Robot Pressure: The Impact of Robot Eye Gaze and Lifelike Bodily Movements upon Decision-Making and Trust

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Abstract. Between people, eye gaze and other forms of nonverbal communication can influence trust. We hypothesised similar effects would occur during human-robot interaction, predicting a humanoid robot's eye gaze and lifelike bodily movements (eye tracking movements and simulated "breathing") would increase participants' likelihood of seeking and trusting the robot's opinion in a cooperative visual tracking task. However, we instead found significant interactions between robot gaze and task difficulty, indicating that robot gaze had a positive impact upon trust for difficult decisions and a negative impact for easier decisions. Furthermore, a significant effect of robot gaze was found on task performance, with gaze improving participants' performance on easy trials but hindering performance on difficult trials. Participants also responded significantly faster when the robot looked at them. Results suggest that robot gaze exerts "pressure" upon participants, causing audience effects similar to social facilitation and inhibition. Lifelike bodily movements had no significant effect upon participant behaviour.

Keywords: human-robot interaction, nonverbal communication, eye gaze, trust, compliance, persuasion.

1 Introduction

In coming years, it is expected that social robots will become increasingly common, assisting and collaborating with people in a wide variety of environments such as public spaces, the home, office, school, and health care. For such human-robot collaborations to be successful, social robots must be capable of fostering the trust and confidence of people they interact with. Between people, nonverbal communication plays a significant role in establishing rapport and influencing others. For example, doctors who sit with uncrossed legs with arms symmetrically side-by-side are rated more highly by patients [1], mirroring another's posture can increase rapport within groups [2], hand shaking has been shown to increase compliance when requesting money [3], and eye gaze has been shown to increase likability, request compliance, and perceptions of truthfulness [4]. Thus, it is important to investigate whether nonverbal communication can have similar effects in interactions between robots and people.

Trust and rapport is also affected by a person's appearance. Initial judgments of a political candidate's facial appearance can predict the outcomes of political elections [5], while positive characteristics such as intelligence, competence, leadership, and trustworthiness are attributed to attractive persons [6]. Perhaps most importantly, in the context of human-robot interaction (HRI), is that people are most likely to cooperative with and trust others who are physically similar to themselves [7, 8], thus providing clues for the physical design of humanoid robots. While some attention has been paid to humanoid robot form and appearance, especially with regards to androids (e.g. the uncanny valley [9]), less attention has been devoted to investigating the impact of robots imitating "human-like" movements during HRI, such as shifting postures, blinking or breathing. In this study we investigate the influence of robot eye gaze and two different "lifelike" bodily movements upon participants' willingness to trust and interact with the robot during a cooperative visual task.

2 Nonverbal Communication, Trust and HRI

A large body of research has discovered how particular forms of human to human nonverbal communication can influence trust, perceptions of truthfulness, and rapport [10]. For example, leaning forward, using eye gaze, nodding, and smiling can all help build rapport [11]. Even the nature of a smile can provide an indication of whether a person is telling the truth [12].

Gaze, in particular, is a powerful nonverbal cue, with every culture having strict but unstated rules governing eye contact [13]. Gazing at the eyes of another can signal willingness to interact [14]. When people first meet, gaze enhances attraction and liking [4]. In court rooms, witnesses are viewed as more credible when they employ eye gaze [15]. People who avert gaze are more likely to be perceived as lying [16]. However, liars actually increase eye contact [17], a cunning ploy playing on the widespread belief that liars avert eye gaze [18]. Gaze can also impact the likelihood of people complying with a request. People on the street are more likely to take a leaflet offered by a person who looks them in the eye [19], hitchhikers have more success in finding a ride when they gaze at drivers [20], and eye gaze can increase the amount of money people are willing to donate to charity [21].

HRI research concerning nonverbal communication has generally replicated the findings of human-human interaction research. For example, an android mirroring the posture of its human interaction partner increased the partner's ratings of likability towards the robot [22]. Between people, students who receive eye gaze have better recollections of a story told to them by their teacher [23], and a similar effect was found when people were told a story by a robot [24]. Gaze has been shown to increase the persuasiveness of a story-telling robot [25], and people are more likely to comply with a robot's suggestions when it uses nonverbal cues such as gaze and gesture [26]. Furthermore, it has been demonstrated that people respond to a humanoid robot's trust-relevant nonverbal signals (such as crossing the arms and leaning away) in the same manner as they respond to similar signals from people [27].

With regards to the nature of robotic movement and its ability to influence compliance, trust and perceptions of capability, this research question remains largely unexplored. A meta-analysis of trust in HRI found that although reliable and predictable task performance was the most important factor, robot anthropomorphism could also influence trust [28]. In a virtual environment where participants are represented by avatars with no movement, a lifelike avatar resulted in a poor social interaction as the degree of realism portrayed by the avatar raised participants' expectations about its' capabilities [29]. In a study using simulated robots in immersive virtual environments, where participants viewed smooth versus trembling motions of a robot performing a physical manipulation task, participants rated the smooth moving robot more trustworthy. However, in a second interactive experiment with the virtual robot, motion fluency had no impact upon trustworthiness [30].

2.1 Hypotheses

In the current study, participants complete repeated trials of a cooperative visual tracking task (the "shell game") with a humanoid robot, with trial difficulty ranging from easy to very hard. The robot acts as an assistant to the participant, with participants able to ask the robot for help, while on occasion the robot will volunteer an answer.

Hypothesis 1. As previous research indicates eye gaze can increase compliance and persuasion, and is also associated with truthfulness, we predict robot eye gaze will increase the likelihood of participants changing their answer to the robot's suggested answer.

Hypothesis 2. As eye gaze is a cue for indicating interest in another and willingness to interact, we predict robot eye gaze will increase the likelihood of participants asking the robot for assistance.

Hypothesis 3. While largely exploratory in nature, we hypothesise robot "lifelike" bodily movements will increase the likelihood of participants changing their answer to the robot's suggested answer due to these movements positively influencing participants' perceptions of the robot's capabilities.

Hypothesis 4. As task difficulty increases and participants become more unsure of the correct response, participants will be more likely to ask the robot for help and trust the robot's opinion.

3 Method

Experimental Design. A mixed design (2x2x2x4) was employed, with within-subjects variables Eye Gaze (2 levels, On/Off) and Task Difficulty (4 levels), and between-subject variables Breathing and Eye Tracking (both 2 levels, On/Off).

Independent Variables. Task Difficulty (four levels, ranging from easy to very hard) was manipulated to prevent ceiling and floor effects, and to aid in participant vigilance. Three robot behaviours were manipulated, described below.

Eye Gaze. When asking for the participant's answer, if Eye Gaze was On the robot would look directly at the participant (direct gaze). If Eye Gaze was Off, the robot would look at the monitor displaying the shell game (averted gaze). Eye Gaze On versus Off was randomised across 50% of trials.

Eye Tracking. During the cup shuffling process, if Eye Tracking was On the robot's head would move to create the appearance of tracking one of the moving cups. When Eye Tracking was Off, the robot's head would not move, and instead face the centre of the monitor displaying the shell game.

Breathing. When Breathing was On, the robot's body was never completely still, and instead it would rhythmically oscillate between two very similar poses to create the appearance of breathing. When Breathing was Off, the robot's body was still.

Stimuli. Participants played a graphical computerised version of the classic "shell game", in which an object is hidden under one of three cups, and those cups are quickly shuffled to create doubt and uncertainty as to the true location of the object (see Figure 1). Game trials were comprised of 4 levels of difficulty, ranging from easy to very difficult, with difficulty determined by the speed of cup movement (Slow, Medium, Fast, Very Fast). At total of 48 trials (12 trials of each level of difficulty) were presented to each participant, randomised for difficulty. No feedback was given to the participant regarding whether their answers were correct or incorrect after each trial, but a score update was displayed after every 12 trials for the purpose of keeping the participant interested in the game.

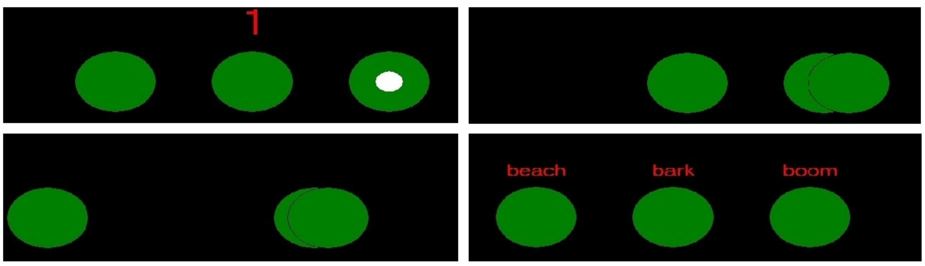

Fig. 1. Screen shots of the shell game stimuli. *Top left*: the game would initiate with a "3, 2, 1" countdown (countdown at time "1" is displayed), with the object of interest displayed as a white circle. *Top right & bottom left*: When the game begins the white circle disappears, and the cups are shuffled horizontally with overlap, occlusion and changes of direction creating doubt as to the object's true location. *Bottom right*: When the cups stop moving after 4 seconds words appear above each cup to identify the different cups.

Participants. A total of 59 first year psychology students, 51 female and 8 male, ranging in age from 18 to 49 years (M=22.4 years, SD=7.1 years), participated in the experiment in return for course credit.

Procedure. A cover story was used, with participants told the purpose of the experiment was to test the robot's vision and speech recognition systems, and that their participation would allow benchmarking of the robot's vision system against human performance. Participants were told to treat the robot as a team member, and they should aim to achieve the highest possible team score. In truth, the robot was controlled using a "Wizard of Oz" set up to which the participant was blind to. The robot, an Aldebaran Nao, sat on a chair-like box, with a computer mouse on either side of the robot, with the robot clicking a mouse button with its hand after each trial to create the illusion of logging the participants' answers. Participants sat facing the shell game display, with the robot situated to the left of the participant in a position that allowed the robot to move its head to either look at the shell game or the participant.

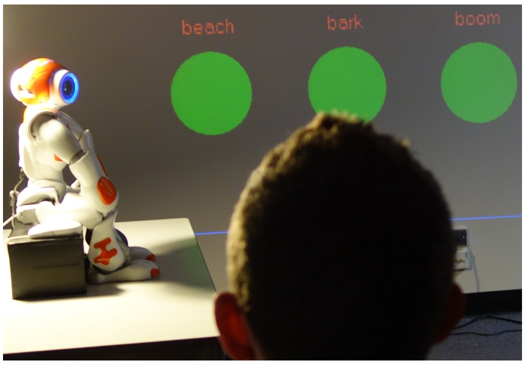

Fig. 2. Experimental setup. The Aldebaran Nao humanoid robot sits on a "chair" between the participant and game stimuli. In the picture displayed Eye Gaze is Off as the robot is looking at the shell game (rather than the participant) when asking for the participant's answer.

For each trial, the cup shuffling process took four seconds, after which a one syllable word appeared above each cup. The robot would ask the participant "What is your answer?", and participants would identify their answer to the robot using the word that appeared above the cup they believed to be hiding the object. Participants were informed they could ask the robot for help using key phrases such as "What do you think?" or "I don't know, please help me". Furthermore, on a total of 16 randomised trials per participant the robot was programmed to either help (8 trials) or deliberately hinder (8 trials). When helping the participant, if the participant had stated the correct answer the robot would say "I agree", while if the participant had given an incorrect answer the robot would say "Are you sure? I think it is <*correct answer*>. What is your final answer?”. When hindering the participant, the robot would say “Are you sure? I think it is <*incorrect answer*>. What is your final answer?”.

Dependent Variables. The following data were recorded: the frequency with which each participant asked the robot for help; the frequency with which each participant changed their answer to the robot’s answer when it differed to their own; task accuracy (i.e. did the participant choose the correct answer); and the time taken by each participant to provide each answer.

4 Results

A total of 2829 trials were conducted (59 participants, 48 trials per participant, and 3 trials were discarded due to technical problems). Each participant’s response means were calculated and mixed repeated measures analyses of variance (ANOVA) were conducted with Breathing and Eye Tracking as between-subjects factors and Eye Gaze and task Difficulty as within-subject factors.

Trusting the robot’s opinion. As expected (**H4**), a main effect of task Difficulty was found, $F(3,324)=5.4, p=.001$, with participants more likely to change their answer to the robot’s as cup movement speed increased. On the easiest difficulty level participants accepted the robot’s advice on 16.4% of trials ($SD=.335$) versus 32.3% of the hardest trials ($SD=.418$). There was a significant interaction between Eye Gaze and Difficulty, $F(3,324)=2.827$, $p=0.039$, with participants more likely to trust the robot’s opinion when it gazed at them on the hardest trials, but less likely to trust the robot on all easier difficulties (see Figure 3). There were no significant effects related to Eye Tracking or Breathing. The hypothesis (**H1**) that participants would trust the robot more when the robot gazed at them was not supported, nor was the hypothesis (**H3**) lifelike bodily movements would increase trust towards the robot.

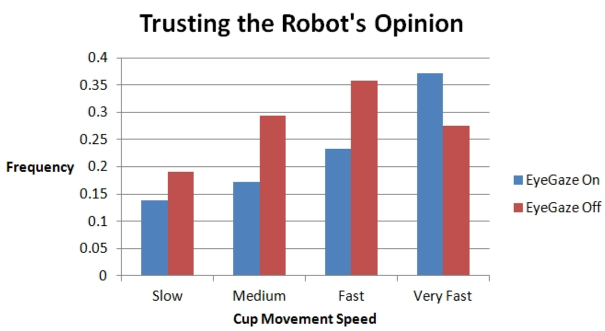

Fig. 3. Results for Eye Gaze and Trusting the Robot’s Opinion. A significant interaction between Eye Gaze and Task Difficulty (cup movement speed) was found, with participants less likely to trust the robot when Eye Gaze is used on Slow, Medium and Fast trials, but more likely to trust the robot on Very Fast trials.

Asking for the robot's opinion. As hypothesised (**H4**), a main effect of Difficulty was found, $F(3{,}162)=16.535$, $p=.000$, with participants asking for Nao's opinion more often as the speed of cup movement increased. On Easy trials participants asked for help on 9.9% of trials ($SD=.203$) compared to 25.0% of Very Hard trials ($SD=.286$). There was a significant interaction between Eye Gaze and Difficulty, $F(3{,}162)=5.424$, $p.=.001$, with participants more likely to ask the robot for help with Eye Gaze for Fast trials, but less likely for Medium trials. To further understand this interaction between Eye Gaze and Difficulty, a second ANOVA was conducted in which task Difficulty was determined not by speed of cup movement, but by grouping trials into quartiles using accuracy means. Using this new measure of task difficulty there was a significant main effect of Eye Gaze $F(1{,}54)=4.826$, $p=0.032$, with participants asking for help more often when Eye Gaze was On as opposed to Off (see Figure 4). Thus, there is some, but not unequivocal, support for the hypothesis (**H2**) participants would be more likely to ask the robot for help when the robot looks at them.

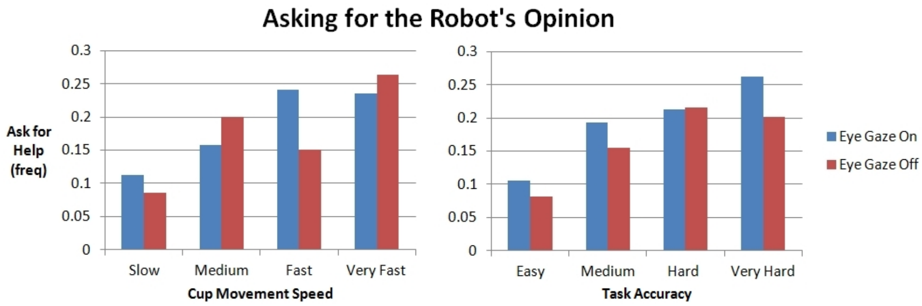

Fig. 4. Results for Eye Gaze and Asking for the Robot's Opinion. *Left*: difficulty is determined by cup movement speed, with a significant interaction between Eye Gaze and Cup Speed. *Right*: difficulty is determined by dividing the 48 trials into quartiles using each trial's accuracy mean. A significant main effect of Eye Gaze was found.

Task Performance. Two measures of task accuracy were used: 1) participants' initial answers, excluding answers which were changed in response to robot advice; 2) participants' final answers. For initial answers, there was a significant interaction between Difficulty and Eye Gaze, $F(3{,}162)=39.348$,$p=.000$, with participants more likely to choose the correct answer on easier trials when the robot looked at them, but less likely to choose the correct answer on harder trials when the robot looked at them. For participants' final answers, the same significant interaction between Eye Gaze and Difficulty was obtained, $F(3{,}162)=28.487$, $p=.000$. Results are shown in Figure 5.

Response Time. A main effect of Eye Gaze was found, $F(1{,}54)=24.73$, $p=.000$, with participants on average 0.6 seconds quicker to answer when Eye Gaze is On ($M=6.79$,$SD=4.05$) as opposed to Off ($M=7.39$, $SD=4.48$). A significant interaction was found between Difficulty and Eye Gaze, $F(3{,}175)=4.012$,

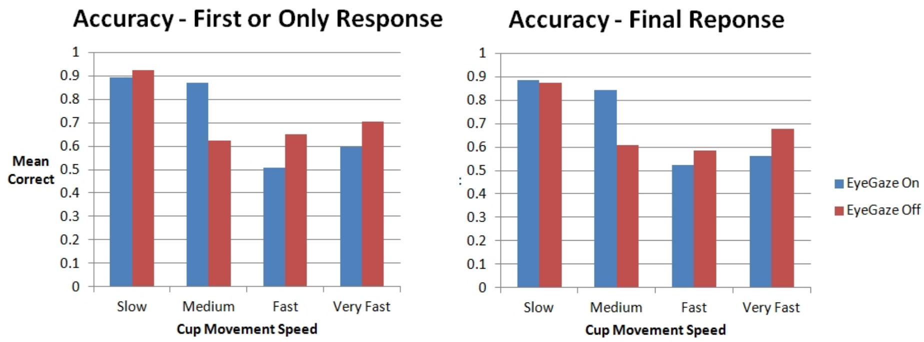

Fig. 5. A significant interaction between Eye Gaze and task Difficulty (cup movement speed) upon participants' accuracy was found. Eye Gaze has little effect on the easiest trials, assists performance on Medium trials, and hinders performance on the more difficult Fast and Very Fast trials.

p=.008, with the effect of eye gaze upon trial duration increasing as task difficulty increases. For example, the difference between Eye Gaze On and Off for Easy trials is just 0.2 seconds, but for Very Hard trials participants are on average 0.74 seconds quicker to respond when Eye Gaze is On.

5 Discussion

Eye Gaze had two unpredicted but powerful effects upon participant decision-making and behaviour. Firstly, robot gaze impacted participant performance, with direct gaze improving participant performance on easier trials, but hindering it on more difficult trials. We postulate this was caused by robot gaze creating "pressure" and anxiety in participants, generating audience effects similar to social facilitation and inhibition - a well researched effect in which people, when in the presence of others as compared to alone, perform better at easy tasks but worse at difficult tasks [31]. While social facilitation is usually studied as an effect of mere presence (as opposed to eye gaze), there is evidence that direct gaze versus averted gaze can induce social facilitation effects [32]. Furthermore, social facilitation arising from robot presence has been observed [33]. The notion of "robot pressure" is supported by response times, with participants markedly quicker to respond to the robot when the robot gazed at them. Interestingly, robot gaze occurs after the trial has completed but before the participant has provided their answer to the robot, demonstrating robot gaze is causing participants to doubt and rethink their initial response on difficult trials. A practical implication of these findings is that when people are performing difficult tasks or making difficult decisions, it may be best for robots to look the other way.

We hypothesised robot eye gaze would increase the likelihood of participants trusting the robot's opinion. Instead, a significant interaction was found between eye gaze and task difficulty, with participants more likely to comply with the robot's suggested answer when it gazed at them on the hardest trials, but conversely on easier trials direct gaze reduced trust. This suggests robot gaze can have either a positive or negative impact upon trust and compliance, depending upon the nature of the robot's request or suggestion. Between people, direct gaze can reduce compliance for unreasonable, illegitimate requests, but increase compliance for reasonable, legitimate requests [34]. Thus, a robot's request for a participant to change their answer on an easy trial could be construed as illegitimate, especially if the participant is confident they are correct, while for a difficult trial the opposite would be true.

We also hypothesised that robot gaze would increase the likelihood of participants asking the robot for help. Evidence was found to support this hypothesis when task difficulty was recategorised using quartile accuracy means, rather than cup movement speed. As shown in Figure 5, cup movement speed is not a perfect indicator of task difficulty, with participants performing better on Very Fast trials as opposed to Fast trials, highlighting an area for improvement when developing future shell game stimuli.

No support was found for the hypothesis that a humanoid robot's lifelike bodily movements of "breathing" and "eye tracking" would make participants more likely to trust the robot's judgments in a visual tracking task. During debriefing many participants reported they failed to notice the robot's eye tracking behaviour in their peripheral vision as they were focused on the shell game, perhaps explaining the absence of effects. While many participants reported noticing the robot's breathing motion, it had no impact on their behaviour.

Lastly, as task difficulty increased, participants were more likely to ask the robot for help and more likely to trust the robot's suggested answer, demonstrating people are willing to accept a robot's advice when making difficult decisions.

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