, as the ability to extract relevant information from partner's gaze. Indeed, during human-human interaction the eyes constitute a privileged channel for non-verbal communication. Through others' eyes we gain information regarding their intent to interact with us, their action goals, and the focus of their attention [8-10]. One of the most powerful social signals in humans is eye contact (mutual gaze) which is used to initiate communication and convey interpersonal attitudes [11-12].

Mutual gaze modulates a wide range of cognitive processes in humans [13-16], including social attention and memory [17-22]. Early in development, humans are sensitive to eye-contact [17]. For instance, it has been shown that newborns prefer direct gaze rather than an averted one or closed eyes [18]. Furthermore, it has been demonstrated that establishing eye contact is a prerequisite to follow another's gaze and establish joint attention [19-20] in 4-and 6-old month infants. Mutual gaze captures attention in two ways; either resulting in a delayed attentional disengagement from the gaze or in enhanced memory processes [14, 21-22]. On one hand, Senju and Hasegawa showed that faces with direct gaze compared to averted gaze or closed eyes, attracted attention and, as a consequence, delayed detection of a following peripheral target [21]. On the other hand, there is evidence that faces with eye contact, compared to faces with averted gaze, improved identity recognition [22] and gender discrimination [14]. Direct gaze does not only have an impact on cognitive processes but also on affectional aspects such as arousal and likeability [23-24]. Kuzmanovic et al. demonstrated that likeability was larger for virtual characters looking straight compared to showing an averted gaze and the likeability linearly increased with the increase of gaze duration (1, 2.5 or 4 s) [23]. Previous studies have also shown that the longer the eye contact duration was, the more favorably this person was judged with respect to likeability, potency and self-esteem [13, 24-26]. Furthermore, Mason et al. [27] showed that people engaged in eye contact are perceived as more likable and attractive than the ones who showed avoiding gaze. Similarly, female faces with direct gaze were rated as more attractive by male perceivers [28].

Despite the importance of eye contact in human-human interaction little is known about the role of eye-contact in human-robot interaction (HRI). One limitation in implementing mutual gaze in HRI is the actual realization of human-like robot eyes, both in terms of appearance and capabilities. Despite the constraints, it has been shown that eye contact with a robot increases its subjective social evaluation, intentionality attribution and engagement. For example, Yonezawa et al. showed that eye contact with a stuffed-toy robot induced a favorable feeling towards the robot and this feeling was enhanced when the robot further followed the user's gaze [29]. In another study, in which participants were teaching a robot object recognition, they took more time, were more attentive and returned verbal responses more often to the robot with eye contact compared to a robot with random gaze. All these cues implied an increase in the feeling of intentionality towards the "eye-contact" robot [30]. Furthermore, a robot holding its gaze while replying to a normal question seemed more sociable and intelligent relative to a robot with gaze avoidance, while the reverse effect held for an embarrassing question [31]. Finally, Zhang et al., have demonstrated that an intermittent mutual gaze behavior between a human and a robot resulted in a positive social effect, improved fluency in interactive applications, and drew more attention of the participants towards the robot compared to a continuous robot-user eye contact [32], see [33] for an extensive review on social eye gaze in HRI. To sum up, the importance and pivotal role of eye contact in human interactions in contrast to the limited number of studies of HRI on this topic, calls for the need of examining meticulously the effect of mutual gaze in HRI.

1.1 Aim of the study

In the present study we examined the sensitivity of humans to an online eye contact initiated by a humanoid robot, the induced social engagement and the attribution of human-likeness. In two experiments, we used an interactive non-verbal paradigm which encompasses eye-contact (or not) and a subsequent referential gaze (gaze directed at an object or location in space), initiated by the humanoid robot iCub [34]. In our paradigm, iCub detected the eyes of the participant and either established eye-contact (mutual gaze condition) or avoided it by looking down (neutral gaze condition), before shifting its gaze to the left or right to indicate a target appearing on two laterally positioned screens. The main task of the participants was to identify the target. Across experiments, we manipulated the predictiveness of gaze concerning the target location, to be either non-predictive (50% congruency between gaze direction and target location) or counter-predictive (25 % congruency). Thus, we created two types of social interaction following the eye contact, i.e. a 1) non-predictive and 2) a counter-predictive referential gaze and we tested the sensitivity to the eye contact, the engagement level and attribution of human-likeness through analysis of subjective reports.

2. Experiment 1

2.1 Methods

2.1.1 Participants

The experiment was held at the Italian Institute of Technology (IIT). Twenty-four participants (mean age = 26.71 ± 6.39; 11 female; 3 left-handed) took part in the study and received an honorarium for their participation. Both experiments were approved by the local ethical committee (Comitato Etico Regione Liguria), and all participants signed a consent form before taking part in the experiment.

2.1.2 Apparatus and materials

Participants seated face-to-face with iCub (125 cm away) at the opposite side of a desk. Two screens (21.5 inches) were used for stimulus presentation, and they were positioned on the left and on the right of the robot at the distance of 105 cm from the participants. iCub was programmed to look to the following positions in every trial: 1. towards a location in space between the desk and participants' upper body (resting), 2.a. towards participants' eyes (mutual gaze), or 2.b. - towards the table (neutral gaze), 3.a. - towards the left screen (left), or 3.b. towards the right screen (right).

2.1.3 iCub and algorithms

iCub is a full humanoid robot. The head has three degrees of freedom in the eyes (tilt, vergence, and version) and three additional degrees of freedom in the neck (roll, pitch, yaw). In order to control the movement of the iCub we used YARP, which is a multi-platform open-source framework [35]. To control the eyes and the neck, we used the iKinGazeCtrl (a YARP Gaze Interface), from the available open source repository[1], which allows the control of iCub's gaze through independent movement of the neck

[1] [https://github.com/robotology/iCub-main/tree/master/src/modules/iKinGazeCtrl]

and eyes in a biologically-inspired way [36]. iCub's gaze shift was always combined with a head movement, in order to make it more naturalistic. The vergence angle was set to 5 degrees, while the trajectory duration of eyes and neck movement was set to 200 ms and 400 ms respectively.

The human eyes were detected using the face detector of the "human sensing" module[2], which uses the dlib library[3]. This algorithm allows detecting a human face looking approximately towards the camera, see Fig. 1.

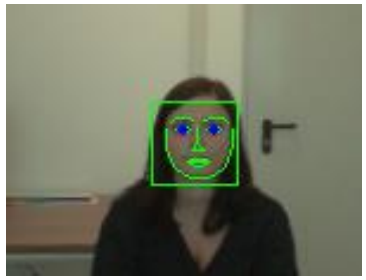


Fig. 1 Output of the left robot eye camera depicting the result of the face detector algorithm. Blue circles indicate the position of the detected eyes

2.1.4 Procedure

Every trial started with robot having its eyes closed. Then, it opened its eyes and located the eyes of the participant based on the output of the face detection algorithm. After establishing eye contact or not (depending on the experimental condition) the robot gazed laterally to one of the screens where the target letter (V, T) appeared. The robot gaze was non-predictive of the target location (50% congruency). Participants were required to discriminate the letter by pressing the mouse button assigned to each letter. The experiment was divided in 8 blocks of mutual gaze condition and 8 blocks of neutral gaze condition (see Fig. 2). Each block consisted of 10 trials, while the block sequence was randomly selected. At the end of every block, participants were asked to rate their engagement with the robot on 10 point Likert scale (1= strongly disengaged; 10= strongly engaged). The task lasted about 25 minutes.

Fig. 2 Gaze conditions. Left panel: Mutual gaze. Right panel: Neutral gaze

After the completion of the task, participants were administered a customized questionnaire to assess the familiarity with the robot, the sensitivity to eye contact, the level of engagement, and attribution of human-likeness, see Table 1.

[2] [https://github.com/robotology/human-sensing]
[3] [http://dlib.net]

Table 1. Questionnaire (Exp. 1)

Questions
1. How familiar are you with the robots (1=not familiar –5=very familiar)?
2. Did you perceive any difference across the trials (not related to the letter identity)?
3. In total, how engaged did you feel with the robot? (1= strongly disengaged – 10= strongly engaged). Which factor influenced your engagement during the experiment?
4. According to you, was the robot thinking like a human (H) or was it processing like a machine (M)? Please indicate evidence for or against the statement.
5. Did you feel that this was constant during the experiment? Please indicate evidence for or against the statement.

2.2 Questionnaire evaluation

Two independent evaluators rated the responses to the questionnaires and categorized them into four categories, see Table 2. More specifically, Category 1 included replies related to the establishment of eye contact with the robot. Category 2 involved statements about robot behavior that we did not manipulate, e.g. participant's idea that the robot was moving more fluently after half of the experiment. In Category 3 were included statements related to the congruency of the robot gaze with respect to the target location. Finally, category 4 included responses related to features of the task that we did not manipulate, e.g. participant's belief that one of the letters was more frequent in comparison to the other. Only responses that were assigned to the same category by both raters were included in the results. If a participant gave more than one responses to a specific question, each response was categorized accordingly. Questions 4 and 5 questioned the mind attribution to the robot and were combined as a representation of a modified version of a "Turing test" [37]. In particular, if participants replied "human" or "machine" in Question 4 and their belief remained constant during the experiment (i.e. answering "yes" to Question 5), their response was assigned to the label "human" or "machine" respectively. If their belief changed during the experiment (i.e. replying "no" to Question 4) and they mentioned both human- and machine-like arguments, they were categorized as "both".

Table 2. Categorization of the answers

Category	Explanation
1. **Mutual gaze**	Statements related to robot's gaze behavior that we manipulated
2. **Other, robot-related**	Statements about robot's behavior that we did not manipulate
3. **Congruency**	Statements referring to congruency between the robot's gaze direction and target position.
4. **Other, task-related**	Statements about task features that we did not manipulate

2.3 Results

Overall, the level of participants' engagement with the robot across the blocks averaged to M = 6.32, SD = 1.64), on a 10-point Likert scale. As shown by the Wilcoxon signed-rank test, users rated social engagement significantly higher in the mutual gaze (M = 7.0, SD = 1.34) compared to the neutral gaze condition (M = 5.62, SD = 1.68): Z = -3.93, p < .001. Fig. 3 shows the mean participants' engagement rating across gaze condition and per block.

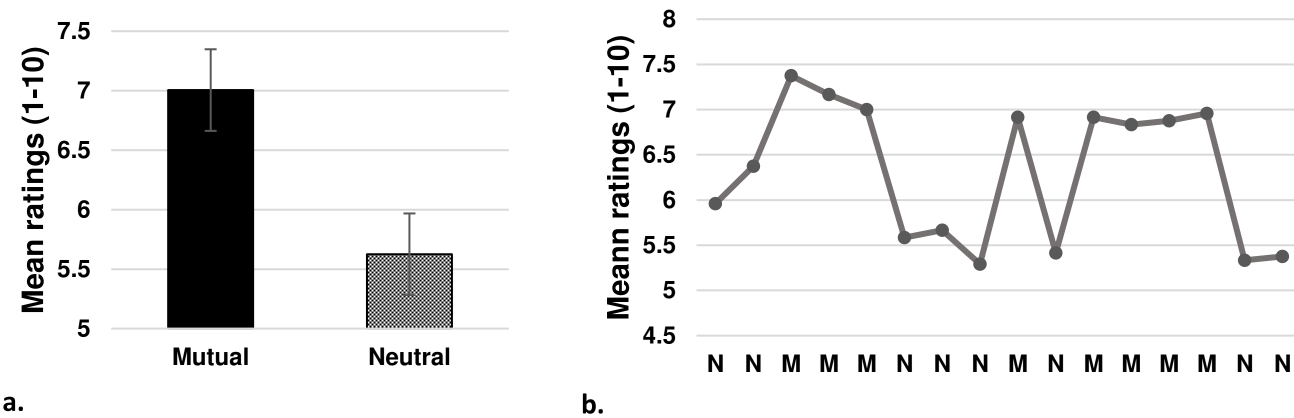


Fig. 3 Engagement ratings across gaze conditions and blocks **3.a** Mean engagement ratings averaged across conditions (mutual, neutral). Error bars represent standard error of the means **3.b** Mean engagement ratings averaged across blocks (M= mutual gaze; N= neutral)

The mean familiarity rating (answers to Question 1) was: M = 2.16, SD = 0.92. Related to the question of perceiving any difference during the experiment (Question 2), 22 participants (91%) responded "yes". 7 people were not included in further analysis, because they did not refer to the difference itself, their response was unclear or were classified into different categories by the two raters. The remaining 15 participants gave 17 answers in total, which were categorized in the four different labels as follows: 64.7% of the answers involved mutual gaze, 23.5% included other-robot related reasons, 5.88% indicated congruency, while 5.88% mentioned to task-related reasons (Fig. 3). A one-sample chi-square test was run to investigate whether the frequencies of the assigned categories differed from expected equal frequencies (0.25). The test showed that the frequency of the answers was significantly different from equal, χ^2 (3) = 15.7, p=.001.

Concerning the Question 3, i.e. the factor that enabled their engagement, 2 participants were not included in the results of the questionnaire because their response was not clear. The responses of 22 remaining participants were 30 in total and they were evaluated as follows: 63.3% of the responses included the mutual gaze, 16.67% other robot-related reasons, 16.67% mentioned congruency and a 3.33 % reported other task-related reasons (Fig. 3, middle). According to the results of chi-square the frequency of the answers was significantly different from equal, χ^2 (3) = 24.9, p<.001.

Regarding the responses related to the "Turing test", 1 participant was excluded because raters assigned his/her response to different categories; 14 participants perceived the robot's behavior as pure mechanistic and their reasoning referred mostly to the random robot's behavior (50%) and its repetitive movements (33.33%). Finally, 9 participants were assigned to the category "both" as their belief about the nature of the robot behavior alternated between “machine-like” and “human-like”. Among these participants, 77.78% of them reported mutual gaze as the factor that made them attribute a human-like behavior to the robot, while 22,2% mentioned other robot-related reasons (Fig. 4).

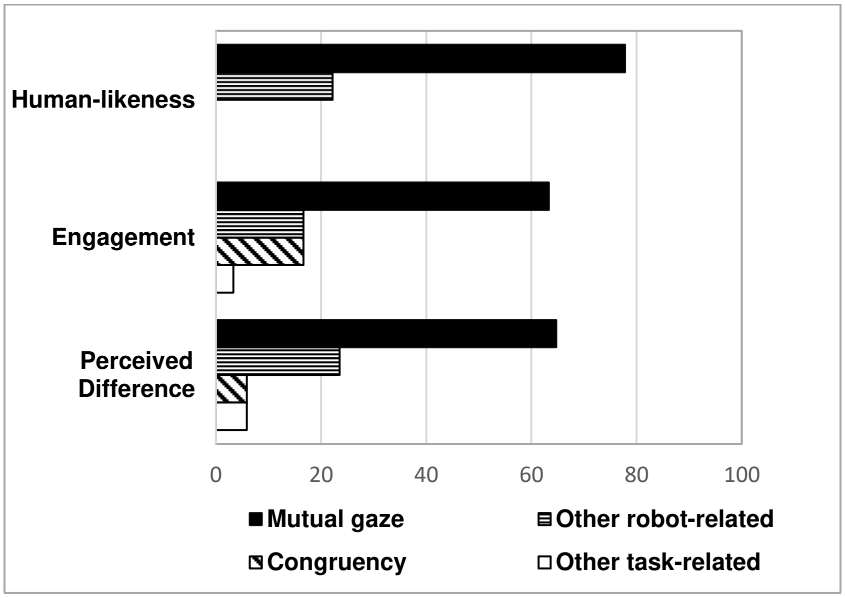


Fig. 4 Responses of the participants (in percentages) plotted as a function of four different categories: Mutual gaze (filled bars), Other robot-related (horizontally striped bars), Congruency (checked bars), Other task-related (empty bars). The lower bars refer to the responses to Question 2 (perceived difference across the conditions), the middle bars display responses to Question 3 (factor of engagement), and the upper bars account for answers to Questions 4,5 (features of human-likeness). For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article

2.4 Discussion

Overall, the majority of individuals were sensitive to eye-contact initiated by iCub, even while performing another task, orthogonal to the gaze contact manipulation. Additionally, participants felt more engaged with the robot during the mutual gaze condition compared to the neutral condition, mentioning mostly eye-contact as the engaging factor. Finally, the majority of the participants who attributed human-like behavior to the robot reported mutual gaze as the main reason. This shows that establishing mutual gaze is a crucial factor impacting on the quality of human-robot interaction.

3. Experiment 2

Experiment 2 examined the sensitivity to eye-contact, engagement and the attribution of human-likeness when the eye-contact is followed by a counter-predictive referential gaze. In order to test the attribution of human-likeness, we investigated whether participants adopted the intentional stance towards iCub when it looked at their eyes. Intentional stance refers to the attribution of mentalistic explanation towards behavior, assuming that the agent behaves as a result of mental states, beliefs or desires [38].

3.1 Method

3.1.1 Participants

Twenty-four new participants (mean age = 26.8 ± 4.4; 17 female; 1 left-handed) took part in the study and received an honorarium for their participation.

3.1.2 Apparatus, materials and procedure

The apparatus, stimuli and procedure were the same as in Exp. 1. Methods and algorithms for programming iCub's behavior were the same as in Exp. 1. However, iCub, after establishing (or not) eye contact with the participant, directed its gaze with a lower probability (25% congruency) to the screen in which the target letter would appear. In order to have a similar amount of congruent trials with Exp. 1 we increased the total amount of presented trials to 256 (divided into 16 blocks of 16 trials each). The block order differed across participants using the same (Sequence Type A) or opposite sequence (Sequence Type B) with respect to Exp. 1. At the end of every block, participants were asked to rate their engagement with the robot on 10 point Likert scale (1= strongly disengaged; 10= strongly engaged). The task lasted about 40 minutes.

After the completion of the task, participants were administered a questionnaire similar to the one used in Exp. 1. The questionnaire included 4 questions addressing familiarity with robots, sensitivity to eye contact, level of engagement, and attribution of human-likeness, see Table 3 (Questions 1 - 3). The last question (Question 4) was administrated to investigate adoption of the intentional stance. Furthermore, participants completed the Godspeed questionnaire [39] in order to measure the Anthropomorphism and the Likeability level for each gaze condition (mutual gaze, neutral gaze).

Table 3. Questionnaire (Exp. 2)

Questions
1. How familiar are you with the robots (1=not familiar –5=very familiar)?
2. Did you perceive any difference across the trials (not related to the letter identity)?
3. Concerning the question during the experiment: "How much did you feel engaged with the robot", which factors did enable your decision.
4. Why do you think the robot orients its gaze towards your eyes?

3.2 Questionnaire Evaluation

The same evaluating procedure was applied and the same categories were used for the first three questions. As mentioned above, the Question 4 was used as an intentional stance test towards the robot's eye contact. The following labels were used to categorize responses to Question 4:

1. Human-like explanation of the behavior (e.g. to distract me, to grab my attention);

2. Mechanistic explanation (e.g. to test my engagement in the task, to replicate eye-contact);

3. Task-related (e.g. signal the position of the letter).

The responses of the Godspeed questionnaire were averaged for the Anthropomorhism and Likeability subscales separately for every person while the statistical difference between the ratings of the two gaze conditions (mutual vs neutral) was assessed using a Wilcoxon signed-rank test.

3.3 Results

Overall, participants' engagement with the robot across the blocks averaged to M = 5.82, SD = 1.8. Participants rated social engagement significantly higher for the mutual gaze (M = 6.15, SD = 1.65) compared to neutral gaze condition (M = 5.49, SD = 1.9): Z = -2.85, p = 0.004, see Fig. 5a.

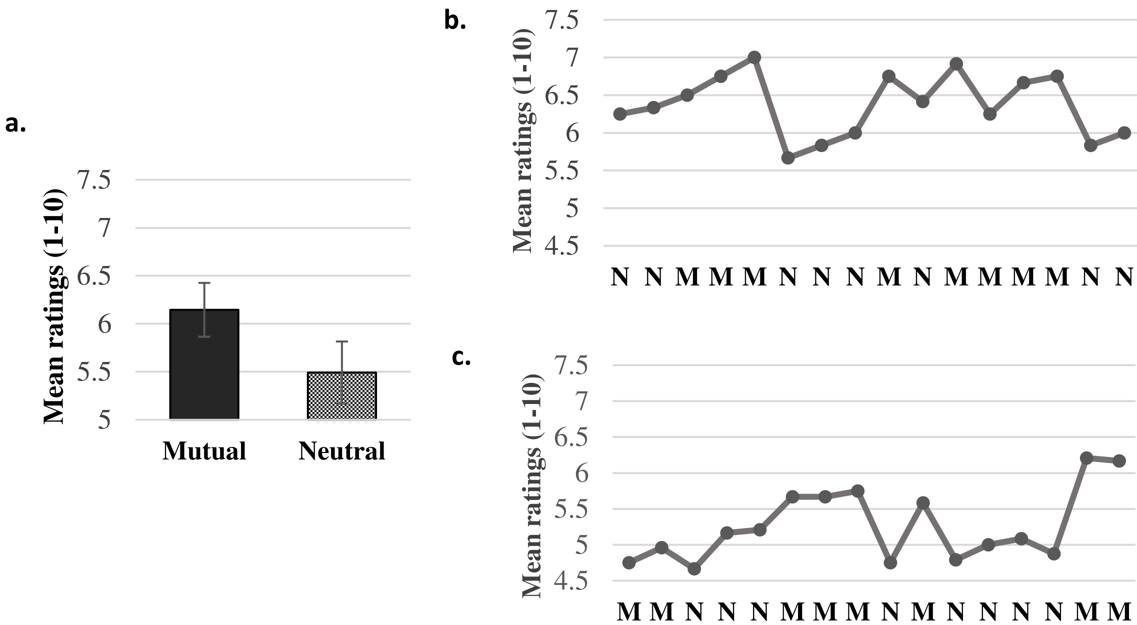
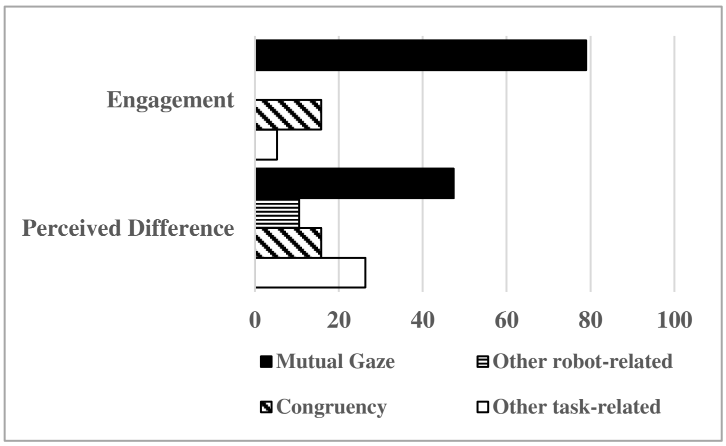


Fig 5 Engagement ratings across gaze conditions and blocks **5.a** Mean engagement ratings averaged across conditions (mutual, neutral). Error bars represent standard error of the means **5.b** Mean engagement ratings averaged across blocks (M= mutual gaze; N= neutral) for Sequence A. **5.c** Mean engagement ratings across blocks (M= mutual gaze; N= neutral) for Sequence B

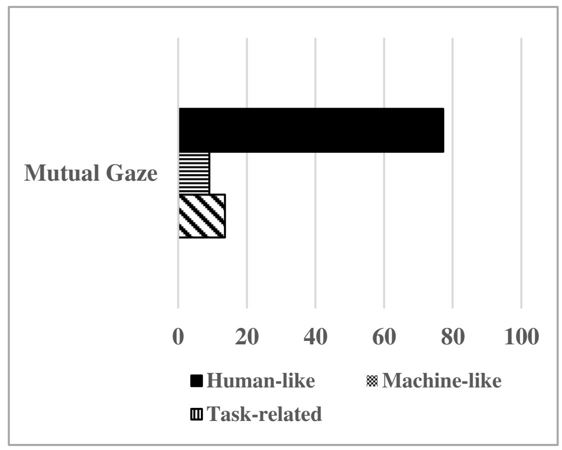
The mean familiarity rating (Question 1) was: M = 1.6, SEM = 0.78. Related to the question of perceiving any difference during the experiment (Question 2), 22 participants responded "yes". 4 people were not included in further analysis, because they did not refer to the difference itself, their response was unclear or were classified into different categories by the two raters. The remaining 18 participants gave 19 answers in total, and were categorized in the five different labels as follows: 47.4% of the answers involved mutual gaze, 10.53% included other-robot related reasons, 15.79% indicated congruency, while 26.32% mentioned task-related reasons, see Fig. 6 (panel a). The results do not provide evidence that the four categories were not equally preferred, χ^2 (3) = 6.05, p=.1.

Concerning the Question 3, in which participants explained the criteria according to which they rated their engagement during the task, 7 participants were excluded from the analysis since their response was not clear, or were not categorized identically by the two evaluators. The responses of 17 remaining participants (19 responses in total) were further labelled into the four categories. More specifically, 78.95% of the responses mentioned the mutual gaze, 15.79% mentioned congruency, 5.26% referred to other task-related reasons, see Fig. 6 (panel a). No one reported robot-related statements. Due to null amount of responses for the robot-related category, no statistical analysis was performed for this question.

Concerning the Question 4, 3 participants were excluded from analysis because their responses were labelled differently. The remaining 21 participants gave in total 22 answers which were categorized into the following way: 77.27% included human-like explanations, 17.14% mechanistic, 17.14% task-related reasons, see Fig. 6 (panel b). The chi-square test indicated that the frequency of the answers was significantly different from equal, χ^2 (2) = 19.82, p<.001.



a.



b.

Fig 6.a Responses of the participants to Question 2 (below) and 3 (above) in percentage plotted as: Mutual gaze (filled bars), Other robot-related (horizontally striped bars), Congruency (diagonally striped bars), Other task-related (empty bars). **6.b.** Responses of the participants to Question 4 in percentage plotted as: Human-like (filled bars), Machine-like (horizontally striped bars), Other task-related (diagonally striped bars). For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article

Concerning the Godspeed questionnaire, the responses were averaged for the Anthropomorphism and Likeability subscale for every participant. Participants rated the mutual gaze as more human-like compared to the neutral gaze, Z = -2.11, p = .04 (Mmutual= 3.32, SD = 0.78; Mneutral=3.07, SD = 0.91). Similarly, participants rated the mutual gaze as more likeable in comparison with the neutral gaze, Z = -3.5, p <.001(M_{mutual} = 4.15, SD = 0.71; $M_{neutral}$ = 3.58, SD= 0.78).

3.4 Comparison between experiments

In order to examine whether the predictiveness of the subsequent referential gaze (non-predictive, counter-predictive) influenced the level of engagement elicited by mutual gaze, we compared the engagement ratings across the two experiments using a Wilcoxon signed-rank test of two-independent samples. There was no significant difference in ratings either in mutual (Z = -1.7, p = .09) or neutral gaze condition (Z = -.19, p = .85).

Furthermore, a chi-square association test was run to investigate whether the frequencies of answers for the perceived difference and the engagement factor differed across the two experiments. Regarding the questions of the perceived difference along the experiment there was no statistically significant association between Experiment and perceived difference, χ^2 (3) = 4.4, p= .22. Concerning the engagement factor, we included only the answers categorized as mutual gaze, congruency and task-related since no reply of Experiment 2 was categorized as robot-related. Again, no significant association emerged between Experiment and engagement factor, χ^2 (2) = 0.16, p=.93.

4. General Discussion

In the present study, we examined the impact of eye contact with an embodied humanoid robot on the sensitivity to detect mutual gaze, the perceived human-likeness, and the level of engagement with the robot, through assessment of subjective evaluations. We were interested in examining the evaluation of the abovementioned parameters across different types of social interaction following the eye-contact. To this end, we manipulated the gaze of the iCub robot in two similar non-verbal experimental paradigms. In Experiment 1, iCub either looked toward participant's eyes or at a neutral position and then gazed randomly at one of the peripheral screens where a target appeared (Exp. 1: non-predictive referential gaze, 50% congruency). In the second experiment, iCub after establishing (or not) the eye contact gazed most frequently at the screen that would not contain the target (Exp. 2: counter-informative referential gaze, 25% congruency). During and after the completion of the task, participants were administered a questionnaire to assess their engagement, sensitivity to eye contact, and human-like attribution to the robot.

The results of both Experiment 1 and 2 showed that the majority of the participants 64.7% (Exp. 1) and 47.4% (Exp.2) mentioned the mutual gaze as a noticeable difference along the experiment, suggesting that users are sensitive to the eye contact while executing an orthogonal task. There was no significant difference between experiments regarding sensitivity to eye contact.

Concerning the level of engagement, participants rated mutual gaze condition as significantly more engaging, compared to the no eye contact condition in both experiments. Although the engagement level for mutual gaze was lower in Exp.2, it did not differ from the average level of engagement reported in Exp. 1. It should be noted that participants rated higher the mutual gaze condition compared to the neutral gaze repeatedly across Exp. 1. However, in Experiment 2, the same effect is clear for Sequence A (same sequence with Exp.1). In contrast, for Sequence B the level of engagement seems to stabilize after block 6, i.e. after participants experienced both conditions. Regarding the criteria that participants used to rate their engagement with the robot, the majority of the participants mentioned mutual gaze in both experiments, 61.3% in Exp. 1 and 79.8% in Exp. 2. No significant difference between experiments emerged regarding social engagement with iCub.

The responses regarding the "Turing test" in Exp.1 show that almost 40% of participants attributed mental states to the robot. Within this group, the main reason mentioned by participants was the mutual gaze (77.8%). A similar result was found for Exp.2, where the majority of the responses 77.2% included a mentalistic explanation for the establishment of eye-contact by the robot (Question 3).

Results from the Godspeed questionnaire showed that on anthropomorphism subscales, ratings were significantly higher for the mutual than the neutral condition. Finally, in Experiment 2 participants liked significantly more the robot when it was looking at them, compared to when it was looking toward a neutral position.

Overall, our findings show that eye-contact with a humanoid robot is noticeable, even if the task is orthogonal to detection of eye contact, is perceived favorably, increases perceived human-likeness of the robot, and engages users more in the task they are performing with the robot. Such results could have important implications in the design of robots' behavior. For example, a robot designed to perform as a teaching assistant should actively establish mutual gaze with its audience in order to increase their engagement. In a clinical context, it is known that children with autism spectrum condition (ASC) face difficulties in initiating and responding to social cues, such as eye contact and joint attention. Such social capabilities could be enhanced by the appropriate design of robot assistants in therapies that would crucially engage children with an online eye-contact and subsequently train other social signals [40]. Moreover, since eye-contact is easily detected even when humans are engaged in another task, robots placed in public spaces could use eye contact to grab user's attention.

More generally, understanding factors that positively impact social interactions with robots benefits not only HRI, but informs also research related to social cognition in humans. It has been recently argued that with the use of natural interactive paradigms, we gain knowledge about social cognition that is over and above knowledge acquired through more classical experimental protocols with stimuli presented on the screen and participants passively observing them [41-42]. Our approach of using robots in interactive experimental paradigms increases ecological validity of paradigms used in social cognitive neuroscience, and allows also high degree of controllability, relative to human-human interactions. Therefore, embodied robots provide an efficient tool for studying human cognition [see 43-44 for a review]. This study is an excellent example where – through the use of an embodied robot and naturalistic eye contact – we gained new insights regarding human mechanisms of social cognition. Our results showed that, for example, attribution of human-likeness to a robot is dependent on subtle human-like features in robot's behavior (gaze contact) to which humans are apparently very sensitive [45-47].

5. Conclusions

The results of our study indicate that the mutual gaze increases the level of engagement, likeability and ascription of intentionality to a humanoid robot independently, and orthogonally, to the task participants are actually performing. We suggest that embodied humanoid robots which can establish a human-like eye-contact can be easily socially-attuned to humans allowing for a smoother HRI and higher degree of engagement of the user. Gaze contact can be used as a signal to attract (and keep) attention of users towards the robot.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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Biographies

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Francesca Ciardo is a Post-Doctoral researcher in the group of Social Cognition in Human-Robot Interaction (S4HRI) at the Italian Institute of Technology, Genova (2017- now). She obtained her PhD in Neuroscience at the University of Modena and Reggio Emilia, Italy (2015). Her PhD project investigated the relationship between social interactions and visual attention. Her work focused on attentional mechanisms underlie joint attention and joint action. Francesca Ciardo research interests are social cognition, joint attention and joint action in HRI.

Vadim Tikhanoff graduated in Computer Science at the University of Essex, UK in 2004, presenting a study based on Artificial Intelligence and in particular Multi-Agent Systems. In 2005 he accomplished his MSc in Interactive Intelligent Systems presenting a work in Interactive Entertainment Robotics at the University of Plymouth UK. In 2009 he accomplished his PhD at the University of Plymouth with the thesis "Development of Cognitive Capabilities in Humanoid Robots." During his PhD he was a visiting student at the Italian Institute of Technology (IIT) for 10 months working in the Robotics, Brain & Cognitive Sciences Department under the supervision of Prof. Giorgio Metta where, apart from his research, he developed the prototype simulator of the iCub Humanoid Robot, which is widely used in robotics and cognitive modeling laboratories. Currently he has a senior post-doc position at the Italian Institute of Technology (IIT) working in the iCub Facility. Vadim Tikhanoff has a background in Artificial Intelligence and Robotic Systems and is now focusing on the development of innovative techniques and approaches for the design of skills in a robot to interact with the surrounding physical world and manipulate objects in an adaptive, productive and efficient manner.

Giorgio Metta is Vice Scientific Director at the Istituto Italiano di Tecnologia (IIT) and Director of the iCub Facility Department at the same institute. He coordinates the development of the iCub robotic project.He holds an MSc cum laude (1994) and PhD (2000) in electronic engineering both from the University of Genoa. From 2001 to 2002, he was postdoctoral associate at the MIT AI-Lab. He was previously with the University of Genoa and since 2012 Professor of Cognitive Robotics at the University of Plymouth (UK). He is also deputy director of IIT delegate to the training of young researchers. He is member of the board of directors of euRobotics aisbl, the

European reference organization for robotics research. Giorgio Metta research activities are in the fields of biologically motivated and humanoid robotics and, in particular, in developing humanoid robots that can adapt and learn from experience. Giorgio Metta is author of more than 250 scientific publications. He has been working as principal investigator and research scientist in about a dozen international as well as national funded projects.

Agnieszka Wykowska is PI of the Social Cognition in Human-Robot Interaction (S4HRI) research line at the Italian Institute of Technology, Genova. She is also affiliated with the Luleå University of Technology, Sweden as adjunct professor in Engineering Psychology. Her research focuses on social cognitive neuroscience and human-robot interaction. She uses behavioral measures (eyetracking, psychophysics) and EEG in HRI research. She obtained PhD in Psychology from the Ludwig-Maximilians-University in Munich (LMU) in 2008. Her background is cognitive neuroscience (M.Sc. in neuro-cognitive psychology, LMU, 2006) and philosophy (M.A. in philosophy, Jagiellonian University Krakow, Poland, 2001). She is an Associate Editor of the International Journal of Social Robotics, and she has served as a member of the Program Committee for the International Conference on Social Robotics (2010-2016), Human-Agent Interaction (2016, 2017) and Human-Robot Interaction (2016). In 2013 she received an Early Stage Career Prize at the COST meeting "The future concept and reality of Social Robotics: challenges, perception and applications - Role of Social Robotics in current and future society". In 2016 she has been awarded an ERC Starting Grant "Intentional Stance for Social Attunement": InStance.