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# The importance of mutual gaze in human-robot interaction

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**Abstract.** Mutual gaze is a key element of human development, and constitutes an important factor in human interactions. In this study, we examined –through analysis of subjective reports– the influence of an online eye-contact of a humanoid robot on humans' reception of the robot. To this end, we manipulated the robot gaze, i.e., mutual (social) gaze and neutral (non-social) gaze, throughout an experiment involving letter identification. Our results suggest that people are sensitive to the mutual gaze of an artificial agent, they feel more engaged with the robot when a mutual gaze is established, and eye-contact supports attributing human-like characteristics to the robot. These findings are relevant both to the human-robot interaction (HRI) research - enhancing social behavior of robots, and also for cognitive neuroscience - studying mechanisms of social cognition in relatively realistic social interactive scenarios.

**Keywords:** Social Human-Robot interaction, iCub, Mutual Gaze

## 1 Introduction

One of the major research topics in Human-Robot Interaction (HRI) research is designing robots that react to human needs, coordinate with humans by means of human-like actions, appear intentional, and behave like social agents. These features would allow for a better social attunement with humans and would facilitate their smooth integration into society. Besides design of robots for optimal adaptation in everyday environments, developments in HRI could benefit from investigation of social cognition in humans. More specifically, empirical findings in social neuroscience indicate the need for investigating social cognition during involvement in truly real-time interactive scenarios rather than through mere observation of social stimuli on a screen [1-3]. In order to examine mechanisms of social cognition in various naturalistic settings, humanoid robots consist an ideal trade-off between ecological validity and experimental control, for a review see [4]. In terms of ecological validity, humanoid robots increase perception of social presence due to their embodiment [5]. They can induce both low-level social cognition mechanisms (perceptual and motor processes) [6-8] and higher-order mechanisms, such as mentalizing [9]. In terms of experimental control, precise behavioral parameters of the robot can be manipulated, and subsequently, influence of these parameters on the social cognition mechanisms of humans can be examined [10]. Although low-level social processes are typically evoked when robots are used as interaction partners [6-8], they can be modulated by human-likeness of the robot, as people are sensitive to subtle human-like features in robot's behavior [11-12]. Therefore, increasing human-likeness of humanoid robots, should allow for more natural HRI on the one hand, and for understanding social cognition in more natural interactive scenarios on the other.

One of the most crucial cues of typically human communication is mutual gaze or eye contact; a reciprocal exchange of gaze between two people. The effect of eye contact has been long investigated and has been shown to modulate various aspects of cognitive processing, such as social attention, arousal, and memory [13-17]. Several studies have revealed that mutual gaze is an important factor of early development and that newborns are sensitive to eye contact [18]. For instance, neonates show a preference to direct gaze compared to an averted gaze or closed eyes [19]. Moreover, Farroni et al. showed that 4-old month infants require an established eye contact in order to shift their attention towards another's gaze and establish joint attention [20]. Similarly, 6-month infants followed the adults' gaze shift only when it was preceded by eye contact [21]. With regard to arousal effects, Mason et al. [22] showed that people engaged in eye contact are perceived as more likable and attractive than the ones who showed disengagement. Similarly, female faces with direct gaze were rated as more attractive by male perceivers [23]. Direct gaze does not only produce arousal effects, but also captures attention [24], improves identity recognition [25] and gender discrimination [14]. For example, Senju and Hasegawa showed that direct gaze at participants resulted in delayed disengagement of attention from the face, and therefore slower detection of peripheral targets, as compared to averted gaze or closed eyes [24].

Interestingly, in HRI, Yonezawa et al. showed that the eye contact with a stuffed-toy robot, induced a favorable evaluation of the robot [26]. In another study, in which humans were teaching a robot, it seemed more intentional when it displayed eye contact compared to a random gaze [27]. Furthermore, robots with direct gaze during a normal conversation were perceived as more social and intelligent relative to robots with avoiding gaze, while the opposite effect held for an embarrassing situation [28]. A detailed review of various types of social gaze (mutual, referential, joint attention, averted) in HRI is provided by Admoni et al. focusing both on human-, design- and technology-centered approaches [29]. Although some studies have addressed the effect of mutual gaze in HRI, research in this line is not extensive. This might be due to limitations in the actual implementation of biologically-inspired robot eyes, since every degree of freedom in eye movements involves addition of small but powerful actuators increasing both cost and complexity [29]. Unlike virtual agents, which offer a high degree of human-likeness in eyes, most social robots lack behavioral realism. However, the importance of eye-contact for human communication calls for biologically-inspired robot eyes and points towards the need of investigating thoroughly the impact of mutual gaze in HRI using both subjective and objective measures.

### 1.1 Aim of study

Our study examined the impact of mutual gaze with an embodied humanoid on engagement and perceived human-likeness. We involved participants in an interactive experiment with the humanoid robot iCub [30]. iCub has physically embodied 3D mechanical eyes with 3 degrees of freedom (common tilt and independent vergence in each eye) and 3 additional degrees of freedom in the neck (roll, pitch, yaw). Participants were engaged in a target identification task, with targets presented on screens positioned laterally with respect to iCub. The question of interest was whether participants would be sensitive to mutual gaze, while being involved in a different, orthogonal task (target identification), and whether mutual gaze would influence engagement and perceived human-likeness. We manipulated gaze contact by programming iCub to look at the participants' eyes in one condition or to look down in another condition. To evaluate engagement, sensitivity to mutual gaze as well as perceived human-likeness, participants were asked to respond to a number of questions during-, and after the experiment.

## 2 Materials and Methods

### 2.1 Participants

Twenty-four healthy participants provided responses in the questionnaires we administered (mean age = 26.71 ± 6.39; 11 female; 3 left-handed). The study was approved by the local ethical committee (Comitato Etico Regione Liguria) and participants gave a written consent prior to their participation. All had normal or corrected-to normal vision, received an honorarium for their participation, and were debriefed about the purpose of the study at the end of the experiment.

The experimental setting consisted of two screens (21.5 inches), the iCub and a desk. Participants seated on a chair at the opposite side of the desk at a distance of 125 cm from the robot and 105 cm from the center of the screens. The height of iCub's and participants' eyes was at the same level, and 124 cm from the ground.

### 2.2 Methods

**Procedure**

The experiment consisted of 160 trials, divided into 16 blocks of 10 trials each. The blocks were randomly assigned to one of the gaze condition: mutual gaze when the robot was looking at the eyes of the participant or neutral gaze when the robot was looking down (see Figure1). In the beginning of every trial the robot had its eyes closed. Then, it opened its eyes and extracted the information regarding the face of the participant and the position of their eyes. After establishing mutual or neutral gaze the robot shifted randomly to one of the screens where a target letter (V, T) appeared. Participants were instructed to identify the letter by pressing a mouse button as fast as possible. One trial lasted for the fixed time of 6.2 s plus subject's response time (RT). At the end of every block, participants rated their engagement with the robot on 10 point Likert scale (1= strongly disengaged; 10= strongly engaged). During the experiment, subjects were asked to keep their gaze constant towards the eyes of the robot. The task lasted about 25 mins. After the end of the task, they filled a questionnaire regarding their experience with the robot. The questions of the questionnaire are presented in Table 1. The task and the questionnaire were completed within one experimental session lasting about 60 mins.

**Table 1.** Administered questionnaire

| 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. |

**Figure 1.** Gaze conditions. Mutual Gaze: the robot looking at participants' eyes (left panel). Neutral Gaze: the robot looking down (right panel)

## iCub and algorithms

In order to detect the human eyes, the face detector, available from the following repository [https://github.com/robotology/human-sensing] was used. This detector makes use of the dlib library [http://dlib.net]. It detects frontal human faces using the classic Histogram of Oriented Gradients (HOG), combined with a linear classifier, an image pyramid and a sliding detection window scheme (see Figure 2 for the visual output of the algorithm).

In order to control the movement of the neck and the eyes of iCub, we used the YARP Gaze Interface, iKinGazeCtrl [31]. This interface allows for controlling iCub's gaze in a biologically-inspired way, with independent movement of neck and eyes.

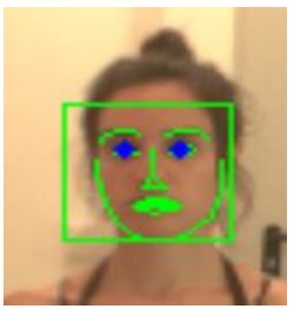

**Figure 2.** Output of the face detector algorithm drawn from the left robot eye camera; blue circles represent the detected position of the eyes.

## Rating

Response to the questionnaires were rated by two independent evaluators. When a response was not included in the same category by both reviewers, it was excluded from the results. Additionally, if one participant gave more than one response, all the responses were included in the corresponding categories. Questions 4 and 5 were combined together as representation of a "non-verbal Turing test" probing mind attribution to the robot. If participants answered "machine" or "human" in question 4 and then "yes" to question number 5 (constant belief along the experiment) their response was assigned to the category “machine” or “human”. If they answered “no” to question 5 (changing belief throughout the experiment) and gave evidence for/against both attributes in any of the two questions they were categorized as “both”. Responses were categorized in four different categories:

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 features of task and congruency between the robot’s gaze direction and target position.
4. **Other task-related**: statements about task features that we did not manipulate.

# 3 Results

12 of the participants reported no or low familiarity with the robot, 9 participants responded some experience (rating score: 3), 1 reported to be substantially familiar (rating score: 4). The mean familiarity rating was: M = 2.16, SEM = 0.92.

## 3.1 Perceived difference between experimental conditions

Regarding the question of perceived difference across conditions of the experiment, 22 (92%) of the participants responded that they noticed a difference. Among them, 7 people were excluded from further analyses, because either they did not indicate any reason, or their statements were not clear. The responses of the remaining 15 participants (17 responses) were further classified into the four above-mentioned categories. More specifically, 64.7% of the answers indicated mutual gaze, 23.5% included other-robot related reasons, 5.88% referred to congruency, while another 5.88% indicated other task-related reasons (see Figure 3, left). To check whether the frequencies of the answer for each category differed from expected equal frequencies (0.25) we run a chi-square test. Results revealed that the frequency of the four answers was significantly different from equal, $\chi^2$ (3) = 15.7, p<0.01.

## 3.2 Engagement

Overall, participants rated their engagement with the robot with a mean of M = 6.32, SEM = 1.64 (see Figure 4 for mean scores across the blocks). Wilcoxon signed-rank test revealed that participants rated significantly higher the mutual gaze (M = 7.0, SEM = 1.34) compared to neutral gaze condition (M = 5.62, SEM = 1.68): Z = -3.9, p < 0.001. 2 participants mentioned unclear reasons for their engagement and were excluded from further analysis. The responses from the remaining 22 participants (31 different responses) were further categorized into the four labels. In particular, 61.3% of the responses included the mutual gaze, 16.1% other robot-related reasons, 16.1% mentioned congruency and a 6.45% reported other task-related reasons (Figure 3, middle). Chi-square test showed that the frequency of the answers was significantly different from equal, $\chi^2$ (3) = 24.9, p<0.001.

## 3.3 Human-likeness (non-verbal Turing test)

Responses to the “nonverbal Turing test” were distributed as following: 1 participant was excluded because evaluators disagreed on the categorization of the statement; 14 participants perceived the robot's behavior as resulting from mechanistic operations and their arguments concerned mostly the random robot’s behavior (50%) and the repetitive movements (33.33%). Finally, 9 participants perceived the robot both as machine-like and as human-like indicating that their belief changed across the experiment. 77.78% of these participants mentioned mutual gaze as the factor that enabled their change of belief, while 22,2% reported other robot-related reasons (Figure 3, right). Due to the small sample size, no statistical analysis was performed for this question.

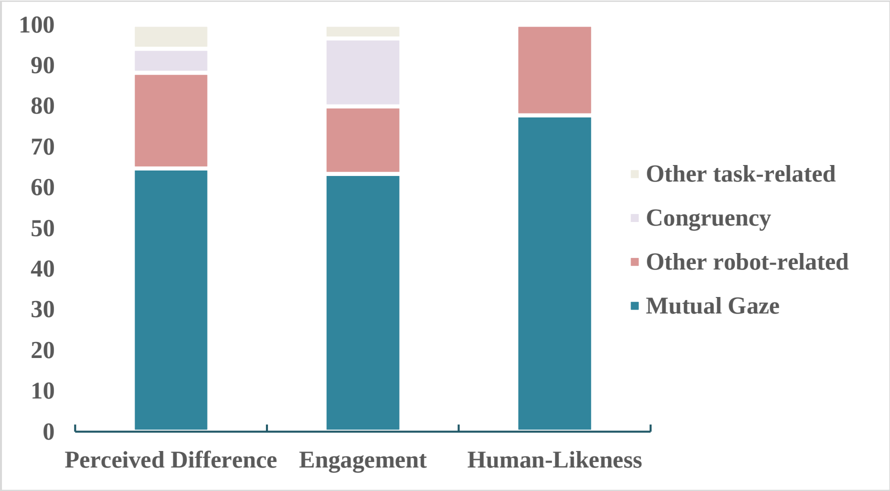


**Figure 3.** The figure presents the responses of the participants (percentages), plotted as: Mutual gaze (blue), Other robot-related (light red), Congruency (light purple), Other task-related (light green). The left bar represents the responses to the question related to a perceived difference across the experiment, the middle to engagement and the right to human-like characteristics that participants attributed to the robot.

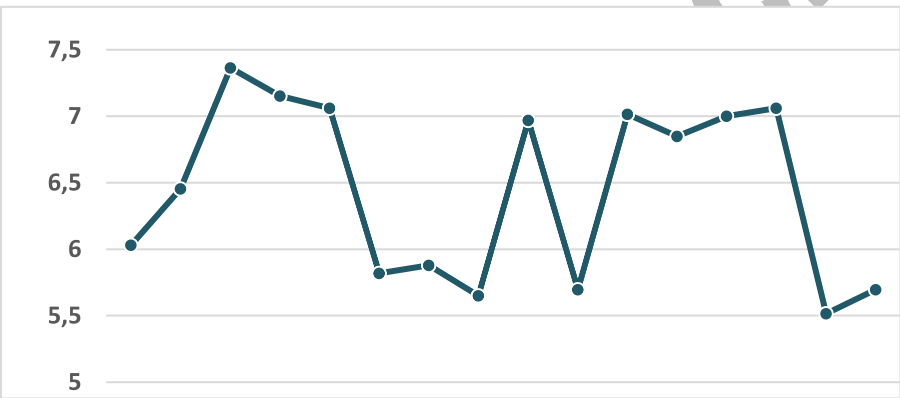


**Figure 4.** Mean ratings of social engagement across experimental blocks plotted as a function of gaze condition: mutual vs neutral.



## 4 Discussion

The question of interest in this experiment was the effect of robot's eye-contact on human engagement and perceived human-likeness. There were two types of robot gaze, mutual and neutral, randomly distributed across the experiment. We were interested in understanding whether people are sensitive to mutual gaze (while being involved in a different task), whether mutual gaze results in higher degree of engagement, and if it also impacts perceived human-likeness.

Results showed that the largest number of participants (64.7%) were sensitive to the difference in the gaze despite the fact that they were engaged in a different task. Regarding the mean rating of engagement with the robot, the scores were above the middle value of 5 for all blocks. Interestingly, the blocks of mutual gaze were rated constantly higher than the neutral gaze blocks and the mean rating was significantly different across the two conditions. Additional, mutual gaze with the robot was reported as a reason for engagement in the highest portion of the responses (61.3%). This result suggests that the direct gaze of a robot engages humans and this effect could have important implications for HRI. For instance, a robot acting as a tutor, or trainer can better engage attention of human users by gazing frequently at participants. More specifically, robot-assisted therapies for children with autism spectrum condition (ASC), could benefit from increasing engagement during mutual gaze, so that children can improve both in terms of social eye contact, which is usually part of their disorder, and also engagement in joint attention, for which mutual gaze is crucial [29].

The responses regarding their belief of human- or machine-processing, indicate that although all participants believed that the robot was processing like a machine, 40% of the participants thought that this was not constant throughout the experiment. Interestingly, mutual gaze was one of the key factors in perception of behavior as resulting from human-like reasoning (77.7% of the responses).

Regarding machine-like features, 50% of the participants who thought that the robot was only processing like a machine, pointed out that its behavior was random. This suggests that a robot which would be aware of the environment and would perform more meaningful actions could be easier perceived as a human-like interactor. Moreover, almost 35% of the participants attributed machine-like behavior to the robot because of the repetitive movements.

Present findings indicate for the first time that ostensive communicative behaviors, such as mutual gaze, increase the human-likeness of robots' behavior and can engage humans in social interactions with humanoids.

## Conclusion

Mutual gaze is an important factor of communication and should therefore consist a crucial feature in HRI. The results of our study showed that mutual gaze has a positive effect on the human user both in terms of engagement and in attributing human-likeness to the humanoid robot. We propose that the design of social robots with biologically-inspired eyes and eye movements, allowing for human-like mutual gaze, will have a large impact on the social integration of the robots.

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