Robot gaze does not reflexively cue human attention

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Abstract

Joint visual attention is a critical aspect of typical human interactions. Psychophysics experiments indicate that people exhibit strong reflexive attention shifts in the direction of another person's gaze, but not in the direction of non-social cues such as arrows. In this experiment, we ask whether robot gaze elicits the same reflexive cueing effect as human gaze. We consider two robots, Zeno and Keepon, to establish whether differences in cueing depend on level of robot anthropomorphism. Using psychophysics methods for measuring attention by analyzing time to identification of a visual probe, we compare attention shifts elicited by five directional stimuli: a photograph of a human face, a line drawing of a human face, Zeno's gaze, Keepon's gaze and an arrow. Results indicate that all stimuli convey directional information, but that robots fail to elicit attentional cueing effects that are evoked by non-robot stimuli, regardless of robot anthropomorphism.

Introduction

Joint visual attention is an important aspect of typical social interactions. A single gaze communicates information—there are predators hiding behind that tree; a tasty source of food is over there; you are crossing into my territory—and supports social conventions such as conversational turn-taking and joint referencing. As robots become more integrated into daily human life, social interactions occur with increasing frequency between humans and robots, as well: robots assist nurses in hospitals, act as companions for the elderly, and interact with children in schools and in therapy. In this paper, we investigate whether people are responsive to joint attention cues from robots. We focus on one aspect of joint attention: recognizing the direction of another person's gaze and shifting one's own attention in that direction.

Evidence from psychophysics suggests that typical humans readily shift their attention in response to a directional cue, such as averted eyes or an arrow. In traditional *non-predictive* cueing experiments, participants view a centrally-presented stimulus followed by a peripherally-presented visual probe, and press a keyboard key in response to the probe. Key press response times are theoretically correlated with attention: participants will respond more quickly to probes located in the direction to which they are already attending. Studies have found that when the stimulus contains directional information (such as a face with averted eyes, or an arrow pointing in one direction), people respond more quickly to probes at *cued* locations, in which the probe is on the same side as indicated by the stimulus, than to probes at *uncued* locations, even when they are told that the cue does not indicate probe location and should be ignored (Downing, Dodds, & Bray, 2004; Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999). Attention shifting via directional cue seems to be an early and reflexive skill for humans: children as young as three months old attend more quickly to a peripheral probe on cued trials than on uncued trials when the cue is a human face (Hood, Willen, & Driver, 1998).

When cues are *counterpredictive* of probe location, however, social stimuli such as faces and eyes elicit different patterns of behavior than other directional stimuli. In *counterpredictive* cueing paradigms, probes appear with significantly higher probability *opposite* the location cued by centrally-located stimuli (Driver et al., 1999). For example, when the centrally-located stimulus is directed toward the left, probes have a 75% chance of appearing to the right of center, and vice versa. In counterpredictive experiments, it is beneficial for participants to orient attention away from the cued direction; therefore, shorter response times to probes in cued directions are attributed to reflexive or uncontrollable attention shifts. In contrast, shorter response times to probes in uncued (but *predicted*) locations are interpreted as *volitional* orienting of attention. Counterpredictive experiments reveal that participants reflexively orient in the direction of eyes (Driver et al., 1999) but volitionally orient away from the direction of arrows (Friesen, Ristic, & Kingstone, 2004) or extended tongues (Downing et al., 2004). A stimulus that is ambiguously social will elicit reflexive attention shifts when presented to participants as a social cue (a picture of eyes), but not when presented as a non-social cue (a picture of a car) (Ristic & Kingstone, 2005). Furthermore, the effect of this cue on reflexive attention persists if the cue is presented first as social and then as non-social, but not vice versa. This reflexive cueing effect seems strongest for faces, but not necessarily unique to them: arrows have also been shown to trigger reflexive orienting, with magnitude of reflexive orienting toward arrow cues positively correlated with individuals' voluntary attention control (Tipples, 2008), suggesting that dissimilarities in attention directed at eyes and arrows are differences of magnitude (strong versus weak), rather than of kind (reflexive versus volitional).

Eye-tracking and brain-imaging studies reveal similar results. People make more erroneous eye saccades in the direction of a "distracter" cue they are told to ignore if that cue is a face, rather than an arrow (Ricciardelli, Bricolo, Aglioti, & Chelazzi, 2002). Functional MRI studies show that the same cue activates different neural pathways depending on whether it is perceived as eyes or as a non-social directional image (Kingstone, Tipper, Ristic, & Ngan, 2004). Attentional orienting to gaze cues and to arrow cues activates different cortical networks, with attentional orienting to arrow cues relying on a pathway associated with voluntary shifts of attention (Hietanen, Nummenmaa, Nyman, Parkkola, & Hämäläinen, 2006). In a different fMRI study, however, the same cue activated the same extensive cortical network regardless of whether it was interpreted as an eye or an arrowhead, though the eye cue more strongly engaged some parts of this network (Tipper, Handy, Giesbrecht, & Kingstone, 2008).

Psychologists have suggested that shared attention is a precursor to developing a theory of mind for other people, and that lacking ability to interpret others' visual attention might indicate social disorders such as autism (Baron-Cohen, 1995). Children with autism fail to show preferential sensitivity to socially relevant cues such as human gaze: they demonstrate similar response times to both arrows and faces on a counterpredictive cueing task (whereas typically developing children are cued by faces but not by arrows) (Senju, Tojo, Dairoku, & Hasegawa, 2004), and they avoid shifting their gaze in response to non-predictive gaze cues (Ristic et al., 2005). Participants' scores on the Autism-Spectrum Quotient have also been negatively correlated with reflexive gaze cueing magnitude (Bayliss, Pellegrino, & Tipper, 2005).

In summary, evidence suggests that for non-predictive cues, both social and non-social directional stimuli elicit reflexive attention shifts in cued directions, but that for counterpredictive cues, socially relevant stimuli (such as human faces) continue to elicit reflexive attention shifts while non-social directional stimuli, such as arrows, exhibit weak or no reflexive attentional influence. This paper applies the psychophysical methods used to isolate attention shifts for faces and arrows to novel stimuli to inform the field of human-robot interactions (HRI). HRI is interested in how people perceive robots and how designers can create robots that interact naturally with people. To date, there has been little research on the cognitive effects of robots on human attention. As the presence of robots in day-to-day social situations increases, however, it becomes important to evaluate robots' cognitive influence to better understand the roles robots can perform and to improve designs of human-assistive robots.

Some evidence suggests that robots can use gaze cues to "leak" information to humans. In conversations between robots and human participants, robots were able to define participants' roles (addressee, bystander, or eavesdropper) through visual attention cues (Mutlu, Shiwa, Kanda, Ishiguro, & Hagita, 2009). Another study found that robots can influence people's decisions in a game by shifting their eyes briefly to a target, even when participants do not report seeing those cues (Mutlu, Yamaoka, Kanda, Ishiguro, & Hagita, 2009). In the latter study, robot appearance influenced the effectiveness of gaze cues: Geminoid, a very human-like robot, was more effective at revealing intentions through gaze cues than Robovie, a robot with more abstract human features.

In this paper, we ask: will robots be treated like humans or like arrows? That is, will robot gaze be interpreted by humans' cognitive systems as a social cue on par with human gaze, with attendant reflexive shifts of attention in the gaze direction? Or will robots be perceived by humans as non-social entities, such as arrows or cars, allowing participants to override reflexive attention shifts in favor of volitional orienting toward predicted probe locations? Because robots are designed with varying levels of anthropomorphism, we use two robot stimuli, one from a very human-like robot called Zeno, and one from a less anthropomorphic robot named Keepon. Cueing effects from human faces have been found to be stronger for schematic faces than for real faces (Hietanen & Leppänen, 2003), suggesting that cueing information contained in schematic faces is overshadowed by the complexity of real faces. For this reason, we also use two types of human face stimuli: a photograph of a human face and a line drawing of a face. Finally, we use an arrow as a non-social but directional stimulus.

Methods

This experiment employs two commercially available robot platforms. Zeno is produced by Hanson Robotics as a realistic, expressive robot (Figure 1(c)). In addition to eyes and a nose, Zeno's face has human-like features such as eyebrows, lower eyelids, an expressive mouth, and hair. In contrast, Keepon's features are less human-like (Figure 1(d)). Developed by Hideki Kozima, Keepon is a 20 cm tall robot made of two stacked yellow spheres of deformable rubber; its eyes are white circles overlapped by smaller, concentric black circles and its nose is a black circle. Keepon's deformable body and eyes with sclera suggest biological features, but its form and color (bright yellow) clearly indicate that it is robotic. The aim of selecting such different robots is to identify whether human-like features are necessary to evoke the same (purportedly social) response as to a human face.

Participants were 41 male and 29 female Yale University students between the ages of 18 and 34 (mean age 21.4). Each participant was assigned to a single stimulus condition (human, line drawing, Zeno, Keepon, or arrow). Participants were recruited in person or with flyers around campus, and were rewarded with candy at the end of the experiment.

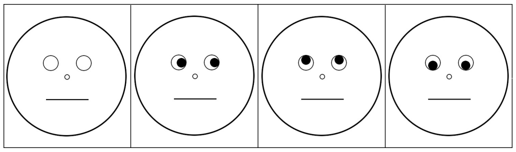
Stimuli

The human gaze stimulus is a head-and-neck photograph of a woman (Figure 1(a)). Her head subtends a visual angle of 6.2° horizontally. Each eye subtends 1.0° and the center of each eye is 1.2° to the right or left of center. This stimulus was chosen as a social analogue to photographs of the robots.

The line drawing stimulus, re-created from Friesen et al. (2004), is a black-and-white line drawing of a face with circular eyes and nose, and a line for the mouth (Figure 1(b)). The head subtends 7.5°; each eye subtends 1.0° and its center is 1.0° left or right of image center, where the nose is located. This stimulus has been previously shown to elicit both reflexive and volitional shifts of attention (Friesen et al., 2004).

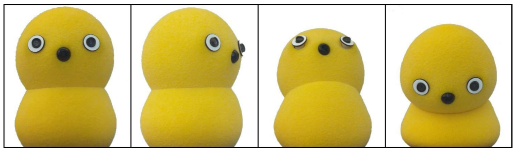
Zeno is example of a highly anthropomorphic robot (Figure 1(c)). The Zeno stimulus is a head-and-neck photograph

(a) Human gaze stimulus

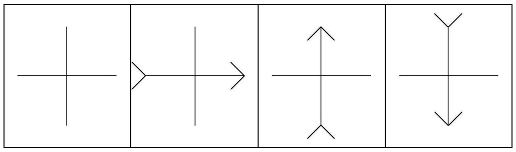


(b) Line-drawn face stimulus

(c) Zeno gaze stimulus



(d) Keepon gaze stimulus



(e) Arrow stimulus

Figure 1: Each subject was assigned to one of five stimulus conditions. This figure shows the front, right, up and down versions of each stimulus; left versions are mirrors of right-facing versions and are omitted here for brevity.

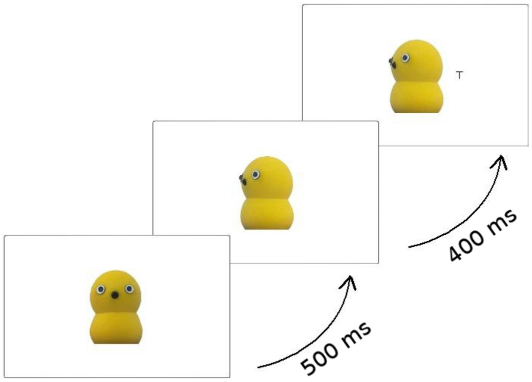


Figure 2: Time course for a single (predicted) trial of the Keepon gaze condition. Setup is similar for other stimuli and gaze directions.

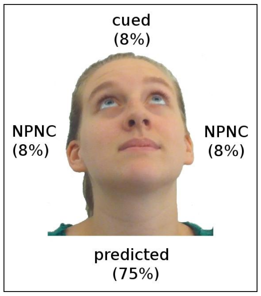


Figure 3: Three types of trials were presented: *cued*, in which probe and gaze are congruent; *predicted*, in which probe location is opposite to gaze direction; and *not-predicted-not-cued* or *NPNC*, in which probe is on a different axis than gaze. Percentages indicate probability of occurrence.

of the robot, with face subtending 6.7° horizontally (7.8° including hair) and each 1.0° eye located 1.3° to the left or right of center. Keepon is a less anthropomorphic robot (Figure 1(d)). The Keepon stimulus is a full-body photograph of the robot, subtending 6.2° horizontally, with each 1.0° eye located 1.75° to the left and right of center.

The arrow stimulus is 7.1° long and drawn over a 6.2° fixation cross; equal amounts of visual information are presented at the head and tail of the arrow, thereby avoiding the possibility that cueing results simply from additional features in the cued direction (Figure 1(e)).

Each stimulus had left-, right-, up- and down-facing variants (see Figure 1). In a single trial of the cueing condition, the front-facing variant was presented for 500 milliseconds, followed by one of the other ("turned") variants. After a 400 millisecond SOA (or a 600 millisecond SOA in human and Zeno conditions), a probe letter, either "T" or "L," appeared on the screen either above, below, to the left, or to the right of the stimulus image. Each probe letter was 0.9° tall and wide, and was presented along the midline 4.8° from center. Cue and probe remained on screen until participants responded by pressing a keyboard key or until 2 seconds elapsed. (See Figure 2 for an example.)

Following Friesen et al. (2004), for each trial of the cueing condition, the probe had a 75% chance of appearing on the opposite (*predicted*) side of where the cue directed, and a 25% chance of appearing in one of the other three locations (approximately 8% chance each)—on the same side as where the cue directed (*cued*), or orthogonal to the direction of the cue (*not-predicted-not-cued* or *NPNC*), as shown in Figure 3.

Once participants responded to the probe or 2 seconds elapsed, all images were replaced by a prompt asking participants to press any key to proceed to the next trial.

Procedure

Participants were seated approximately 60 cm in front of a 29 cm by 18 cm laptop screen. They were told which stimulus they would observe and the sequence of images they would see during the experiment (as in Figure 2). Participants were told they would first observe a front-facing stimulus, replaced

Stimulus	Trial type	Avg. RT (ms)	SD	N
Human	cued	444	46	15
	predicted	428	54	
	NPNC	462	61	
Line	cued	458	73	16
	predicted	449	73	
	NPNC	474	70	
Zeno	cued	473	147	13
	predicted	452	108	
	NPNC	473	116	
Keepon	cued	464	65	14
	predicted	428	52	
	NPNC	469	55	
Arrow	cued	453	66	12
	predicted	433	44	
	NPNC	461	53	

Table 1: Average response times and standard deviations, in milliseconds, for all participants (rounded to the nearest millisecond). Each row represents a stimulus condition separated into trial types. The last column indicates the number of participants in each condition.

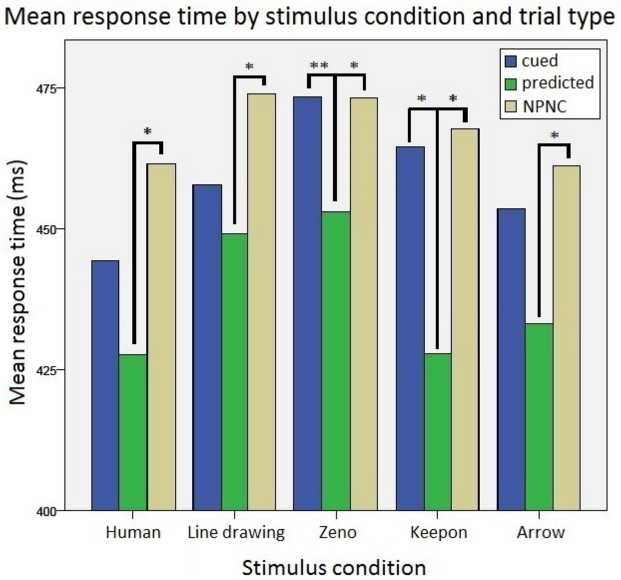


Figure 4: Mean response times in milliseconds for each trial type and stimulus condition. A single asterisk indicates significant differences ($p < 0.05$), a double asterisk indicates borderline significant differences ($p < 0.10$).

by a "turned" stimulus, then a probe letter ("T" or "L"). They were also informed that the probe was three times more likely to appear on the side opposite where the gaze or symbol directed. Participants were asked to press the keyboard key of the letter appearing on the screen as quickly and accurately as possible. These instructions were also presented textually on the screen before the start of the experiment. Key press response times were recorded for analysis.

All participants saw 99 trials, consisting of 96 test trials and 3 additional practice trials drawn at random from the test trials and presented first. The set of test trials comprised 72 *predicted* trials (the probe appeared opposite where the cue indicated), 8 *cued* trials (the probe appeared on the side indicated by the cue), and 16 *NPNC* trials (the probe appeared on a different axis than the one directed by the cue), with "T" and "L" presented equally frequently.

Results

Mean response times and standard deviations are listed by condition and trial type in Table 1. Figure 4 shows mean response times by stimulus condition and trial type.

Data from four participants were excluded for noncompliance (not following directions to respond as quickly as possible, or pressing keys at random as evidenced by high error rates). Trials in which participants incorrectly identified probe letters, response times exceeded 1.5 seconds, or response times were less than 100 ms were treated as errors and excluded from analysis. The error rate was 3.9% for analyzed data. In total, results from 70 particpants across the five conditions were analyzed, as shown in Table 1.

A repeated measures analysis of variance with stimulus type (human, line drawing, Zeno, Keepon, and arrow) as the between-subjects variable and trial type (cued, predicted and NPNC) as the within-subjects variable revealed significant main effects for trial type ($F(2,130) = 19.819$, $p < 0.001$) though not for stimulus condition ($F(4,65) = 0.196$, $p = 0.939$). There was no interaction between stimulus type and trial type ($F(8,130) = .673$, $p = 0.703$).

Because there was a significant main effect of trial type, we further analyzed the data within each stimulus condition with a repeated measures analysis of variance on trial type, which found significant main effects for trial type on most conditions (human: $F(2,28) = 3.675$, $p = 0.038$; line drawing: $F(2,30) = 4.328$, $p = 0.022$; Zeno: $F(2,26) = 3.409$, $p = 0.048$; Keepon: $F(2,26) = 13.558$, $p < 0.001$), and borderline significance main effects in the arrow condition ($F(2,22) = 2.672$, $p = 0.091$). In all conditions, pairwise comparisons reveal that each stimulus elicited significantly faster response times to predicted than to NPNC trials (human: mean difference = 33.921, sd = 8.764, $p = 0.002$; line drawing: mean difference = 24.892, sd = 5.902, $p = 0.001$; Zeno: mean difference = 24.515, sd = 8.335, $p = 0.011$; Keepon: mean difference = 39.878, sd = 9.410, $p = 0.001$; arrow: mean difference = 27.875, sd = 11.120, $p = 0.029$). Only in the robot conditions, however, were there significant or borderline-significant differences between predicted and cued trials as well (Zeno: mean difference = 23.746, sd = 12.712, $p = 0.084$; Keepon: mean difference = 36.698, sd = 8.613, $p = 0.001$).

Discussion

Results suggest that participants recognized the directional significance of all stimuli, but only responded to the cueing significance of non-robot stimuli. Though they were able to extract directional information from robot gaze, participants in either robot condition were not susceptible to reflexively reorienting in the direction of robot gaze, in contrast to participants in face and arrow conditions.

Response times were statistically faster for predicted trials than for baseline NPNC trials in all stimulus conditions, which indicates that participants directed their attention toward predicted locations—where they expected a stimulus to appear—more than toward not-predicted not-cued (NPNC) locations. For robot stimuli (Zeno and Keepon), response times were also statistically faster for predicted than for cued trials (borderline significance in the Zeno case, $p = 0.084$). In other words, participants directed their attention significantly more quickly toward predicted locations than toward cued locations, and thus show no evidence of having been cued by robot gaze: participants in robot conditions attended to cued locations just as infrequently as NPNC locations that were neither cued nor predicted. In contrast, response times were not significantly different between predicted and cued trials in the non-robot conditions (human face, line drawing of a face, and arrow). Participants in these conditions were not significantly more attentive to predicted than to cued locations; in fact, Figure 4 shows that cued trial response times were, on average, greater than predicted trial response times but less than NPNC trial response times. This suggests that non-robot stimuli attracted participants' reflexive attention to cued locations despite the fact that participants were no more motivated to look at cued locations than at NPNC locations.

This counterpredictive cueing task involved four possible probe locations on each trial: a cued location, in the direction of gaze or pointing; a predicted location, opposite the cued location, where participants were told probes were likely to appear; and two not-predicted not-cued locations (NPNC), which have the same probability of probes appearing at each of them as at the cued location. NPNC trials provide a good baseline because they involve an identical task (responding to a probe with a key press) but do not represent cued or predicted locations. In this study, participants were significantly faster at responding to probes at predicted locations than at NPNC locations for every stimulus, revealing that they recognized the direction indicated by the stimulus and used that to inform them of predicted probe position.

In contrast, participants in both robot conditions were also significantly faster at responding to probes at predicted locations than those at cued locations. In essence, participants seem to be ignoring the natural interpretation of robot gaze in favor of the counterpredictive interpretation demanded by the task. This behavior has been observed in children with autism, who are able to ignore non-predictive gaze cues, while their typically-developing peers are susceptible to reflexive cueing from non-predictive stimuli (Ristic et al., 2005). The fact that robots do not seem to cue reflexive attention, in a way that even non-social stimuli such as arrows do, suggests that robots are cognitively processed differently than common directional symbols or social entities.

Previous studies (e.g., Friesen et al., 2004; Tipples, 2008) use a similar counterpredictive experimental design in which participants are asked to press a key when *any* probe appears. This detection task elicits covert attention shifts, in which participants' eyes do not move (in fact, Friesen et al. (2004) tracked several participants' eyes to ensure that they did not shift). The task in the current experiment requires identifying probes (either "T" or "L") by pressing corresponding keyboard keys, so results from this identification task are not directly comparable to results from previous detection-based experiments. It would be interesting, however, to analyze covert attention effects of various robots using detection tasks. Some robotics studies (e.g., Mutlu, Yamaoka, et al., 2009; Mutlu, Shiwa, et al., 2009) suggest that highly anthropomorphic robots are more successful than less anthropomorphic robots at conveying intentions through gaze, suggesting that robot anthropomorphism influences covert attention.

Attentional cueing is more pronounced with schematic drawings of faces than with real faces (Hietanen & Leppänen, 2003), so this study included both a photograph of a human face and a line drawing of a face as stimuli. Both faces elicited significantly faster responses to predicted versus NPNC trials, but not to predicted versus cued trials. Though the arrow stimulus also showed this effect statistically, differences between NPNC and cued trial response times are larger for the two social stimuli, with 17.183 ms average difference for the human face, and 16.140 ms average difference for the line drawing, compared with 7.548 ms average difference for the arrow.

Some stimuli were tested at 400 ms SOA (line drawing, arrow, and Keepon) while others were tested at a 600 ms SOA. This represents a methodological change undertaken partway through the experiment, in order to align more precisely with previous research. Both SOA times are within the threshold for "short" SOAs as described by Friesen et al. (2004), and reflexive cueing effects have been found at up to 600 ms SOAs (Friesen et al., 2004; Tipples, 2008). Therefore, we believe these SOAs to be comparable.

This study provides some of the first insight into cognitive processing of robot stimuli, using psychophysical techniques common in cognitive psychology but largely unused in the field of human-robot interaction (HRI). There is significant information to be gained from analyzing the cognitive effects of robots on human attention, both for cognitive scientists interested in which features cue attention, and robot designers interested in creating robots that engage in natural social interactions with people. Robot stimuli provide a "real life" testbed for cognitive attention experiments by allowing researchers to manipulate robotic features to test theories about what features cue reflexive attention. Robot designers can use this information in their designs, which would improve robot usability by allowing people to employ the same social cues with robots as they do with other humans. The current study suggests that these two robots, Zeno and Keepon, are unable to cue human attention in this task the way real faces, schematic faces, or even arrows do. These results should be further explored to identify what kinds of visual manipulations can make robots appear reflexively social.

Conclusions

Human eyes elicit strong attentional shifts in the direction of their gaze, even when this shift is detrimental to viewers' goals, while non-social directional cues such as arrows have demonstrated weaker attentional cueing effects. Little evidence currently exists for the cognitive effects of robot gaze cues, however. Using an established counterpredictive cueing experiment, we analyzed the attentional influence of two robots that vary in level of anthropomorphism, and compared our findings to attentional effects of human faces and arrows. Results indicate that all of the stimuli conveyed directional information to participants, but that neither robot stimulus evoked reflexive attentional cueing, though all non-robot stimuli elicited this effect. These findings suggest that when participants are motivated to look away from a directed location, common directional symbols still engage an automatic attention shift to the directed location, while robots do not. This paper is among the first to apply psychophysical techniques to the analysis of cognitive effects of robot appearance, and further experimentation using these techniques might reveal what features influence natural social responses from people, and may help robot designers who are interested in creating social robots.

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