Biological Psychology 175 (2022) 108451

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

Being watched by a humanoid robot and a human: Effects on affect-related psychophysiological responses☆

Helena Kiilavuori [a], Mikko J. Peltola [a,b], Veikko Sariola [c], Jari K. Hietanen [a,*]

[a] *Human Information Processing Laboratory, Faculty of Social Sciences, Tampere University, FI -33014, Finland*
[b] *Tampere Institute for Advanced Study, Tampere University, Finland*
[c] *Faculty of Medicine and Health Technology, Tampere University, Korkeakoulunkatu 3, FI - 33720, Finland*

ARTICLE INFO

Keywords:
Electroencephalography
Electromyography
Mutual gaze
Social robot
Skin conductance

ABSTRACT

Eye contact with a humanoid robot has been shown to evoke similar affect and affiliation related psychophysiological responses as eye contact with another human. In this pre-registered study, we investigated whether these effects are dependent on the experience of being "watched". Psychophysiological responses (SCR, zygomatic and corrugator facial EMG, frontal EEG asymmetry) to a humanoid robot's or a human model's direct vs. averted gaze were measured while manipulating the participants' belief of whether the robot/human model could see them or not. The results showed greater autonomic arousal responses and facial responses related to positive affect both to the robot's and the human model's direct vs. averted gaze, regardless of the belief condition. The belief condition influenced the overall magnitude of these responses to both stimulus models, however, to a lesser extent for the robot than for the human model. For the frontal EEG asymmetry, the effect of gaze direction was non-significant in both belief conditions. The results lend further support for the importance of eye contact in human-robot interaction and provide insights into people's implicit attributions of humanoid robots' mental capacities.

1. Introduction

Previous research on human-robot interaction (HRI) has shown that interacting with a humanoid robot may activate similar socio-cognitive processes as interacting with another human. For instance, perceiving a humanoid robot's motor actions has been shown to evoke similar motor resonance in human observers as observed in human-human interaction, including (putative) mirror neuron system activity, motor interference effects, and spontaneous mimicry of the observed actions (for a review, see Wykowska, Chaminade, & Cheng, 2016). Robots have also been found to induce joint attention, one of the most fundamental processes of social cognition (Kompatsiari, Bossi, & Wykowska, 2021; Kompatsiari, Ciardo, De Tommaso, & Wykowska, 2019; Wykowska et al., 2016). In the study of Kompatsiari et al. (2021), a physically embodied humanoid robot (iCub) was shown to induce standard gaze-cuing effects evidenced both at the behavioral and neural level measurements.

Among humans, one of the most powerful social signals is another individual's gaze directed towards the self. Perceiving another individual's direct gaze (eye contact) indicates that this person's attention is directed at the self, and it is usually perceived as a positive social signal and an initiative for interindividual interaction (for a review, see Kleinke, 1986). Perceiving another's direct gaze has various effects on several cognitive and affective processes, including attention, memory, pro-social behavior, self-awareness, and positively valenced affective reactions (for reviews, see; Conty, George, & Hietanen; 2016; Hadders-Algra, 2021; Hietanen, 2018; Senju & Johnson, 2009).

Interestingly, recent studies in HRI have provided evidence that perceiving direct gaze of a humanoid robot may evoke similar effects as that of another human. To date, the majority of these studies have focused on the attentional effects of a humanoid robot's direct gaze. Two eye-tracking studies exploring the effect of humanoid robots' gaze direction on participants' fixation patterns showed that the more the robot looked at the participants the more the participants fixated to the robot's face (Kompatsiari et al., 2019; Xu, Zhang, & Yu, 2016). Studies employing brain activity measurements have also provided evidence for the attentional effects of humanoid robots' direct gaze (Belkaid,

---

☆ This research was supported by The Academy of Finland (grant #330158). We would like to thank Samuli Pyssysalo, Sonja Veistinen and Katariina Sarlund for helping in the data collection.

* Corresponding author.
E-mail address: jari.hietanen@tuni.fi (J.K. Hietanen).

https://doi.org/10.1016/j.biopsycho.2022.108451
Received 21 February 2022; Received in revised form 27 October 2022; Accepted 31 October 2022

Kompatsiari, De Tommaso, Zablith, & Wykowska, 2021; Kompatsiari et al., 2021). For instance, one EEG study investigated the effect of a humanoid robot's gaze (direct vs. averted) on the participants' neural activity and decision making during a strategic game with the robot (Belklaid et al., 2021). The results showed that the participants responded with longer decision times and greater power in electroencephalographic (EEG) alpha-band activity when the robot established eye contact before the decision as compared to when the robot avoided eye contact before the decision. The researchers suggested that eye contact with the robot increased the need to suppress the distraction to irrelevant information (the robot's gaze), which resulted in delayed decisions during the game (Belklaid et al., 2021). Taken together, these findings imply that a humanoid robot's direct gaze may have similar attention-capturing effects as direct gaze of another human.

To date, less is known about the affect-related effects of a humanoid robot's direct gaze. Previous studies have provided evidence that eye contact established by a humanoid robot may induce positive subjective evaluations, such as perceived friendliness, animacy, and anthropomorphism, of the robot (Kühnlenz, Wang, & Kühnlenz, 2017; Shiomi, Nakagawa, & Hagita, 2013; Yonezawa, Yamazoe, Utsumi, & Abe, 2007). Some studies have shown that making eye contact with a robot induces increased self-reported feelings of engagement towards the robot (Kompatsiari et al., 2021, 2019). Even though these studies have provided important information on how eye contact affects the subjective attitudes towards robots, they have not been able to reveal the automatic, non-controlled reactions to these agents. In natural social interaction, mechanisms of social cognition are often subconscious and, therefore, not accessible by explicit measurements (Evans & Stanovich, 2013).

To specifically investigate the automatic, implicit affective effects of eye contact in HRI, we recently compared both affect-related and attentional psychophysiological responses to direct vs. averted gaze of a humanoid robot (NAO) and of another human (Kiilavuori, Sariola, Peltola, & Hietanen, 2021). Participants' skin conductance responses (SCR) indexing autonomic arousal, facial electromyographic (EMG) activity reflecting positively valenced affective responses, and heart rate deceleration responses reflecting attention allocation were measured in response to a (live) humanoid robot's or a human partner's direct vs. averted gaze. The results showed a similar pattern of responses to the robot's and the human model's direct vs. averted gaze: all these responses were greater in response to direct versus averted gaze, with both the robot as well as the human partner. For the skin conductance and facial zygomatic responses, however, the effect of gaze direction was greater for the human partner as compared to the robot. We suggested that the human partner's greater effect of gaze direction could reflect greater social relevance being ascribed to another human's vs. a humanoid robot's gaze (Kiilavuori et al., 2021).

Previous studies investigating human-human eye contact have shown that the effects of another's direct gaze seem to be evoked only in certain circumstances – only when the observer believes to be *seen* by the gazer. Several studies have demonstrated that another person's direct gaze elicits enhanced psychophysiological responses only when facing a real, physically present person, but not when perceiving a mere picture (Donovan & Leavitt, 1980; Hietanen, Leppänen, Peltola, Linna-aho, & Ruuhiala, 2008; Pönkänen, Alhoniemi, Leppänen, & Hietanen, 2011) or a pre-recorded video of a human face (Hietanen, Peltola, & Hietanen, 2020; Lyyra, Myllyneva, & Hietanen, 2018; Prinsen & Alaerts, 2019). The effect of being seen was directly shown in a study where participants' autonomic and brain responses to direct vs. averted gaze of a live human model were measured while manipulating the participants' belief of whether the human model was able to see them or not (Myllyneva & Hietanen, 2015). In one condition, the participant and the human model were able to see each other normally through a voltage sensitive liquid crystal window (LC-window), whereas in the other condition, the participant was led to believe that the vision from the model person's side of the window was blocked with an alleged one-way window. The results showed that eye contact elicited enhanced autonomic (skin conductance and heart rate deceleration) and brain (frontal P3 event-related potential) responses only in the condition where the participant knew that the model person could see them, but not when the vision from the model person's side was believed to be blocked. Further evidence for the effect of being seen came from a recent study where autonomic responses to another's direct vs. averted gaze were measured in live interaction, in a bidirectional video call, and during watching a mere video (Hietanen et al., 2020). Direct gaze was found to elicit increased autonomic arousal in live interaction and bidirectional video call but not when the participants were watching a mere video of another's face.

Considering that the experience of being seen seems to be an important requirement underlying the psychophysiological effects of eye contact, how is it possible that similar effects are evoked when making eye contact with a humanoid robot, a mere machine whose behavior follow preprogrammed scripts? The results by Kiilavuori et al. (2021) suggest that despite humanoid robots' artificiality, their direct gaze maybe intuitively perceived as a social signal indicating that the robot is looking at the observer (Kiilavuori et al., 2021). Ascribing such agency to a robot could, in turn, be an indication of people's tendency to ascribe mental states to robots (Gray, Gray, & Wegner, 2007). Indeed, previous studies in HRI have provided evidence that people tend to perceive humanlike characters, sometimes even mind, in robots (Airenti, 2015; De Graaf & Malle, 2019; Gazzola, Rizzolatti, Wicker, & Keysers, & 2007; Krach et al., 2008; Oberman, McCleery, Ramachandran, & Pineda, 2007; Thellman, Silvervarg, & Ziemke, 2017).

In the present study, we wanted to directly investigate whether the observers' experience of the state of a humanoid robot's "mind", specifically, the experience of the robot watching the observer, has an impact on the psychophysiological responses to the robot's direct and averted gaze. To this end, we measured participants' affect-related psychophysiological responses to a humanoid robot's or a human model's direct vs. averted gaze presented through a voltage sensitive LC window while manipulating the participants' belief of being seen or not by the robot/human model. The responses were measured in two kinds of conditions: in one condition, the participant knew that the robot (or the human model) could see them through the LC window (Belief of Being Watched condition, BW), whereas in the other condition, the participant was made to believe that "a one-sided window" was inserted onto the robot's side of the LC window so that the robot (or the human model) could not see them (Belief of not Being Watched condition, BnW). In reality, the "one-sided window" was only a sheet of transparent plexiglass and did not block the vision from the robot's side. A similar procedure has been used in previous studies from our laboratory (Myllyneva & Hietanen, 2015; Hietanen, Kylliäinen, & Peltola, 2019).

Participants' psychophysiological responses to different gaze conditions were investigated by measuring autonomic arousal (skin conductance) (Critchley, 2002), and facial electromyography (EMG) from the muscles *zygomaticus major* and *corrugator supercilii.* Facial EMG has been used to measure automatic emotional responses (Cacioppo, Petty, Losch, & Kim, 1986; Dimberg, Thunberg, & Elmehed, 2000), although they may also reflect communication of social motives, i.e. automatized social responses signaling affiliative intentions (Fridlund, 1991; Parkinson, 2005). Furthermore, we also measured relative hemispheric asymmetry derived from the frontal alpha frequency band EEG activity associated with approach-withdrawal motivational tendencies (Harmon-Jones, Gable, & Peterson, 2010). Earlier studies have found relatively greater left than right frontal brain activity associated with positive affect and approach motivation in response to another individual's direct vs. averted gaze (Hietanen et al., 2008; Pönkänen, Peltola, & Hietanen, 2011; Soriano, Daniels, Prinsen, & Alaerts, 2020; Uusberg, Allik, & Hietanen, 2015). To the best of the authors' knowledge, only one study has investigated frontal EEG asymmetry in response to eye contact with a humanoid robot (iCub) (Kompatsiari et al., 2021). In this study, eye contact with the robot was not found to induce significant differences in the activity between the left and right hemispheres (Kompatsiari et al., 2021).

In the present study, the participants were divided into two experimental groups. In one group, the stimulus was a humanoid robot (human-robot group) and, in the other group, the stimulus was a human model (human-human group). We chose a between-subject design for the manipulation of the stimulus model to eliminate the potential transfer effects across the stimulus conditions due to participants repeatedly comparing the conditions with each other. In addition, to protect the quality of the data, we wanted to avoid the experiment becoming too long. A within-subject design would have doubled the number of trials and this, in turn, would have increased the risk for strong habituation effects, especially on SCRs (Boucsein, 2012), and the participants becoming increasingly inattentive in the course of the experiment.

According to preregistered hypotheses (see https://osf.io/htyu9/?view_only=05ac7270191b489382dfe27e4caed3bb), we expected similar pattern of responses to the humanoid robot's and the human model's gaze stimuli in each measure. That is, we expect greater autonomic arousal (SCR) and greater facial EMG activity associated with an affective/affiliative response (enhanced activation of the *zygomaticus major* muscle and enhanced relaxation of the *corrugator supercilii* muscle) in response to direct vs. averted gaze of the humanoid robot as well as of the human model. Furthermore, despite the somewhat inconsistent earlier findings regarding the effect of gaze direction on the frontal EEG asymmetry, we also expected greater relative left-sided frontal alpha band EEG activity reflecting approach motivation in response to direct vs. averted gaze both for the robot and for the human model. Importantly, for autonomic arousal and frontal EEG asymmetry, we expected the effects of gaze direction only in the condition where the participants know that they can be seen by the robot/human model (BW-condition). This finding would indicate that direct gaze induces these responses only when it is accompanied by the experience of being seen by the robot/human model. For the facial EMG responses, however, previous studies have indicated that the facial reactions may not be sensitive to this type of top-down influence (Hietanen et al., 2018, 2019, 2020). Thus, for the EMG responses, we expected the effect of gaze direction regardless of BW vs. BnW condition.

2. Methods

2.1. Participants

We gathered data from 100 participants recruited from students and staff members of Tampere University and Tampere University of Applied Sciences. According to an A priori analysis performed with G*Power 3 software (Faul, Erdfelder, Lang, & Buchner, 2007) ($1-\beta = .80$, $\alpha = .05$), this sample size exceeds the required sample size ($n = 62$) for finding medium size interaction effects ($\eta_p^2 = 0.06$) between factors in a $2 \times 2 \times 2$ mixed ANOVA. This test is crucial for determining whether responses to the direct vs. averted gaze differ between any of the conditions. The participants were assigned in either of the two experimental groups: human-robot group or human-human group. The participants were required to not have any neurological or psychiatric diagnosis. Participants who reported severe neurological or psychiatric symptoms were also excluded from the final analyses. Some participants were excluded from the final sample due to a technical or other error occurring during the data collection session (e.g. recording error, participant's extensive movement during the session, error of the model person's gaze behavior during the trials). Furthermore, the participants in the human-robot group who reported having extensive previous experience with NAO robot or robotics, in general, were excluded from the final analyses. After the above-mentioned exclusions, the sample consisted of 82 participants ($n_{robot} = 40$; 29 females and 11 males; mean age = 29.43, SD = 12.30; $n_{human} = 42$; 32 females and 10 males; mean age = 30.55, SD = 11.23). All participants gave a written, informed consent, and received either course credits or movie tickets for their participation. Ethical statement for the experiment was obtained from the Ethics Committee of the Tampere Region.

2.2. Stimuli

One male and one female, previously unknown to the participants, served as stimulus persons (models) in the human-human group. The model's and the participant's gender was matched. This was done to control for the potential gender-related effects (e.g. Argyle & Dean, 1965; Pönkänen et al., 2011). The models bore a neutral expression and kept their face as motionless as possible throughout the experiment. When necessary, eye blinks were allowed to occur. The models were instructed to maintain a slight muscle tonus in the lower part of the face in order not to look sullen or fatigued. Depending on the trial, the models had their head and gaze either straight ahead or averted 65° to the left or right (see Fig. 1). When averting their head and gaze side-ways (gaze always pointing to the direction of the nose), the models were instructed to turn their heads but not their shoulders. The stimulus in the human-robot group was a humanoid robot NAO by SoftBank Robotics. The behavior of the robot was programmed with Choregraphe software (SoftBank Robotics). As in the human-human group, the robot had its head and gaze either straight ahead or averted to the left or right. When the robot's head and gaze was rotated 65° to the left or right, the participant could only see a part of the "pupil" of the robot's left or right eye (see Fig. 1). This ensured that the difference between the robot's direct and averted gaze was as clear as possible. The robot's eye LEDs were programmed to blink every third second in order to make an impression of eye blinking. Because the stimuli were always presented for 3000 ms, the blink occurred once during each stimulus-presentation period. During the stimulus presentation, the models and the robot were static except for occasional blinks.

Fig. 1. An illustration of the direct and averted gaze for a human model and the NAO robot.

2.3. Experimental procedure

The experiment was conducted in four separate blocks: two for the Belief of Being Watched condition where the participant knew that the partner (robot/human) could see them through the transparent shutter (BW condition) and two for the Belief of not Being Watched condition where the participant was misled to believe that the partner could not see them (BnW condition). The BW and BnW blocks were presented alternately, and the starting order of the blocks was counterbalanced. Between each block, there was a short pause during which the participant was told which condition (BW or BnW) was going to be presented next. Each experiment was led by two experimenters, the leading and the assisting experimenter. In the beginning of the experiment, the experimenters introduced themselves and informed the participant that the purpose of the study was to measure physiological responses during a simple interaction situation. The placement of the electrodes was performed after the instructions had been given.

The participants were informed that the experiment would consist of four separate and two kinds of blocks (BW/BnW) which they would carry out with a partner (NAO/[name of the model person]). The partner would be seated on the other side of the LC window. For the BW blocks, it was instructed that the LC window would alternate between transparent and opaque states. During the transparent periods, the participant and the partner would be able to see each other. The participant was instructed to simply look at the partner while the window was transparent and to remain focused on the window when it was opaque. The experimenters demonstrated the functioning of the LC window for which the assisting experimenter got seated on the partner's side of the window.

For the BnW blocks, the participants were told that the blocks would be otherwise similar to the BW blocks, but this time the vision from the partner's side of the window would be blocked by inserting "a silver-covered one-way window" onto the partner's side of the LC window. Thus, only the participant would see the partner during the transparent periods, but the partner would not be able to see them. However, similarly to the BW block, the participant's task would be to look at the partner each time the window turns transparent. To demonstrate the function of the "one-way window", the assisting experimenter slid an extra sheet with a thin black frame onto their side of the LC window. In reality, the "one-sided window" was only a sheet of plexiglass transparent from both sides. When the sheet had been placed onto the window and the participant saw that they could still see the assisting experiment through the window, the participant was taken to the other side of the window to show them the "one-sided window" from that side. During the walk, the assisting experimenter quickly slid another sheet with an opaque, silver-colored surface on top of the previously placed (transparent) sheet to demonstrate that it was impossible to see through the window from that side. When the participant returned to their own side, the assisting experimenter quickly removed the opaque sheet from the top of the transparent sheet so that the window was transparent again when the participant reached the other side. This procedure has been used and described, in detail, also in our previous studies (Hietanen et al., 2019; Myllyneva & Hietanen, 2015).

After the instructions, the partner was introduced to the participant. In the human-human group, the human model entered the laboratory and greeted the participant after which they got seated on the other side of the LC window. In the human-robot group, the experimenter opened the curtains behind which NAO was hidden during the instructions. The robot stood up autonomously, introduced itself by saying [in Finnish] "hi, my name is NAO" and performed some human-like gestures, such as nodding and some arm and hand movements. The participant was asked to move their body from left to right to notice that NAO was able to follow the participant's movements by turning its head. Then the assistant experimenter placed NAO on the other side of the LC window.

Before starting the experimental trials, it was confirmed that the participant felt that their eyes were at the same level with the human model's/NAO's eyes. In the human-human group, either the participant's or the human model's seat was adjusted (if necessary) to obtain the same level of eyes. In the human-robot group, the experimenter "asked" NAO to adjust its gaze/head towards the participant after which the robot started to perform some head movements (initiated by the assistant experimenter who was standing behind the curtains) as if it was searching for the right head position. After the movements, if still necessary, the participant's seat was adjusted to obtain the level of NAO's eyes.

On each trial, the shutter became transparent for 3000 ms, during which the human model/robot looked either directly at or away (right or left) from the participant. The order of the trials/gaze directions was randomized and delivered by E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA). The instructions for the human model's gaze directions were presented on a monitor hidden from the participants' view. The robot's gaze direction was controlled by the experimenter via a laptop. The experimenter monitored the participant's skin conductance level on-line and initiated the next trial when the skin conductance level had returned to the baseline level, however, not before at least 10 s had passed from the shutter turning opaque. In each block, 6 trials were collected for both gaze directions (direct gaze: 6; averted gaze: 3 left/3 right). Thus, altogether 12 trials were collected for both gaze directions in both BW and BnW conditions. During each pause between the sessions, the LC window was opened so that the participant could see how the "half-silvered one-way window" was either inserted to or removed from the partner's side of the window. Both experimenters sat behind curtains during the experimental trials so that the participants could not see them.

After the experimental trials, the participants completed brief questionnaires regarding their subjective affective feelings in response to different gaze directions in both belief conditions. In order to help the participants recall their feelings in each condition, the shutter was opened six times for 3000 ms to show the three different gaze directions in both conditions. The order of the gaze direction presentations was counterbalanced. After each stimulus presentation, the participants evaluated their own feelings of affective valence and arousal on a 9-point Self-Assessment Manikin (SAM, see Bradley & Lang, 1994) scales (1 = unpleasant/calm, 9 = pleasant/arousing). In addition, the participants were asked to evaluate whether they felt the human model/robot was looking at them or not. The purpose of this task was to confirm that the participants felt that the robot and the human model were looking at them when their gaze/head was direct. The participants were asked to answer to a single statement on a 9-point scale: "The model/robot looked directly at me" (1 = totally disagree, 9 = totally agree). For each gaze direction presentation, the participants were instructed to first evaluate the subjective affective feelings and then the gaze direction.

At the very end of the experiment, to find out possible suspicions regarding the "one-way window" deceit, the participants were first asked whether they felt that the knowledge of the partner's possibility to see through the window affected them in some way during the experimental trials. After that, the participants were directly asked whether they had any suspicions about the experiment or whether they felt that the experimenters left something unsaid during the instructions.

2.4. Acquisition of the physiological data

For SCR measurements, participants were asked to wash their hands without soap before entering the laboratory. The SCR was measured with two electrodes (Ag/AgCl) filled with isotonic paste and attached to the palmar surface of the distal phalanxes of the index and middle fingers of the participant's left hand. EMG was used to measure facial muscle activity over *Zygomaticus major* and *Corrugator supercilii* muscle regions. The skin over the recording sites was rubbed with alcohol. Electrode paste (Signa gel) was injected to bipolar 4-mm Ag/AgCl electrodes (BioMed Electrodes) which were then attached over the recorded muscle sites according to the placement guidelines by Fridlund and Cacioppo (1986). To disguise the purpose of the facial EMG electrodes, the participants were told that the facial sensors were attached for measuring skin temperature. Continuous EEG was recorded from 64 electrode sites using active Ag–AgCl electrodes (actiCAP, Brain Products, GmbH, Munich, Germany). Horizontal (HEOG) and vertical (VEOG) eye movements were monitored bipolarly from the sites beside the outer canthi of each eye (HEOG) and above and below the left eye (VEOG). Electrode paste was used to reduce the electrode impedances below 30 kΩ. All electrodes were referenced to the common average. The signals were amplified by a QuickAmp amplifier and continuously recorded with BrainVision Recorder software (Brain Products GmbH, Munich, Germany) at a sampling rate of 1000 Hz.

2.5. *Analysis of the physiological data*

The plan for the analysis of the physiological data is reported in the preregistration of the study. Deviations from the preregistered analysis plan are reported in the final section of the *Methods*.

Skin conductance. The SCR data were re-sampled offline to 100 Hz and filtered with a 10-Hz low pass filter using BrainVision Analyzer 2.1 software. A response was defined as the maximum skin conductance change within a time frame of 900–6500 ms after stimulus onset. To calculate the maximum change, the lowest skin conductance was detected within 900–3500 ms after stimulus onset and subtracted from the largest skin conductance value detected within 900–6500 ms after stimulus onset (Sjouwerman & Lonsdorf, 2019). In a case of two peaks within one response, only the first one was taken into account. The trial was coded as a zero response if the maximum amplitude change was less than 0.01 μS. Trials with no amplitude rise (of at least 0.01 μS) until the first 3500 ms after stimulus onset were coded as zero responses as well. If there was an amplitude rise of 0.01 μS or more during the first 900 ms after stimulus onset, the trial was rejected. One participant in the human-human group was excluded entirely from the subsequent analyses because more than 50 % of the trials were rejected due to the afore mentioned criteria in at least one of the conditions. Thus, for the SCRs, the final sample consisted of 41 participants for the human-human group and 40 participants for the human-robot group. The data from accepted trials (the overall mean number of accepted trials/condition: 10.9) were averaged in each condition for each participant, including trials with zero responses. Including zero responses into the calculations results in a measure that combines response size and response frequency (i.e., magnitude of the skin conductance responses; Dawson, Schell, & Filion, 2000). Because the SCRs were not normally distributed, a Log10-transformation was performed to normalize the SCR data (Lg10 (SCR+1)).

Facial muscle activity. EMG activity was quantified for 6 time intervals, each lasting 500 ms. The signal was filtered offline with a 28–249 Hz bandpass filter (BrainVision Analyzer 2.1). The EMG signal around each experimental trial was visually inspected for artifacts due to excessive muscle movements and blinks. The inspection of the signal was performed individually for both investigated muscle regions, independently from each other. For corrugator responses, one participant was excluded from the human-robot group due to more than 50 % of the trials being rejected in at least one of the conditions ($n_{human:}$: 42; n_{robot}: 39). For the final analyses, the signal was rectified and segmented into 500-ms epochs from 500 ms prior to stimulus onset (baseline) to 3000 ms post-stimulus. Within each participant, condition, and time epoch, the signal was averaged across all accepted trials (the overall mean number of accepted trials/condition for *Zygomaticus major*: 11.8; and for *Corrugator supercilia*: 11.8). After that, these values were standardized within participant and within muscle region to reduce the influence of extreme values. Finally, the muscle response was calculated as change scores by subtracting the baseline muscle activity (the average of the activity during the 500-ms pre-stimulus period) from each 500-ms post-stimulus average value within each experimental condition.

Electroencephalography. Offline, the continuous EEG signal was filtered with 0.5–30 Hz band-pass filter (infinite impulse response filter) with a 24 dB/oct slope on both ends (BrainVision Analyzer 2.1). The filtered signal was ocular-corrected using a Gratton/Coles algorithm. After the ocular correction, automatic raw data inspection was performed to detect bad channels, in typical cases resulting from a consistently noisy signal or flat signal due to faulty electrodes. The criteria for the automatic raw data inspection were the same as the criteria used in the artifact rejection for segmented data (described below). Based on the automatic inspection, bad channels with less than 50 % artifact-free signal as well as channels with flat signal were interpolated with spherical spline interpolation. Also channels with more than 50 % of artifact-free signal were interpolated if the minimum of three (out of six) accepted trials per gaze direction (direct/averted) in each of the four blocks could be achieved. When the minimum of three accepted trials per gaze direction was achieved, no more channels were interpolated. Maximum of 6 interpolated channels were allowed, otherwise the participant was excluded from the subsequent analyses. EEG during the 3.5-s period after stimulus onset was segmented to six 1000 ms epochs with 50 % overlap between adjacent epochs. Artifact rejection was applied to the segmented data using automatic segment selection. The following criteria was used: (1) Maximal allowed voltage step: 50 μV/ms; (2) Maximal allowed absolute difference: 150 μV/1000 ms; (3) Minimal allowed amplitude: − 75 μV, Maximal allowed amplitude: 75 μV; (4) Lowest allowed activity in 100-ms intervals: 0.5 μV. Trials with less than 50 % artifact-free epochs were excluded from the averaging. In principle, if the minimum of three accepted trials per both gaze directions per each block could not be achieved, the participant was excluded from the subsequent analyses. However, in cases where the entire first or second half of the experiment (e.g. both the first BW and the first BnW block) were rejected, but the entire other half of the experiment remained accepted, the participant was not excluded from the final analyses. Due to the afore-mentioned exclusion criteria, 2 participants in the human-human group and 4 participants in the human-robot group were excluded from the final analyses. After these exclusions, 40 participants remained in the human-human group and 36 participants in the the human-robot group. After artifact rejection, CSD transformation was applied to the data ($m = 3$, $\lambda = 10^{-5}$) (Kayser & Tenke, 2015). Spectral power was calculated for each artifact-free epoch using Fast Fourier Transform (FFT) with a 50 % Hanning window. The power spectra obtained was averaged over all artifact-free epochs within each experimental condition (the overall mean number of accepted trials/condition: 11.6). For the average power spectra within each condition, power values ($\mu V^2/m^2$) within the alpha band (8–13 Hz) were calculated and natural log-transformed to normalize the distributions. Asymmetry score was calculated for electrode pair (F4/F3) at the frontal scalp region by subtracting the ln-transformed power value for the left hemisphere electrode site from that for the right site (Allen, Coan, & Nazarian, 2004). To detect relative asymmetry differences, asymmetry scores were calculated also for pairs F8/F7 and Af4/Af3 (frontal), C4/C3 (central), and P4/P3 (parietal).

2.6. *Statistical analyses*

The main statistical analyses were conducted using a 2(Stimulus) × 2 (Gaze) × 2(Belief) mixed ANOVA with Stimulus as a between-subjects variable and Gaze and Belief as within-subjects variables. When interactions between the factors were observed, planned pairwise comparisons were performed for the analysis of simple main effects. When exploratory (unplanned) t-tests were performed, α levels were Bonferroni-corrected for multiple comparisons. When considered relevant, non-significant results were further explored with an equivalence test, i.e., the Two One-Sided Tests (TOST) procedure. For the TOST procedures, the α levels were Bonferroni-corrected by the number of TOST procedures performed for a given variable. For the EMG analyses, time was included as a third within-subjects factor (6 epochs, each lasting 500 ms). A Greenhouse-Geisser correction procedure was applied when the assumption of sphericity was violated. Because interactions between Time and other independent variables were not of our main research interest (no specific hypotheses were drawn upon them), these interactions and subsequent pairwise comparisons are reported in Supplementary material. Also, additional analyses due to violations of test assumptions were performed for some of the dependent variables. For conciseness, the additional analyses are reported in Supplementary material as well.

The primary statistical analyses were performed on the entire sample of 82 participants including those participants who expressed doubts regarding the one-way window deceit during the final debriefing. In cases where the primary analysis did not show a significant main effect of Belief nor an interaction between Belief and other variables, a secondary analysis was performed including only the participants who did not express such doubts (number of participants expressing these doubts: *human-robot group*: 2; *human-human group*: 8). This was done to confirm that the lack of the effects of Belief was not associated with the doubts of the deceit.

2.7. Deviations from the preregistered data analysis plan

In the preregistration (see https://osf.io/htyu9/?view_only=05ac7270191b489382dfe27e4caed3bb), it was stated that the primary statistical analyses will be performed without the participants who expressed doubts of the one-way window deceit, and that secondary analyses will be performed having these participants included in the data. However, as reported in *Statistical analyses*, the participants expressing these doubts were included in the primary statistical analyses. The original plan of excluding these participants was motivated by the reasoning that if the participants expressing doubts of the deceit were included, this could have decreased the possibility to find the effect of Belief. However, as the analyses showed the effect of Belief even if these participants were included, and the inclusion vs. exclusion had no effect on this result, we decided to include these participants in the primary analyses.

With regard to the analysis of the EEG data, it was reported that channels with less than 50 % artifact-free signal as well as channels with flat signal would be interpolated. As reported in the section *Analysis of the physiological data*, also channels with more than 50 % of artifact-free signal were interpolated if the minimum of three accepted trials per gaze direction in each of the four blocks could be achieved. Furthermore, contrary to the EEG data analysis plan reported in the preregistration, the EEG data was re-referenced offline using a reference-free CSD (current source density) transformation (Kayser & Tenke, 2015). Recent guidelines for the frontal asymmetry measurements and analyses recommend CSD transformation because it may offer better specificity for local electrical sources and reduce the influence of non-frontal volume conduction on the frontal asymmetry scores as compared to other, commonly used references, such as linked mastoid or common average reference (Smith, Reznik, Stewart, & Allen, 2017).

Finally, it was reported that, as an exploratory EEG analysis, general alpha-band activity during the presentation of the different gaze conditions will be investigated and compared. However, we decided to not include this analysis in the present study.

3. Results

As a manipulation check, subjective gaze direction ratings were analyzed with Wilcoxon Signed Ranks Tests to test whether the participants discriminated between the robot's and the human model's direct and averted gaze both in the BW and BnW conditions. Non-parametric tests were chosen due to the non-linearity of the scale/data. The results showed that participants agreed more to the statement ("The model/robot looked directly at me") when both the robot's and the human model's gaze was directed at them as compared when the gaze was averted, and this was observed both in the BW and BnW conditions (Robot/BW: $M_{\text{direct}} = 8.50$, $M_{\text{averted}} = 2.40$ $Z = -5.467$, $p < .001$; Robot/BnW: $M_{\text{direct}} = 7.63$, $M_{\text{averted}} = 2.30$, $Z = -5.234$, $p < .001$; Human/BW: $M_{\text{direct}} = 8.79$, $M_{\text{averted}} = 1.05$, $Z = -6.087$, $p < .001$: Human/BnW: $M_{\text{direct}} = 7.52$, $M_{\text{averted}} = 1.12$, $Z = -5.649$, $p < .001$.

3.1. Skin conductance responses

The results of the skin conductance measurements are shown in Fig. 2. The SCR data were analyzed with a 2(Stimulus) × 2(Gaze) × 2 (Belief) mixed ANOVA. The ANOVA indicated a significant main effect of Gaze ($F_{(1,79)} = 30.739$, $p = <.001$, $\eta_p^2 = 0.280$), indicating that SCRs were greater for direct ($M = 0.147$ μS, $SEM = 0.016$) than for averted gaze ($M = 0.108$ μS, $SEM = 0.012$). Also the main effect of Belief was significant ($F_{(1,79)} = 14.962$, $p = <.001$, $\eta_p^2 = 0.159$). The SCRs were overall greater in the BW condition ($M = 0.148$ μS, $SEM = 0.015$) than in the BnW condition ($M = 0.107$ μS, $SEM = 0.014$). There was also significant interaction between Gaze and Stimulus ($F_{(1,69)} = 5.551$, $p = .021$, $\eta_p^2 = 0.066$). The pairwise comparisons, performed separately for the robot and the human-human group, showed that the SCR was greater to direct than averted gaze both for the human model ($M_{\text{direct}} = 0.162$, $SEM = 0.024$ vs. $M_{\text{averted}} = 0.107$, $SEM = 0.017$; $t_{(40)} = 4.797$, $p < .001$, $d = 0.749$), and for the robot ($M_{\text{direct}} = 0.132$, $SEM = 0.019$ vs. $M_{\text{averted}} = 0.109$, $SEM = 0.018$; $t_{(39)} = 2.852$, $p = .007$, $d = 0.451$). Independent samples *t*-tests (α level adjusted for multiple comparisons) showed no significant differences between the responses to the human model's vs. the robot's direct gaze ($t_{(79)} = 0.996$, $p = .322$, $d = 0.221$), nor between the responses to their averted gaze ($t_{(79)} = -0.082$, $p = .935$, $d = -0.018$). Therefore, the significant interaction between the Gaze and Stimulus indicated that the magnitude of the gaze direction effect (direct gaze minus averted gaze) on SCRs was greater in the human-human group ($M = 0.055$, $SEM = 0.011$) than in the human-robot group ($M = 0.022$, $SEM = 0.008$).

The interaction between Gaze and Belief was not significant ($F_{(1,79)} = 0.342$, $p = .560$, $\eta_p^2 = 0.004$), whereas the interaction between Stimulus and Belief was marginal ($F_{(1,79)} = 3.915$, $p = .051$, $\eta_p^2 = 0.047$). However, a visual inspection of the data indicated that the effect of Belief was smaller in the human-robot group than in the human-human group. Therefore, to test for the equivalence of the effect of Belief within both stimulus groups, a Two One-sided Test (TOST) procedure (with adjusted α level) was performed (Lakens, 2017). The equivalence bounds were set as dz $= \underline{+}\, 0.45$. According to a sensitivity analysis performed with G*Power (1–β = .80, $\alpha = .05$) this was the smallest effect size (dz) that could be detected in the human-robot group. For the human-human group, a paired *t*-test showed a significant difference between BW and BnW conditions ($t_{(40)} = 3.92$, $p < .001$). For the human-robot group, the difference between these conditions was non-significant ($t_{(39)} = 1.43$, $p = .162$). The equivalence test showed that the effect of Belief in the human-robot group was significantly within the lower bound of dz = - 0.45 ($t_{(39)} = 4.59$, $p < .001$), but not within the upper bound of dz $= 0.45$ ($t_{(39)} = -1.74$, $p = .045$). In conclusion, the effect of Belief in the human-robot group was not statistically different from zero nor statistically equivalent to zero. Thus, we are not able to draw a strong conclusion on whether Belief had a meaningful effect on the SCRs in the human-robot group.

To confirm that the undetermined effect of Belief, in the human-robot group, was not associated with the participants' doubts of the one-way deceit, a secondary TOST procedure was performed on the SCR data including only the participants who did not express these doubts. Based on the sensitivity analysis performed for the human-robot group, the equivalence bounds were set as dz $= \underline{+}\, 0.47$. The secondary TOST indicated a similar pattern of results as the primary TOST: there was a significant difference between the BW and BnW conditions in the human-human group, ($t_{(32)} = 3.32$, $p = .002$), but not in the human-robot group ($t_{(37)} = 1.47$, $p = .151$). According to the equivalence test, the effect of Belief in the human-robot group was significantly within the lower bound ($t_{(37)} = 4.36$, $p < .001$), but not within the upper bound

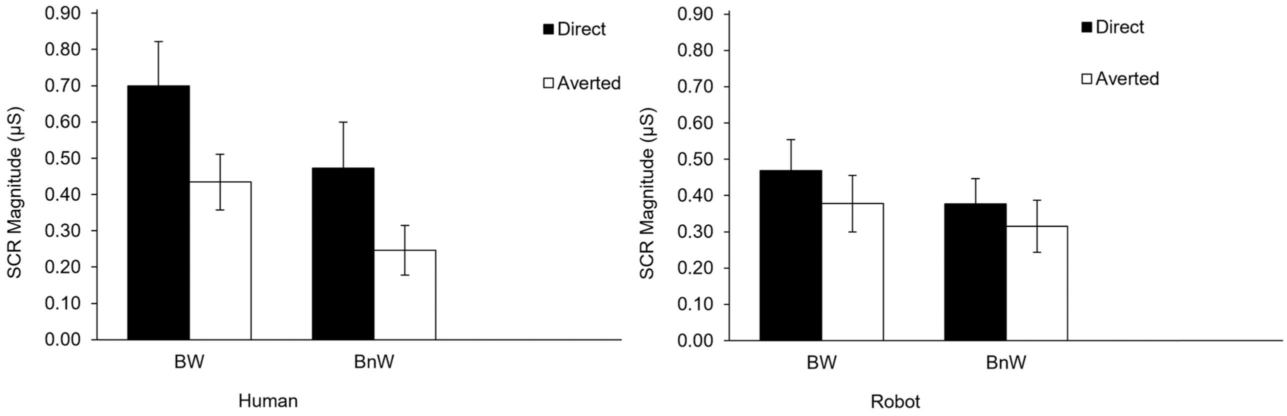

Fig. 2. Mean skin conductance responses (and standard error of means) to a human's and a robot's direct and averted gaze in the BW and BnW conditions. (BW = Belief of Being Watched condition; BnW = Belief of not Being Watched condition).

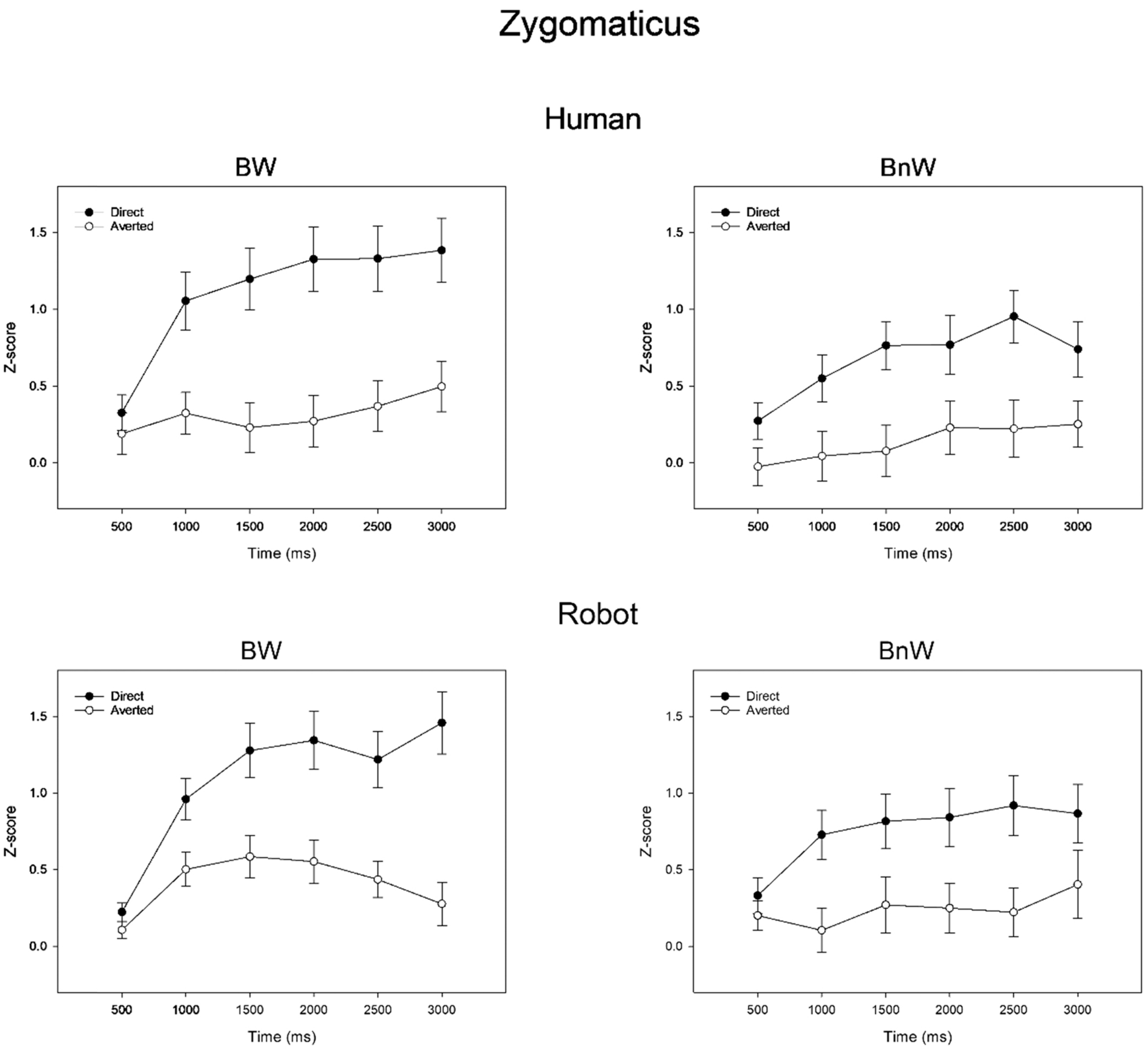

Fig. 3. Standardized mean zygomatic electromyographic (EMG) responses (and SEM) to a human's and a robot's direct and averted gaze in the BW and BnW conditions. (BW = Belief of Being Watched condition; BnW = Belief of not Being Watched condition).

($t_{(37)} = -1.43$, $p = .080$).

3.2. Facial electromyography responses

The results of the zygomatic region EMG measurements are shown in Fig. 3. The zygomatic responses were analyzed with a 2(Stimulus) × 2 (Gaze) × 2(Belief) × 6(Time) mixed ANOVA. The ANOVA showed a significant main effect of Gaze ($F_{(1,80)} = 69.553$, $p = <.001$, $\eta_p^2 = 0.465$), indicating that the zygomatic response was greater in response to direct ($M = 0.902$, $SEM = 0.083$) than to averted gaze ($M = 0.274$, $SEM = 0.077$). Also the main effects of Time ($F_{(2.828,\ 226.240)} = 23.012$, $p = <.001$, $\eta_p^2 = 0.223$) and Belief ($F_{(1,80)} = 12.298$, $p = .001$, $\eta_p^2 = 0.133$) were significant. The zygomatic activity increased as a function of time, and the zygomatic responses were greater in the BW condition ($M = 0.726$, $SEM = 0.080$) than in the BnW condition ($M = 0.449$, $SEM = 0.082$). There were no significant interactions between Gaze, Stimulus, and Belief.

The results of the corrugator region EMG measurements are shown in Fig. 4. For the corrugator responses, the 2 × 2 × 2 × 6 mixed ANOVA showed a main effect of Gaze ($F_{(1,79)} = 42.791$, $p = <.001$, $\eta_p^2 = 0.351$) and Time ($F_{(2.094,165.420)} = 7.823$, $p = .001$, $\eta_p^2 = 0.090$). The corrugator activity decreased more in response to direct gaze ($M = -0.304$, $SEM = 0.100$) than to averted gaze ($M = 0.197$, $SEM = 0.085$). The overall corrugator activity decreased as a function of time up to approx. 1500 ms post-stimulus, after which the activity started to return towards its baseline. The ANOVA showed also a significant main effect of Belief ($F_{(1,79)} = 11.164$, $p = .001$, $\eta_p^2 = 0.124$), indicating that the corrugator activity decreased more in the BW condition ($M = -0.160$, $SEM = 0.083$) than in the BnW condition ($M = 0.053$, $SEM = 0.096$). The interaction between Gaze and Stimulus was also statistically significant ($F_{(1,79)} = 4.442$, $p = .038$, $\eta_p^2 = 0.053$). When analyzing the responses in the two stimulus groups separately, the pairwise comparisons showed that the corrugator activity decreased more in response to direct than to averted gaze both for the human model ($M_{\text{direct}} = -0.393$, $SEM = 0.136$ vs. $M_{\text{averted}} = 0.261$, $SEM = 0.110$; $t_{(41)} = -5.802$, $p < .001$, $d = -.895$) and for the robot ($M_{\text{direct}} = -0.208$, $SEM = 0.147$ vs. $M_{\text{averted}} = 0.127$,

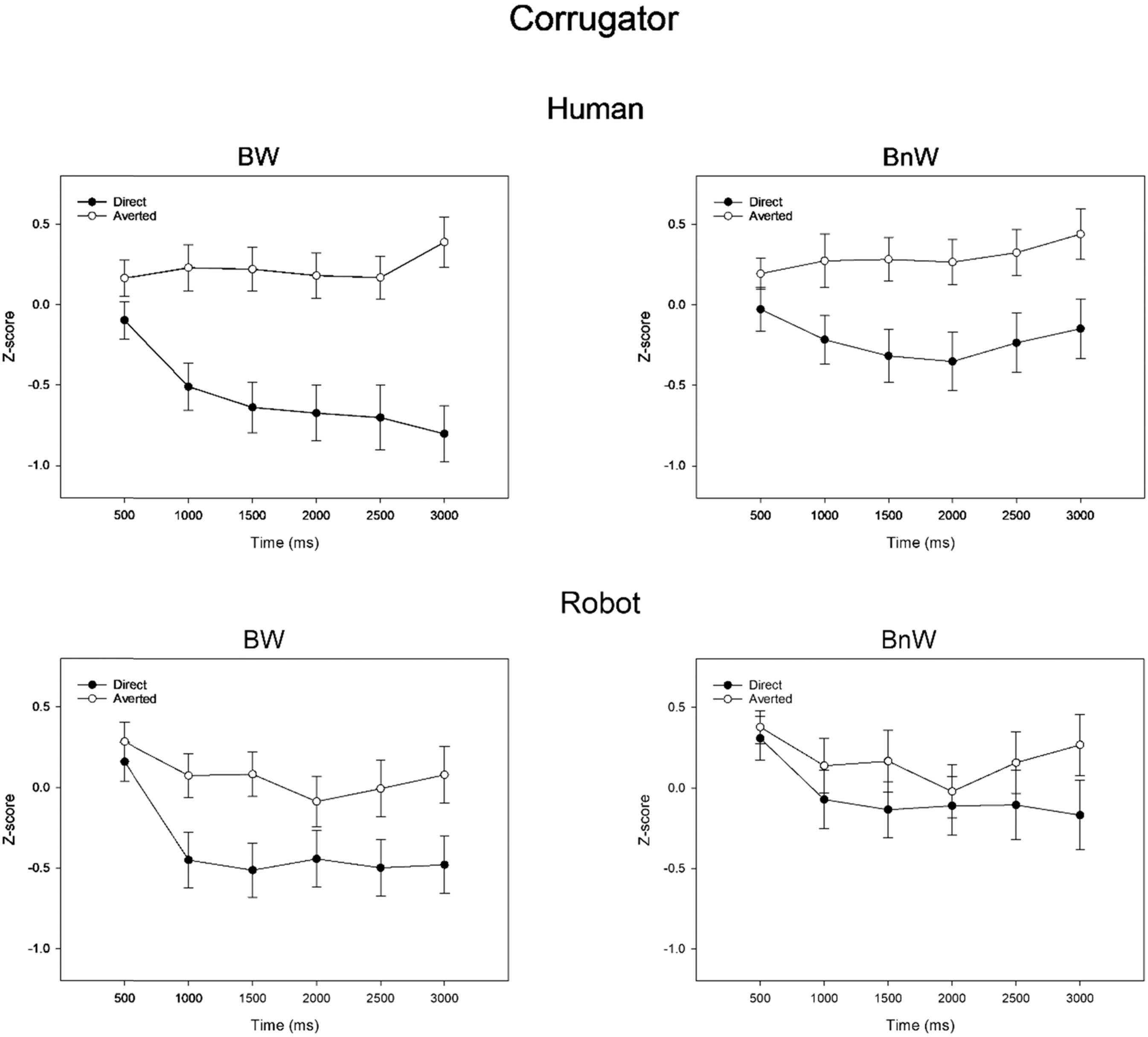

Fig. 4. Standardized mean corrugator electromyographic (EMG) responses (and SEM) to to a human's and a robot's direct and averted gaze in the BW and BnW conditions. (BW = Belief of Being Watched condition; BnW = Belief of not Being Watched condition).

$SEM = 0.130$; $t_{(38)} = -3.371$, $p = .002$, $d = -0.540$). Independent samples *t*-tests (α level adjusted for multiple comparisons) showed that there were no significant differences between the responses to the human model's and the robot's direct gaze ($t_{(79)} = -.922$, $p = .359$, $d = -.205$) nor to their averted gaze ($t_{(79)} = 0.788$, $p = .433$, $d = -.175$). Therefore, the significant interaction between Gaze and Stimulus reflected the fact that the magnitude of the gaze direction effect (direct gaze minus averted gaze) on corrugator activity was greater for the human model ($M = -0.654$, $SEM = 0.113$) than for the robot ($M = -0.335$, $SEM = 0.099$). The interaction between Gaze and Belief was significant ($F_{(1,79)} = 7.356$, $p = .008$, $\eta_p^2 = 0.085$). The pairwise comparisons showed that the corrugator activity decreased more in response to direct gaze than to averted gaze both in the BW condition ($M_{\text{direct}} = -0.473$, $SEM = 0.104$ vs. $\text{M}_{\text{averted}} = 0.153$, $SEM = 0.088$; $t_{(80)} = -6.499$, $p < .001$, $d = -.722$) and in the BnW condition ($M_{\text{direct}} = -0.135$, $SEM = 0.112$ vs. $\text{M}_{\text{averted}} = 0.241$, $SEM = 0.097$; $t_{(80)} = -4.556$, $p < .001$, $d = -.506$). Interestingly, when analyzing the effect of belief condition separately for direct and averted gaze (α level adjusted for multiple comparisons), the corrugator activity decreased more in response to direct gaze in the BW condition as compared to direct gaze in the BnW condition ($t_{(80)} = -4.135$, $p < .001$, $d = -0.459$). The difference between the responses to averted gaze in these two conditions was not statistically significant ($t_{(80)} = -1.189$, $p = .238$, $d = -0.132$).

3.3. Frontal EEG asymmetry

The results of the frontal EEG asymmetry measurements for the electrode pair F4/F3 (CSD-transformed data) are shown in Fig. 5. A 2 (Stimulus) × 2(Gaze) × 2(Belief) mixed ANOVA on the asymmetry scores showed no significant main effects or interactions. Because the effect of Belief did not have a significant effect on EEG asymmetry, nor was it interacting with other variables, a secondary analysis including only the participants who did not express doubts regarding the one-way window deceit was performed. The secondary analysis showed similar results as the primary analysis.

Alpha asymmetry analyses were also performed for electrode pairs F8/F7, Af4/Af3, C4/C3, and P4/P3 (CSD-transformed data). For F8/F7, the analysis revealed a significant two-way interaction between Gaze and Belief and a significant three-way interaction between Gaze, Belief and Stimulus. With regard to the other electrode pairs, the analyses did not show any significant effects regardless of whether the participants doubting the one-way window deceit were included in the analyses or not. For conciseness, the results of these additional alpha asymmetry analyses are reported in detail in Supplementary material.

3.4. Subjective affective feelings

The results for the self-evaluations of affective arousal and valence are shown in Table 1. The arousal ratings (scale range: 1–9, with 9 indicating maximal arousal) were analyzed with a 2(Stimulus) × 2 (Gaze) × 2(Belief) mixed ANOVA. The ANOVA showed a main effect of Gaze ($F_{(1,80)} = 40.692$, $p < .001$, $\eta_p^2 = 0.337$) reflecting that the participants felt more aroused in response to direct gaze ($M = 3.274$, $SEM = 0.166$) than to averted gaze ($M = 2.558$, $SEM = 0.124$). Also the main effect of Stimulus was statistically significant ($F_{(1,80)} = 3.983$, $p = .049$, $\eta_p^2 = 0.047$) indicating that the participants felt more aroused when facing the robot ($M = 3.188$, $SEM = 0.208$) than the human model ($M = 2.658$, $SEM = 0.167$). The results showed a main effect of Belief ($F_{(1,80)} = 7.221$, $p = .009$, $\eta_p^2 = 0.083$). Arousal ratings were higher in the BW condition ($M = 3.070$, $SEM = 0.156$) than in the BnW condition ($M = 2.762$, $SEM = 0.134$). Even though there was no significant interaction between Belief and Stimulus ($F_{(1,80)} = 2.498$, $p = .118$, $\eta_p^2 = 0.030$), the mean values indicated that the effect of Belief in the human-robot group may have been extremely small. A TOST procedure (with an adjusted α level) was performed to test for the equivalence of the effect of Belief within both stimulus groups (Lakens, 2017). The results showed that there was a significant difference between BW and BnW conditions in the human-human group, ($t_{(41)} = 3.30$, $p = .002$) but not in the human-robot group ($t_{(39)} = 0.720$, $p = .476$). According to the equivalence test, the effect of Belief condition in the human-robot group was significantly within the lower bound of dz = - 0.45 ($t_{(39)} = 3.57$, $p < .001$), as well as within the upper bound of dz = 0.45 ($t_{(39)} = -2.13$, $p = .020$). Therefore, the effect of Belief in the human-robot group was not statistically different from zero, and it was statistically equivalent to zero. The results of the TOST procedure remained similar when the participants expressing doubts of the one-way window deceit were excluded from the analysis.

For the valence ratings (scale range: 1–9, with 9 indicating maximal pleasantness), a 2(Stimulus) × 2(Gaze) × 2(Belief) mixed ANOVA showed a main effect of Gaze ($F_{(1,80)} = 28.073$, $p < .001$, $\eta_p^2 = 0.260$) indicating that the participants felt more positive in response to direct gaze ($M = 6.159$, $SEM = 0.163$) vs. averted gaze ($M = 5.503$, $SEM = 0.150$). Other effects were not significant. Because Belief did not have a significant effect on valence ratings, nor was it interacting with other variables, a secondary analysis excluding the participants who expressed doubts regarding the one-way window deceit was performed. Parallel to the primary analysis, the results of this analysis showed no main effect of Belief nor interactions with other variables.

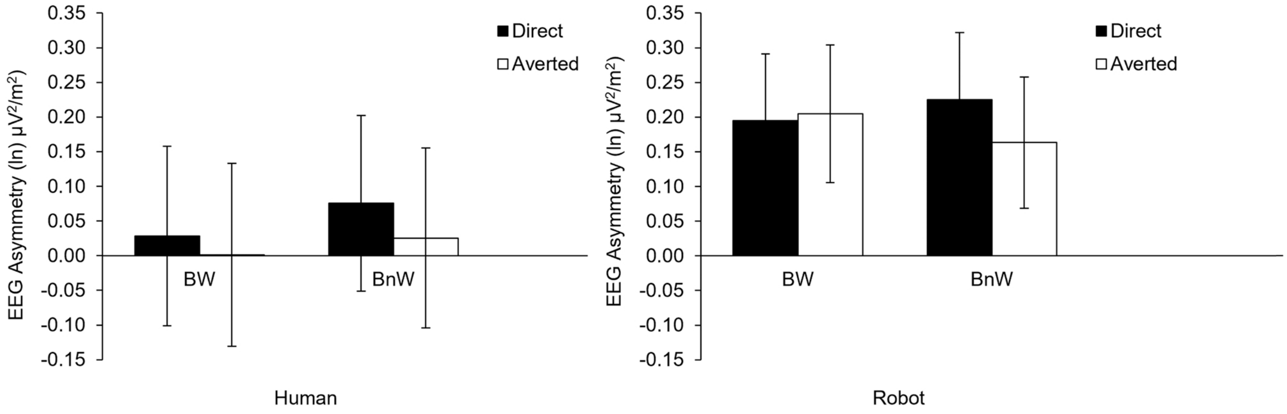

Fig. 5. Mean EEG frontal asymmetry scores for a human's and a robot's direct and averted gaze in the BW and BnW conditions. (BW = Belief of Being Watched condition; BnW = Belief of not Being Watched condition). The graphs express the difference in the EEG alpha power between electrodes F4–F3 (in ln-transformed $\mu V^2/m^2$), with positive values indicating relative left-sided activation and negative values indicating relative right-sided activation.

Table 1

The self-reported ratings (and the standard error of means) of affective arousal and valence (1 = calm/ unpleasant, 9 = arousing/pleasant) to a human's and a robot's direct and averted gaze in the BW and BnW conditions. (BW = Belief of Being Watched condition; BnW = Belief of not Being Watched condition).

	Arousal					Valence			
	Human		Robot			Human		Robot	
Belief condition	Gaze				Belief condition	Gaze			
	Direct	*Averted*	*Direct*	*Averted*		*Direct*	*Averted*	*Direct*	*Averted*
	M (SEM)	*M (SEM)*	*M (SEM)*	*M (SEM)*		*M (SEM)*	*M (SEM)*	*M (SEM)*	*M (SEM)*
BW	3.26 (0.24)	2.54 (0.19)	3.60 (0.30)	2.90 (0.23)	BW	6.33 (0.25)	5.87 (0.24)	6.23 (0.29)	5.24 (0.19)
BnW	2.67 (0.21)	2.17 (0.15)	3.60 (0.28)	2.65 (0.19)	BnW	6.26 (0.20)	5.82 (0.23)	5.8 (0.23)	5.05 (0.21)

4. Discussion

The aim of the present study was to investigate and compare affect-related psychophysiological responses to eye contact with a humanoid robot (NAO) and with another human being. More specifically, we investigated whether these responses are dependent on the psychological experience of being *watched* by the robot/the human model. To this end, we measured participants' autonomic arousal with SCRs, facial zygomatic and corrugator EMG responses reflecting affective and affiliative reactions, and hemispheric asymmetry in the frontal EEG reflecting approach-withdrawal motivational tendencies in response to direct vs. averted gaze while manipulating the participants' belief of whether the robot/human model could see them or not. In addition to the physiological measures, we measured self-evaluations of affective valence and arousal in the different gaze conditions.

The present results showed that autonomic arousal and facial EMG responses associated with positive affect and affiliative responses were, in general, greater in response to direct vs. averted gaze. These results replicate previous findings from studies with a humanoid robot (Kiilavuori et al., 2021) as well as a human (Hietanen et al., 2018, 2020; Hietanen & Peltola, 2021) as the gaze direction stimulus. Therefore, the present study provides further support for the claim that similar type of affective/affiliative responses are elicited when human observers' are making eye contact with a humanoid robot's as when making eye contact with another human.

The participants' belief of whether they could be seen by the humanoid robot/human model affected the overall magnitude of the autonomic arousal and facial EMG responses; the responses were, in general, greater when the participants knew that they could be seen by the gazer (Belief of Being Watched condition, BW), in comparison to when they believed that the gazer could not see them (Belief of not Being Watched – condition, BnW). Importantly, whereas the effect of the belief condition on the facial EMG responses was found both for the robot and the human partner, the effect on autonomic arousal was evident only for the human model. The increased facial responses in the BW condition may reflect enhanced social relevance ascribed to facing the robot/ human model in this condition in contrast to the BnW condition. In other words, this result can be interpreted to suggest that seeing the humanoid robot as well as the human partner triggered a greater affiliative response when the participants knew that there was a possibility for bidirectional interaction with the partner. Indeed, previous research has shown that although facial responses are considered to reflect rather automatic affective or social responses, they can be modulated by different types of top-down influences, including social relevance of the observed stimulus as well as the social context and simultaneous emotional processes (Bourgeois & Hess; 2008; Moody; McIntosh, Mann, & Weisser, 2007; Rychlowska, Zinner, Musca, & Niedenthal, 2012; Soussignan et al., 2013). The participants' belief of being seen or not did not influence the effect of direct vs. averted gaze on the autonomic arousal or zygomatic responses. Instead, for the corrugator response, we found that direct gaze (regardless of the stimulus) evoked stronger decrease of the corrugator activity in the BW condition than direct gaze in the BnW condition. This finding could be interpreted to provide weak evidence that direct gaze of a humanoid robot as well as that of another human evokes a greater affiliative response when the observer knows that the gazer can also see them.

As mentioned above, the effect of the belief condition on autonomic arousal was evident only for the human model. Previous research has indicated that autonomic arousal is sensitive to this type of top-down modulation in human-human interaction (Hietanen et al., 2020; Myllyneva & Hietanen, 2015). The fact that, in the present study, the effect of the belief condition was found in the human-human group, but not similarly in the human-robot group, suggests that autonomic arousal is not contingent on the perceived possibility for bidirectional interaction to the same degree when facing a robot as compared to when facing another human. This speculation is in line with the previous research in HRI suggesting that people ascribe lower degree of mental capacities, such as intentionality, to robots' behavior than to other humans' behavior (Chaminade et al., 2012; Gray et al., 2007; Krach et al., 2008; Martini, Gonzalez, & Wiese 2016; Perez-Osorio & Wykowska, 2020).

Contrary to our expectations, the participants' belief of being seen or not did not influence the effect of direct vs. averted gaze on autonomic arousal, regardless of whether the stimulus was the robot or the human model. For the human model, this finding is particularly unexpected since a previous study, with rather a similar study design, showed that observing another's direct gaze in comparison to averted gaze induced greater autonomic arousal when the participants knew that the human partner could see them, but not when the participant believed that they could not be seen by the human partner (Myllyneva & Hietanen, 2015). There were some differences in the experimental designs between the present and the previous study that could potentially contribute to these discrepant findings. First, in the present study, the human partner (and the humanoid robot) rotated their whole head in the averted gaze condition, whereas in the previous study, the model person moved only their eyes. Therefore, the difference between the direct and averted gaze conditions was visually more salient in the present study, and this may have heightened the effect of the gaze direction relative to the effect of the belief condition on the autonomic responses. The number of blocks presented in the present experiment may have also affected the results. Namely, the present experiment was divided into four blocks that were alternating between the BW and BnW conditions, whereas the previous study had only one block for both belief conditions. Even though the participants were, between each block, carefully reminded of whether the robot/human model was able to see them in the next block, the greater number of blocks may have attenuated the participants' focus on this aspect during the experimental trials to such an extent that the effect of this manipulation was diminished. Given that, in the present study, the results regarding the effect of the belief manipulation on the responses to direct vs. averted gaze differed from those observed in the previous studies even for the human model (Hietanen et al., 2020; Myllyneva & Hietanen, 2015), it is possible that the afore-mentioned factors (the way of presentating averted gaze, number of blocks) impacted the results regarding the humanoid robot as well. Thus, we cannot draw strong conclusions on whether the belief of being seen or not affects the autonomic responses to the humanoid robot's direct vs. averted gaze.

Even though the overall autonomic arousal and facial EMG responses were greater both to the humanoid robot's and the human model's direct vs. averted gaze, the magnitude of the gaze direction effect on the autonomic arousal and corrugator activity was smaller for the humanoid robot than for the human model. For autonomic arousal, this result is fully in line with the previous study that also showed a greater effect of a human partner's vs. a humanoid robot's gaze direction on autonomic arousal (Kiilavuori et al., 2021). Regarding the facial EMG responses, the present findings differ from those of the previous study in that the previous study found a greater effect of the human model's vs. the robot's gaze direction on zygomaticus activity but no difference in the gaze direction effect on the corrugator responses. Given that both facial response patterns (increase in the zygomatic activity and decrease in the corrugator activity) are considered to reflect positive affect/affiliative responses, these results could be interpreted to complement each other and to support the view that another human's gaze may have a greater effect on affective/affiliative responses than a robot's gaze. Therefore, the results of both the autonomic arousal and facial EMG measurements lend further support for the claim that another human's gaze in comparison to a humanoid robot's gaze may be perceived as a more relevant social signal (Kiilavuori et al. 2021).

Contrary to our expectations, gaze direction did not have an effect on the frontal EEG asymmetry scores (for the electrode pair F4/F3) regardless of the belief of being watched or not. This was observed for both stimulus groups. However, for the other frontal electrode pair, F8/F7, the results showed that, in the human-robot group, the robot's averted gaze induced greater relative left-sided frontal asymmetry than direct gaze, but only when the participants' knew that the robot could also see them. Given that previous research has shown affective and motivational effects on frontal EEG asymmetry measured also from the electrode pair F8/F7 (Coan & Allen, 2003; Nash, Mcgregor, & Inzlicht, 2010), this result could indicate, opposite to our hypothesis, that observing the robot's averted gaze induced greater approach-related motivational tendency in comparison to direct gaze when the participant knew that the robot could see them.

We can only speculate possible explanations for these unexpected results. For the human-human group, the non-significant effect of gaze direction on the frontal EEG asymmetry was especially surprising because previous studies have shown relatively greater left than right frontal brain activity in response to another individual's direct vs. averted gaze (Hietanen et al., 2008; Pönkänen et al., 2011; Soriano et al., 2020; Uusberg et al., 2015). However, even though there is previous evidence for the effect of gaze direction on frontal asymmetry, there are also studies which have not replicated these results (e.g., Pönkänen & Hietanen, 2012). The discrepancy among the findings could be related to some differences between experimental settings of the studies, such as differences in how familiar the model person was to the participants (Pönkänen & Hietanen, 2012). Namely, in the present study as well as in the study by Pönkänen and Hietanen (2012), the model person served only as a "stimulus" and did not interact with the participant prior to the experimental trials. In studies that found the effect of gaze direction on frontal asymmetry (Hietanen et al., 2008; Pönkänen et al., 2011), the model was also one the experimenters of the study and, thus, interacted with the participant before the trials, potentially resulting in a somewhat stronger affiliation between the model and the participant. This may have boosted the approach-motivation related tendency towards the model person.

With regard to the human-robot group, the result from the electrode pair F8/F7 indicating greater relative left-sided frontal brain activity (approach-related motivation) to the robot's averted than direct gaze, in the BW condition, could reflect participants' subtle attitudes towards the robot. It is possible that the participants were intrigued by the robot and, therefore, the robot primarily evoked an approach-related motivation in the participants. However, when observing the robot's direct gaze, the approach-related motivation might have been diminished because of feelings of uneasiness. For most people, robots may still appear rather unfamiliar as social companions and, therefore, their direct gaze may be experienced as somewhat intrusive. However, we have to note that this interpretation is in stark contrast with the results of the EMG responses which suggested that the facial responses associated with positive affect/affiliation were enhanced by factors promoting direct, social contact (direct gaze, the BW condition).

We want to emphasize that the discussion related to the results of frontal EEG asymmetry is highly speculative, and caution is warranted when making conclusions of the results. An important limitation of the present EEG measurements was that the number of experimental trials (i.e., the amount of artifact-free data) might have been insufficient for obtaining reliable EEG asymmetry data. According to Smith et al. (2017), the preferred amount of artifact-free data to obtain the best possible reliability is 1–3 min, but in the present study, the maximum amount of artifact-free data (per condition) was 36 s. This limitation might affect the reliability of the results. It is also important to point out that while there is considerable discrepancy among the findings regarding the effect of gaze direction on frontal EEG asymmetry, challenges of replication prevail in EEG asymmetry research also more generally (Harmon-Jones et al., 2010; Kuper, Käckenmester, & Wacker, 2019; Peltola et al., 2014). In fact, due to these challenges, researchers have questioned the validity of frontal EEG asymmetry as a marker (or a predictor) of specific state-level or trait-level factors (Harmon-Jones et al., 2010; Kuper et al., 2019; Peltola et al., 2014).

The results of the subjective evaluations of affective arousal showed that direct gaze of the humanoid robot as well as of the human model evoked greater subjective arousal than averted gaze. Moreover, the self-evaluated arousal was greater in the BW condition than in the BnW condition when facing the human model, but not when facing the robot. These findings match with the results of the physiological measurements (SCRs). Somewhat unexpectedly, facing the robot was generally rated as more arousing in comparison to facing the human model. It is possible that this finding is associated with the (potential) feelings of unfamiliarity with the robot. The present results regarding the subjective affective arousal ratings are different to those of the previous study wherein only the human model's direct gaze was shown to evoke greater arousal than averted gaze (Kiilavuori et al., 2021). However, a difference between these studies was that, in the previous study, each participant was facing both the humanoid robot and the human model, whereas in the present study, the participants saw only either of these. Thus, in the previous study, the participants were able to compare between their experiences of facing the humanoid robot and the human model, which may have enhanced the awareness of the robot's artificiality relative to the human model, and therefore, diminished the subjective arousal evoked by the robot. With regard to the subjective affective valence, the present results replicate the previous findings by showing that the participants felt more positive when the humanoid robot as well as the human model looked at the participant in comparison to when they were looking away (Kiilavuori et al., 2021).

There were some limitations in the present study that should be taken into account when interpreting the results. First, although the sample size of the present study was sufficient to detect medium effect sizes, we cannot rule out the possibility that some small effects were not detected due to limited statistical power of the analyses. This concern is particularly relevant for two unexpected, non-significant effects: the non-significant effect of gaze direction on EEG asymmetry scores and the non-significant interaction effect between gaze direction and belief condition on SCRs and on EEG asymmetry scores. It should be noted, however, that for these effects, previous studies have indicated at least medium effect sizes (Hietanen et al., 2008; Myllyneva & Hietanen, 2015) [Note that, in Hietanen et al., study, the effect size was not reported in the published article, but was now calculated from the data ($d = 0.602$)]. Therefore, it is likely that the non-significant results were not solely associated with the sample size. However, as mentioned earlier, another limitation regarding the EEG measurements was the limited number of trials, which may have also influenced the reliability of the results of EEG asymmetry. In future EEG asymmetry studies, it is crucial to aim at sufficient amount of data in order to achieve optimal reliability of the measure. Finally, although the present study did not show statistically significant differences in the psychophysiological responses to direct gaze (nor to averted gaze) between the human-human and human-robot groups, future studies should track observers' gazing behavior in order to investigate whether differences in psychophysiological responses could reflect differences in allocation of attention to the eye-region when looking at another person vs. a robot. The investigation of gazing behaviors when looking at humans and robots is interesting and important, of course, also in itself.

Taken together, the present study provides further evidence that eye contact with a humanoid robot can elicit similar type of automatic affect-related responses as eye contact with another human being. This finding argues for the importance of eye contact in human-robot interaction, which should be taken into account when designing robots for social roles. Moreover, the study demonstrates that the psychophysiological responses to a humanoid robot can, to some extent, be modulated by an observer's attributions of the robot's mental state. This finding suggests that people have a tendency to ascribe mental states also to robots. Further research is needed in order to gain more understanding of the social cognitive mechanisms behind humans' implicit reactions to direct gaze as well as to other social signals displayed by humanoid robots.

Data Availability

The authors do not have permission to share data.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.biopsycho.2022.108451.

References

Airenti, G. (2015). The cognitive bases of anthropomorphism: From relatedness to empathy. *International Journal of Social Robotics, 7*(1), Article 117127.

Allen, J. J., Coan, J. A., & Nazarian, M. (2004). Issues and assumptions on the road from raw signals to metrics of frontal EEG asymmetry in emotion. *Biological Psychology, 67*(1–2), 183–218.

Argyle, M., & Dean, J. (1965). Eye-contact, distance and affiliation. *Sociometry*, 289–304.

Belkaid, M., Kompatsiari, K., De Tommaso, D., Zablith, I., & Wykowska, A. (2021). Mutual gaze with a robot affects human neural activity and delays decision-making processes. *Science Robotics, 6*(58), eabc5044.

Boucsein, W. (2012). *Electrodermal Activity* (2nd ed.). New York: Springer.

Bourgeois, P., & Hess, U. (2008). The impact of social context on mimicry. *Biological Psychology, 77*(3), 343–352.

Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry, 25*(1), 49–59. https://doi.org/10.1016/0005-7916(94)90063-9

Cacioppo, J. T., Petty, R. E., Losch, M. E., & Kim, H. S. (1986). Electromyographic activity over facial muscle regions can differentiate the valence and intensity of affective reactions. *Journal of Personality and Social Psychology, 50*, 260–268. https://doi.org/10.1037/0022-3514.50.2.260

Chaminade, T., Rosset, D., Da Fonseca, D., Nazarian, B., Lutscher, E., Cheng, G., & Deruelle, C. (2012). How do we think machines think? An fMRI study of alleged competition with an artificial intelligence. *Frontiers in Human Neuroscience, 6*, 103. https://doi.org/10.3389/fnhum.2012.00103

Coan, J. A., & Allen, J. J. (2003). Varieties of emotional experience during voluntary emotional facial expressions. *Annals of the New York Academy of Sciences, 1000*(1), 375–379.

Conty, L., George, N., & Hietanen, J. K. (2016). Watching Eyes effects: When others meet the self. *Consciousness and Cognition, 45*, 184–197. https://doi.org/10.1016/j.concog.2016.08.016

Critchley, H. D. (2002). Electrodermal responses: What happens in the brain. *Neuroscientist, 8*, 132–142. https://doi.org/10.1177/107385840200800209

Dawson, M. E., Schell, A. M., & Filion, D. L. (2000). The electrodermal system. In J. T. Cacioppo, L. G. Tassinary, & G. G. Berntson (Eds.), *Handbook of Psychophysiology* (2nd ed., pp. 200–223). New York, NY: Cambridge University Press.

De Graaf, M.M., & Malle, B.F. (2019, March). People's explanations of robot behavior subtly reveal mental state inferences. In *2019 14th ACM/IEEE international conference on human-robot interaction (HRI)* (pp. 239–248). IEEE.

Dimberg, U., Thunberg, M., & Elmehed, K. (2000). Unconscious facial reactions to emotional facial expressions. *Psychological Science, 11*(1), 86–89. https://doi.org/10.1111/1467-9280.00221

Donovan, W. L., & Leavitt, L. A. (1980). Physiologic correlates of direct and averted gaze. *Biological Psychology, 10*(3), 189–199. https://doi.org/10.1016/0301-0511(80)90014-9

Evans, J. S. B., & Stanovich, K. E. (2013). Dual-process theories of higher cognition: Advancing the debate. *Perspectives On. Psychological Science, 8*(3), 223–241.

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191.

Fridlund, A. J. (1991). Evolution and facial action in reflex, social motive, and paralanguage. *Biological Psychology, 32*(1), 3–100. https://doi.org/10.1016/0301-0511(91)90003-Y

Fridlund, A. J., & Cacioppo, J. T. (1986). Guidelines for human electromyographic research. *Psychophysiology, 23*(5), 567–589.

Gazzola, V., Rizzolatti, G., Wicker, B., & Keysers, C. (2007). The anthropomorphic brain: the mirror neuron system responds to human and robotic actions. *Neuroimage, 35*(4), 1674–1684. https://doi.org/10.1016/j.neuroimage.2007.02.003

Gray, H. M., Gray, K., & Wegner, D. M. (2007). Dimensions of mind perception. *Science, 315*(5812). https://doi.org/10.1126/science.1134475 (619–619).

Hadders-Algra, M. (2021). Human face and gaze perception is highly context specific and involves bottom-up and top-down neural processing. *Neuroscience & Biobehavioral Reviews, 132*, 304–323.

Harmon-Jones, E., Gable, P. A., & Peterson, C. K. (2010). The role of asymmetric frontal cortical activity in emotion-related phenomena: A review and update. *Biological Psychology, 84*(3), 451–462.

Hietanen, J. K. (2018). Affective eye contact: An integrative review. *Frontiers in Psychology, 9*, 1587. https://doi.org/10.3389/fpsyg.2018.01587

Hietanen, J. K., Helminen, T. M., Kiilavuori, H., Kylliäinen, A., Lehtonen, H., & Peltola, M. J. (2018). Your attention makes me smile: Direct gaze elicits affiliative facial expressions. *Biological Psychology, 132*, 1–8. https://doi.org/10.1016/j.biopsycho.2017.11.001

Hietanen, J. K., Kylliäinen, A., & Peltola, M. J. (2019). The effect of being watched on facial EMG and autonomic activity in response to another individual's facial expressions. *Scientific Reports, 9*(1), 1–10. https://doi.org/10.1038/s41598-019-51368-6

Hietanen, J. K., Leppänen, J. M., Peltola, M. J., Linna-aho, K., & Ruuhiala, H. J. (2008). Seeing direct and averted gaze activates the approach–Avoidance motivational brain systems. *Neuropsychologia, 46*(9), 2423–2430. https://doi.org/10.1016/j.neuropsychologia.2008.02.029

Hietanen, J. K., & Peltola, M. J. (2021). The eye contact smile: The effects of sending and receiving a direct gaze. *Visual Cognition, 29*(7), 446–462.

Hietanen, J. O., Peltola, M. J., & Hietanen, J. K. (2020). Psychophysiological responses to eye contact in a live interaction and in videocall. *Psychophysiology.* , Article e13587. https://doi.org/10.1111/psyp.13587

Kayser, J., & Tenke, C. E. (2015). Issues and considerations for using the scalp surface Laplacian in EEG/ERP research: A tutorial review. *International Journal of Psychophysiology, 97*(3), 189–209.

Kiilavuori, H., Sariola, V., Peltola, M. J., & Hietanen, J. K. (2021). Making eye contact with a robot: Psychophysiological responses to eye contact with a human and with a humanoid robot. *Biological Psychology, 158*, Article 107989.

Kleinke, C. L. (1986). Gaze and eye contact: A research review. *Psychological Bulletin, 100*(1), 78–100. https://doi.org/10.1037/0033-2909.100.1.78

Kompatsiari, K., Bossi, F., & Wykowska, A. (2021). Eye contact during joint attention with a humanoid robot modulates oscillatory brain activity. *Social Cognitive and Affective Neuroscience, 16*(4), 383–392.

K. Kompatsiari, F. Ciardo, D. De Tommaso, A. Wykowska (2019). Measuring engagement elicited by eye contact in Human-Robot Interaction. In *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), China* (6979–6985). ⟨https://doi.org/10.1109/IROS40897.2019.8967747⟩.

Krach, S., Hegel, F., Wrede, B., Sagerer, G., Binkofski, F., & Kircher, T. (2008). Can machines think? Interaction and perspective taking with robots investigated via fMRI. *PLoS One, 3*(7), Article e2597. https://doi.org/10.1371/journal.pone.0002597

Kühnlenz, B., Wang, Z.Q., & Kühnlenz, K. (2017). Impact of continuous eye contact of a humanoid robot on user experience and interactions with professional user background. In *26th IEEE international symposium on robot and human interactive communication (RO-MAN)* (pp. 1037–1042). IEEE. ⟨https://doi.org/10.1109/ROMAN.2017.8172431⟩.

Kuper, N., Käckenmester, W., & Wacker, J. (2019). Resting frontal eeg asymmetry and personality traits: A meta–analysis. *European Journal of Personality, 33*(2), 154–175. https://doi.org/10.1002/per.2197

Lakens, D. (2017). Equivalence tests: A practical primer for t tests, correlations, and meta-analyses. *Social Psychological and Personality Science, 8*(4), 355–362.

Lyyra, P., Myllyneva, A., & Hietanen, J. K. (2018). Mentalizing eye contact with a face on a video: gaze direction does not influence autonomic arousal. *Scandinavian Journal of Psychology, 59*(4), 360–367. https://doi.org/10.1111/sjop.12452

Martini, M. C., Gonzalez, C. A., & Wiese, E. (2016). Seeing minds in others–Can agents with robotic appearance have human-like preferences? *PLoS One, 11*(1), Article e0146310. https://doi.org/10.1371/journal.pone.0146310

Moody, E. J., McIntosh, D. N., Mann, L. J., & Weisser, K. R. (2007). More than mere mimicry? The influence of emotion on rapid facial reactions to faces. *Emotion, 7*(2), 447–457.

Myllyneva, A., & Hietanen, J. K. (2015). There is more to eye contact than meets the eye. *Cognition, 134*, 100–109. https://doi.org/10.1016/j.cognition.2014.09.011

Nash, K., McGregor, I., & Inzlicht, M. (2010). Line bisection as a neural marker of approach motivation. *Psychophysiology, 47*(5), 979–983.

Oberman, L. M., McCleery, J. P., Ramachandran, V. S., & Pineda, J. A. (2007). EEG evidence for mirror neuron activity during the observation of human and robot actions: Toward an analysis of the human qualities of interactive robots. *Neurocomputing, 70*(13–15), 2194–2203. https://doi.org/10.1016/j.neucom.2006.02.024

Parkinson, B. (2005). Do facial movements express emotions or communicate motives. *Personality and Social Psychology Review, 9*(4), 278–311. https://doi.org/10.1207/s15327957pspr0904_1

Peltola, M. J., Bakermans-Kranenburg, M. J., Alink, L. R., Huffmeijer, R., Biro, S., & van IJzendoorn, M. H. (2014). Resting frontal EEG asymmetry in children: Meta-analyses of the effects of psychosocial risk factors and associations with internalizing and externalizing behavior. *Developmental Psychobiology, 56*(6), 1377–1389.

Perez-Osorio, J., & Wykowska, A. (2020). Adopting the intentional stance toward natural and artificial agents. *Philosophical Psychology, 33*(3), 369–395.

Pönkänen, L. M., Alhoniemi, A., Leppänen, J. M., & Hietanen, J. K. (2011). Does it make a difference if i have an eye contact with you or with your picture? An ERP study. *Social Cognitive and Affective Neuroscience, 6*(4), 486–494. https://doi.org/10.1093/scan/nsq068

Pönkänen, L. M., & Hietanen, J. K. (2012). Eye contact with neutral and smiling faces: Effects on autonomic responses and frontal EEG asymmetry. *Frontiers in Human Neuroscience, 6*, 122.

Pönkänen, L. M., Peltola, M. J., & Hietanen, J. K. (2011). The observer observed: Frontal EEG asymmetry and autonomic responses differentiate between another person's direct and averted gaze when the face is seen live. *International Journal of Psychophysiology, 82*(2), 180–187. https://doi.org/10.1016/j.ijpsycho.2011.08.006

Prinsen, J., & Alaerts, K. (2019). Eye contact enhances interpersonal motor resonance: Comparing video stimuli to a live two-person action context. *Social Cognitive and Affective Neuroscience, 14*(9), 967–976. https://doi.org/10.1093/scan/nsz064

Rychlowska, M., Zinner, L., Musca, S.C., & Niedenthal, P.M. (2012). From the eye to the heart: Eye contact triggers emotion simulation. In *Proceedings of the 4th workshop on eye gaze in intelligent human machine interaction*, Article No. 5.

Senju, A., & Johnson, M. H. (2009). The eye contact effect: Mechanisms and development. *Trends in Cognitive Sciences, 13*(3), 127–134.

Shiomi, M., Nakagawa, K., & Hagita, N. (2013). Design of a gaze behavior at a small mistake moment for a robot. *Interaction Studies, 14*(3), 317–328. https://doi.org/10.1075/is.14.3.01shi

Sjouwerman, R., & Lonsdorf, T. B. (2019). Latency of skin conductance responses across stimulus modalities. *Psychophysiology, 56*(4), Article e13307. https://doi.org/10.1111/psyp.13307

Smith, E. E., Reznik, S. J., Stewart, J. L., & Allen, J. J. (2017). Assessing and conceptualizing frontal EEG asymmetry: An updated primer on recording, processing, analyzing, and interpreting frontal alpha asymmetry. *International Journal of Psychophysiology, 111*, 98–114.

Soriano, J. R., Daniels, N., Prinsen, J., & Alaerts, K. (2020). Intranasal oxytocin enhances approach-related EEG frontal alpha asymmetry during engagement of direct eye contact. *Brain Communications, 2*(2), fcaa093.

Soussignan, R., Chadwick, M., Philip, L., Conty, L., Dezecache, G., & Grèzes, J. (2013). Self-relevance appraisal of gaze direction and dynamic facial expressions: effects on facial electromyographic and autonomic reactions. *Emotion, 13*(2), 330sivut.

Thellman, S., Silvervarg, A., & Ziemke, T. (2017). Folk-psychological interpretation of human vs. humanoid robot behavior: Exploring the intentional stance toward robots. *Frontiers in Psychology, 8*, 1962. https://doi.org/10.3389/fpsyg.2017.01962

Uusberg, H., Allik, J., & Hietanen, J. K. (2015). Eye contact reveals a relationship between Neuroticism and anterior EEG asymmetry. *Neuropsychologia, 73*, 161–168. https://doi.org/10.1016/j.neuropsychologia.2015.05.008

Wykowska, A., Chaminade, T., & Cheng, G. (2016). Embodied artificial agents for understanding human social cognition. *Philosophical Transactions of the Royal Society B: Biological Sciences, 371*(1693), 20150375.

Xu, T., Zhang, H., & Yu, C. (2016). See you see me: The role of eye contact in multimodal human-robot interaction. *ACM Transactions on Interactive Intelligent Systems, 6*(1), 1–22. https://doi.org/10.1145/2882970

Yonezawa, T., Yamazoe, H., Utsumi, A., & Abe, S. (2007). Gaze-communicative behavior of stuffed-toy robot with joint attention and eye contact based on ambient gaze-tracking. In *Proceedings of the 9th international conference on multimodal interfaces* (pp. 140–145). New York: Association for Computing Machinery. ⟨https://doi.org/10.1145/1322192.1322218⟩.