Does Gaze Reveal the Human Likeness of an Android?

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Abstract— **The development of androids that closely resemble human beings enables us to investigate many phenomena related to human interaction that could not otherwise be investigated with mechanical-looking robots. This is because more humanlike devices are in a better position to elicit the kinds of responses that people direct toward each other. In particular, we cannot ignore the role of appearance in giving us a subjective impression of human presence or intelligence. However, this impression is influenced by behavior and the complex relationship between appearance and behavior. We propose a hypothesis about how appearance and behavior are related and map out a plan for android research to investigate the hypothesis. We then examine a study that evaluates the behavior of androids according to the patterns of gaze fixations they elicit. Studies such as these, which integrate the development of androids with the investigation of human behavior, constitute a new research area that fuses engineering and science.**

I. Introduction

Our everyday impressions of intelligence are subjective phenomena arising from our interactions with other people. The development of systems that support rich, multimodal interactions will be of enormous value. Our research goal is to discover principles underlying natural communication among individuals and to establish a methodology for the development of expressive androids. The top-down design of robots that support natural communication is impossible because there are no adequate human models. We adopt a constructivist approach that entails repeatedly developing and integrating behavioral models, implementing them in humanoid robots, analyzing their faults, and then improving and reimplementing them [1].

By following this constructivist approach in a bottom-up fashion, we have developed a humanoid robot "Robovie" that has hundreds of situation-dependent behavior modules and episode rules to govern their combination [2]. This has allowed us to study how Robovie's behavior influences human-robot communication [3]. However, we may infer that a humanlike appearance is also important from the fact that human beings have evolved specialized neural centers for the detection and interpretation of human hands and faces. Human beings also have many biomechanical structures that support interaction, including scores of muscles for controlling facial expressions and the vocal tract, not to mention gestures. Robovie's machinelike appearance must have an impact on interaction, which therefore prevents us from isolating the effects of behavior. Other studies have also tended to focus on behavior only, entrusting a robot's appearance to an artistic designer. But to isolate the effects of behavior from those of appearance, it is necessary to develop an android robot that looks like a person. Our study tackles the appearance and behavior problem from the standpoint of both engineering and science and explores the essence of communication through the development of androids.

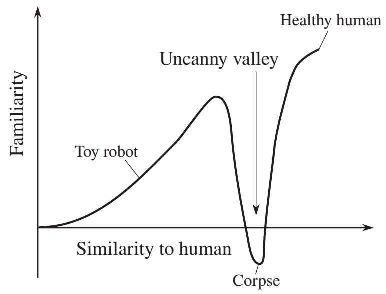


Fig. 1. Uncanny valley

The android study has two research aspects:

- The development of a humanlike robot based on mechanical and electrical engineering, robotics, control theory, pattern recognition, and artificial intelligence.
- An analysis of human activity based on the cognitive and social sciences.

The two aspects interact with each other closely: *to make the android humanlike, we must investigate human activity from the standpoint of the cognitive, behavioral, and neurosciences, and to evaluate human activity, we need to implement processes that support it in the android.*

Research on the development of communication robots has benefited from insights drawn from the social and life sciences. However, the contribution of robotics to these fields has so far been insufficient in part because conventional humanoid robots appear mechanical and, therefore, have an impaired ability to elicit interpersonal responses. To provide an adequate testbed for evaluating models of human interaction, we need robots that allow us to consider the effects of behavior separately from those of appearance.

Conversely, research in the social and life sciences generally takes a humanlike appearance for granted or ignores the issue of appearance altogether. Thus, its applicability is unclear. The judicious use of androids in experiments with human subjects has the potential for overcoming these problems. The application of androids to the study of human behavior can be seen as a new research area that fuses engineering and science in contrast to existing approaches in humanoid robotics that fail to control for appearance. This paper proposes a direction for android research based on our hypothesis on the relationship between appearance and behavior. It also reports a study that evaluates the human likeness of an android based on human gaze fixations.

II. A Research Map based on the Appearance and Behavior Hypothesis

A. A Hypothesis about a Robot's Appearance and Behavior

It may seem that the final goal of android development should be to realize a device whose appearance and behavior cannot be distinguished from those of a human being (in other words, a device that could pass the Total Turing Test at T3 [4]). However, since there will always be subcognitive tests that could be used to detect subtle differences between the internal architecture of a human being and an android [5], [6], an alternative goal could be to realize a device that is nearly indistinguishable from human beings in everyday situations. In the process of pursuing this goal, our research aims to investigate principles underlying interpersonal communication.

A significant problem for android development is the "uncanny valley," first suggested by Mori [7], [8]. He discussed the relationship between how similar a robot is to a human and a subject's perception of familiarity. A robot's familiarity increases with its similarity until a certain point is reached at which imperfections cause the robot to appear repulsive (Fig. 1). This sudden drop is called an uncanny valley. We are concerned in our development of androids that these robots could also fall into the uncanny valley owing to imperfections in appearance and behavior. Therefore, a methodology to overcome the uncanny valley is required.

In the figure, the effect of similarity can be decomposed into the effects of appearance and behavior, since both interdependently influence human-robot interaction. We hypothesize that the relation between appearance and behavior can be characterized by the graph in Fig. 2 [9]. Figure 2 superimposes graphs derived from Mori's "uncanny valley" hypothesis and the hypothesis that there is a synergistic effect on interaction when appearance and behavior are well-matched [10]. Simply put, we hypothesize that an android's uncanniness can be mitigated by its behavior, if the behavior closely resembles that of a person.

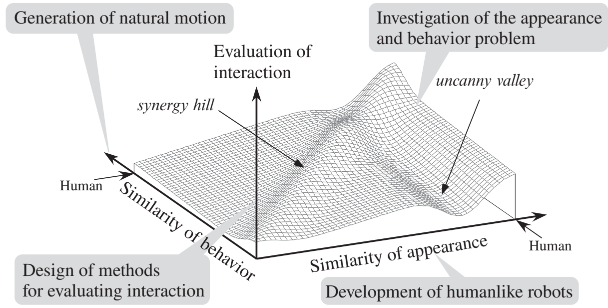


Fig. 2. The extended uncanny valley and a map for investigating it.

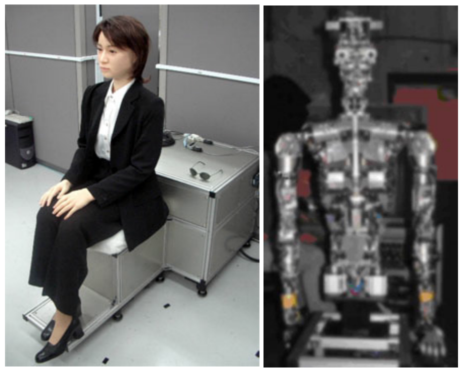


Fig. 3. The android *Repliee Q1*.

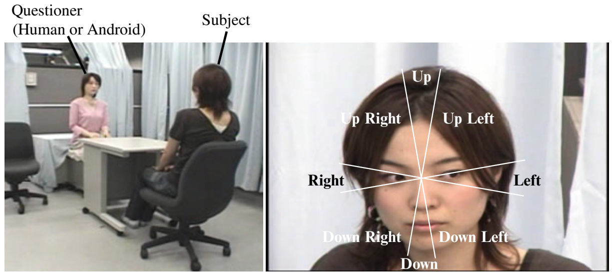
B. Android Research Map

The axes in Fig. 2 are not clearly defined. How do we quantify similarity and how do we evaluate human-robot interaction? There are three main research issues to define them.

a) A method to evaluate human-robot interaction: Human-robot interaction can be evaluated by its degree of "naturalness." Therefore, it is necessary to compare human-human and human-robot interactions. There are qualitative approaches to measure a mental state using, for example, the semantic differential (SD) method. There are also quantitative methods to observe an individual's largely unconscious behavior such as gaze behavior, interpersonal distance, and vocal pitch. These observable responses reflect cognitive processes that we might not be able to infer from answers to a questionnaire. We are studying how a human subject's responses reflect the humanlike quality of an interaction and how they relate to the subject's mental state.

b) Implementing natural motion in androids: To elucidate what kinds of motion make people believe an android's behavior to be natural, we endeavor to mimic an individual's motion precisely and then monitor how a human subject's interaction with the android degrades as we remove some aspect of the android's motion. A straightforward way to animate the android is implementation of the motion of an actual human subject as measured by a motion capture system. Most methods that use a motion capture system assume that a human body has the same kinematic structure as a robot

Fig. 4. The android *Repliee Q2*.



(a) The experimental setup (b) The discrete eye directions

Fig. 5. Experiment scene and eight averted gaze directions

and calculate the joint angles using the robot's kinematics (e.g., [11]). However, since the kinematic structure of human and robot differ, there is no guarantee that the robot's motion as generated from the angles will resemble human motion. Therefore, we need a method to ensure that the motions we see at the surface of the robot resemble those of a human being.

c) The development of humanlike robots: We have developed the android *Repliee Q1*, shown in Fig. 3. It has 31 degrees of freedom in the upper body and can generate various kinds of micro motions such as the shoulder movements typically caused by human breathing. Silicone skin which has a humanlike feel covers the head, neck, hands, and forearms. The compliance of the air actuators makes for a safer interaction. Highly sensitive tactile sensors mounted just under the android's skin enable contact interaction.

Repliee Q1 has now been upgraded to *Repliee Q2* shown in Fig. 4. It has 42 degrees of freedom and can make facial expressions and finger motions in addition to the movements of Repliee Q1. The face was molded after a particular Japanese woman to realize a more humanlike appearance.

We are studying the appearance and behavior problem while integrating this work. In the next section we present a study of the appearance and behavior problem based on human gaze behavior during communication.

III. A STUDY OF THE APPEARANCE–BEHAVIOR PROBLEM

A. Breaking eye contact during thinking

In the evaluation of a human-robot interaction, methods of evaluating a human subject's (largely unconscious) responses provide a complementary source of information to insights gleaned from a questionnaire or focus group. This paper examines subjects' gaze behavior. Gaze behavior in human-human interaction has been studied in psychology and cognitive science, and gaze behavior in human-robot interaction can be compared to it.

Breaking eye contact during a conversation has been studied in psychology. While thinking, people sometimes break eye contact (avert their eyes from the interlocutor). There are three main theories to explain the behavior:

- Arousal reduction theory
  This theory suggests that individuals break eye contact while thinking to reduce their arousal and concentrate on the problem [12].
- The differential cortical activation hypothesis
  This hypothesis suggests that brain activation induced by thinking tasks leads individuals to shift their gaze away from the central visual field [13].
- Social signal theory
  This theory suggests that gaze behavior acts as social signals; people break eye contact to inform others that they are thinking.

If breaking eye contact were a kind of social signal, we would expect it to be influenced by the interlocutor. Psychological researchers have reported that there is experimental evidence to support the social signal theory [14], [15]. We report an experiment that compares subjects' breaking of eye contact with a human and android interlocutor.

We hypothesize that, if the way in which eye contact is broken while thinking acts as a social signal, subjects will produce different eye movements if the interlocutor is not humanlike or if the subjects do not consider the interlocutor to be a responsive agent. Conversely, if eye movement does not change, this supports the contention that subjects are treating the android as if it were a person, or at least a social agent.

B. Experiment 1

1) Procedure: Subjects sit opposite a questioner (Fig. 5 (a)). Subjects' eye movements are measured while they are thinking about the answers to questions posed by the questioner. There are two types of questions: *know questions* and *think questions*. The know questions are used as a control condition. Subjects already know the answer to know questions (e.g., "How old are you?") but not to think questions because they force the subject to derive the answer (e.g., "Please tell me a word that consists of eight letters.").

The subjects were asked 10 know questions and 10 think questions in random order. Their faces were videotaped and the gaze direction was coded beginning from the end of the question to the beginning of the answer. We calculated the

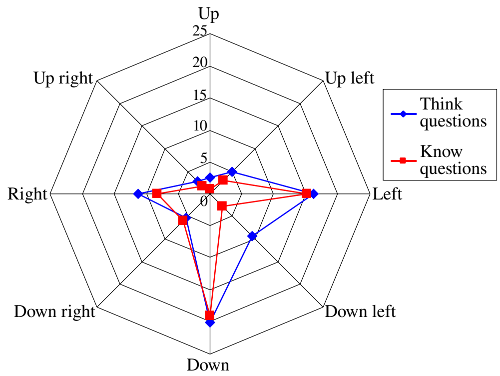


Fig. 6. Average percent duration of gaze in eight averted directions for human questioner (experiment 1) [%]

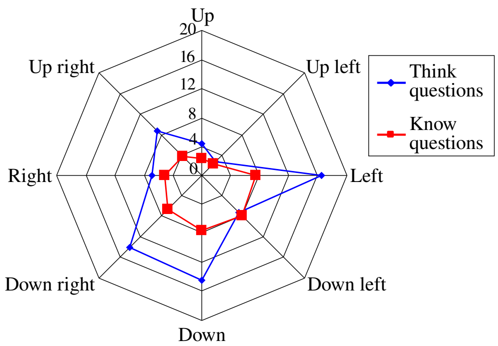


Fig. 7. Average percent duration of gaze in eight averted directions for android questioner (experiment 1) [%]

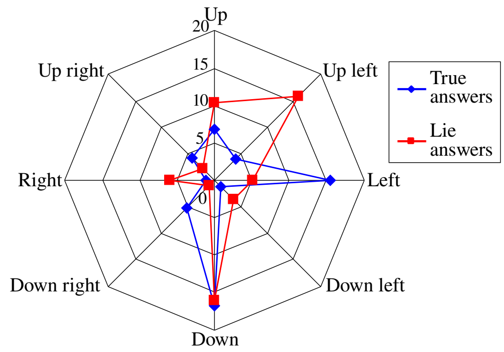


Fig. 8. Average percent duration of gaze in eight averted directions for human questioner (experiment 2) [%]

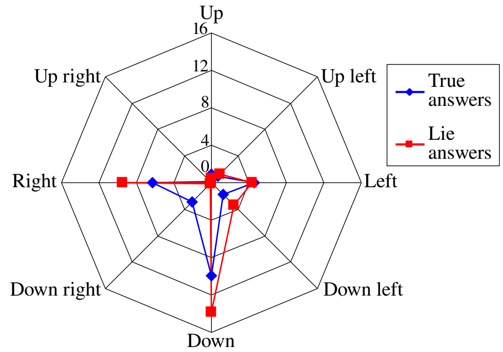


Fig. 9. Average percent duration of gaze in eight averted directions for android questioner (experiment 2) [%]

average duration of gaze in the eight directions shown in Fig. 5 (b).

We prepared two types of questioners: Japanese person (human condition) and the android Repliee Q1 (android condition). To make the android look as humanlike as possible, we conducted the experiment for the android condition as follows: A speaker embedded in the android's chest produced a prerecorded voice. Micro behaviors such as eye and shoulder movements were implemented in the android to make it seem natural. At first the experimenter sitting beside the android explained the experiment to the subject to habituate the subject to the android. The android behaved as an autonomous agent during the explanation (e.g., it continuously made slight movements of the eyes, heads, and shoulders while occasionally yawning). It seemed that the subject believed the android to be asking questions autonomously, although questions were manually triggered by an experimenter seated behind a partition.

The subjects were Japanese adults (six men and six women in human condition and four men and four women in android condition). Every subject participated in only one condition.

2) Result: Table I shows the average percentage of time subjects looked in each eye direction for the human condition, and illustrated by the polar plot in Fig. 6. Table II and Fig. 7 show the results for the android condition in the same manner.

a) Eye contact: A two-sample t-test for the eye contact duration revealed significant effects of question type in both conditions ($t(22) = 1.88, p < 0.05$ in the human condition, $t(14) = 2.57, p < 0.05$ in the android condition). The duration of eye contact for think questions is shorter than that for know questions in both conditions. The result is consistent with the commonsense belief that the time of breaking eye contact increases while people are thinking. There are no significant effects of the questioner in both question types.

b) Averted eye direction: A 2-way, repeated measures question type (2) $\times$ eye direction (8) ANOVA revealed no significant effect in the human condition, but significant effect in the android condition ($F(1, 112) = 5.74, p < 0.05$). There are no significant effects of the questioner in both question types. Table V summarizes the effects of question type and questioner in the experiment 1. As can be seen in Fig. 6, Japanese subjects tend to avert eyes downward when they are posed a question even if they are not required to derive the answer. The averted eye direction does not depend on the question type. It is considered that this gaze behavior is the standard in Japanese culture. For the android questioner, however, the averted eye direction changes depending on the question type as can be seen in Fig. 7. The subjects looked around for the think questions frequently compared to the know questions. The subjects' mental state in the android

TABLE I

MEAN AND STANDARD DEVIATION OF GAZE DURATION IN EACH DIRECTION FOR HUMAN QUESTIONER (EXPERIMENT 1) [%]

		Down right	Down	Down left	Right	Left	Up right	Up	Up left	Eye contact
Think	Mean	5.42	20.0	9.29	11.3	16.2	2.79	2.62	4.96	27.0
	Std.	6.73	17.3	13.1	11.4	17.3	4.36	4.66	6.37	19.3
Know	Mean	5.96	19.0	2.69	8.25	15.2	1.83	0.752	3.05	43.4
	Std.	6.43	24.8	4.07	14.5	12.8	3.40	1.87	5.76	23.2

TABLE II

MEAN AND STANDARD DEVIATION OF GAZE DURATION IN EACH DIRECTION FOR ANDROID QUESTIONER (EXPERIMENT 1) [%]

		Down right	Down	Down left	Right	Left	Up right	Up	Up left	Eye contact
Think	Mean	14.1	14.4	7.23	6.87	16.5	8.62	4.42	2.63	25.2
	Std.	13.8	13.9	4.41	7.89	13.3	14.2	5.93	2.26	21.0
Know	Mean	6.53	7.57	7.87	5.10	7.47	3.73	2.29	2.18	57.3
	Std.	8.26	12.0	9.77	8.47	7.41	8.36	5.73	3.47	28.3

TABLE III

MEAN AND STANDARD DEVIATION OF GAZE DURATION IN EACH DIRECTION FOR HUMAN QUESTIONER (EXPERIMENT 2) [%]

		Down right	Down	Down left	Right	Left	Up right	Up	Up left	Eye contact	Upside
Truth	Mean	5.22	16.7	1.12	1.07	15.4	4.04	6.81	4.02	45.6	14.9
	Std.	8.68	18.6	3.36	2.27	13.7	11.4	10.4	6.03	25.5	16.1
Lie	Mean	0.989	16.0	3.60	6.00	5.08	2.25	10.4	15.9	39.9	28.5
	Std.	1.82	20.9	6.74	10.9	7.94	5.65	12.4	23.8	29.4	30.0

TABLE IV

MEAN AND STANDARD OF GAZE DURATION IN EACH DIRECTION FOR ANDROID QUESTIONER (EXPERIMENT 2) [%]

		Down right	Down	Down left	Right	Left	Up right	Up	Up left	Eye contact	Upside
Truth	Mean	2.94	9.94	1.71	6.31	4.59	0.0682	0.941	0.878	72.2	1.89
	Std.	6.63	14.7	6.62	13.3	7.44	0.273	2.58	2.33	27.0	3.87
Lie	Mean	0.249	13.8	3.37	9.45	4.31	0.00	0.450	1.26	67.1	1.71
	Std.	0.859	17.6	5.49	19.3	6.63	0.00	1.23	2.95	30.1	3.09

TABLE V

THE EFFECTS OF QUESTION TYPE AND QUESTIONER (EXPERIMENT 1)

	Effects of question type		Effects of questioner	
	Human	Android	Think	Know
Eye contact duration	$p < .05$	$p < .05$	ns	ns
Averted eye direction	ns	$p < .05$	ns	ns

condition seemed to be different from when they were asked by a person. According to our hypothesis, this difference suggests that the subjects consider the android to be a different kind of agent from a person. Experiment 2 was conducted to obtain evidence to support the above inference.

C. Experiment 2

In experiment 2 we prepared another situation that required subjects to think about the answer. People generally avoid eye contact when they deceive an interlocutor, that is, when they think a lie answer in a conversation. In the experiment a questioner posed questions to subjects. Subjects were told to answer either truthfully or dishonestly in advance. The subjects had to convince the questioner that they were telling the truth when lying (i.e., to deceive the questioner). We measured subjects' eye movements while they were thinking about the answers. We hypothesized that subjects' gaze behavior changes if they do not treat the android as if it were a person.

1) Procedure: We conducted an experiment almost identical to the one described in section III-B.1 except that subjects were instructed how to answer the questions. Before asking a question subjects were shown a cue card on which the word TRUTH or LIE was written by an experimenter seated behind a partition. The questioner could not see the card. If the card was TRUTH (truth answer) subjects were instructed to answer the following question truthfully. If the card was LIE (lie answer) they were instructed to answer the following question with a convincing lie. Subjects answered five questions with truthful answers and five questions with convincing lie answers. The questions required personal information to answer (e.g., "When is your birthday?") so that the questioner could not know the truth.

2) Result: Table III shows the average percentage of time subjects looked in each eye direction for the human condition, and illustrated by the polar plot in Fig. 8. "Upside" in the tables means a sum of "Up", "Up right", and "Up left". Table IV and Fig. 9 show the results for the android condition in the same manner.

a) Answer types: A two-sample t-test for eye contact duration revealed no significant effects of answer type in the human and android conditions. Furthermore a 2-way, repeated measures answer type (2) $\times$ eye direction (8) ANOVA revealed no significant effect in both conditions. The results

TABLE VI

THE EFFECTS OF ANSWER TYPE AND QUESTIONER (EXPERIMENT 2)

	Effects of answer type		Effects of questioner	
	Human	Android	Truth	Lie
Eye contact duration	ns	ns	$p < .01$	$p < .05$
Averted eye direction	ns	ns	$p < .01$	$p < .05$

are different from experiment 1. This may be because subjects tried to show similar reactions in both answer types. The subjects have succeeded in masking their gaze behavior to deceive the questioner.

b) Questioner conditions: A two-sample t-test for the eye contact duration revealed significant effects of questioner in both answer types ($t(25) = 2.57, p < 0.01$ for truthful answers, $t(25) = 2.34, p < 0.05$ for lies). This means that the duration of averting their gaze in the human condition is longer than that in the android condition. A 2-way, repeated measures answer type (2) $\times$ eye direction (8) ANOVA revealed the significant effect of the questioner in both answer types ($F(1, 200) = 6.88, p < 0.01$ for truthful answers, $F(1, 200) = 4.73, p < 0.05$ for lies). The subjects especially looked upward (“Upside” direction) longer for the human questioner than the android questioner ($t(25) = 3.13, p < 0.005$ for truthful answers, $t(25) = 3.58, p < 0.001$ for lies). Table VI summarizes the effects of answer type and questioner in the experiment 2.

The subjects tend to avert eyes downward when they are posed a question just as with experiment 1. There is no difference in gaze behavior in the two answer types. However, there is difference for the two questioners.

As can be seen in Fig. 8 and Fig. 9, the subjects frequently looked around with the human questioner as compared to the android questioner contrary to the results in experiment 1. Daibo and Takimoto [16] have reported that subjects' body motions (e.g., talking and gaze motion) increase when they are required to persuade a person of an opinion which is different from their own opinion. They considered that subjects have strain or uneasiness owing to their deception and their unintentional behavior becomes more apparent. Our results also suggest that subjects had strain against the human questioner but not against the android questioner. The subjects might think that the android questioner could not detect their deception. This supports that the subjects are not treating the android as if it were a person.

D. Summary

The difference in the gaze behavior with respect to the different questioners suggests that breaking eye contact while thinking not only is induced by brain activity but has a social meaning. Comparing the gaze behaviors elicited by the android and a person is necessary before this evidence is obtained. Furthermore, it was found that the breaking of eye contact can be an evaluation of an android's human likeness. If eye movement is same as in interpersonal communication, it is suggested that subjects are treating the android as if it were a person, or at least a social agent. In order to make the results more persuasive, it is necessary to compare with results for different questioners, such as more machinelike robot.

IV. CONCLUSION

This paper proposed a hypothesis about how appearance and behavior are related and mapped out a plan for android research to investigate the hypothesis. The study of breaking eye contact during thinking was considered from the standpoint of the appearance–behavior problem. In the study, we used the android to investigate the sociality of gaze behavior while thinking and obtained evidence that differs from psychological experiments in human studies. Furthermore, it was found that the breaking of eye contact can be an evaluation of an android's human likeness. This study is only preliminary and a more comprehensive study is needed to explain the results in order to contribute to human psychology.

REFERENCES

[1] M. Asada, K. F. MacDorman, H. Ishiguro, and Y. Kuniyoshi, “Cognitive developmental robotics as a new paradigm for the design of humanoid robots,” *Robotics and Autonomous Systems*, vol. 37, pp. 185–193, 2001.

[2] H. Ishiguro, T. Ono, M. Imai, T. Kanda, and R. Nakatsu, “Robovie: An interactive humanoid robot,” *International Journal of Industrial Robot*, vol. 28, no. 6, pp. 498–503, 2001.

[3] T. Kanda, H. Ishiguro, T. Ono, M. Imai, and K. Mase, “Development and evaluation of an interactive robot “Robovie”,” in *Proceedings of the IEEE International Conference on Robotics and Automation*, 2002, pp. 1848–1855.

[4] S. Harnad, “Minds, machines and Searle,” *Journal of Experimental and Theoretical Artificial Intelligence*, vol. 1, pp. 5–25, 1989.

[5] R. M. French, “Subcognition and the limits of the Turing Test,” *Mind*, vol. 99, pp. 53–65, 1990.

[6] ——, “The Turing Test: The first fifty years,” *Trends in Cognitive Sciences*, vol. 4, pp. 115–121, 2000.

[7] M. Mori, “Bukimi no tani [the uncanny valley] (in Japanese),” *Energy*, vol. 7, no. 4, pp. 33–35, 1970.

[8] T. Fong, I. Nourbakhsh, and K. Dautenhahn, “A survey of socially interactive robots,” *Robotics and Autonomous Systems*, vol. 42, pp. 143–166, 2003.

[9] T. Minato, M. Shimada, H. Ishiguro, and S. Itakura, “Development of an android robot for studying human-robot interaction,” in *Proceedings of the 17th International Conference on Industrial & Engineering Applications of Artificial Intelligence & Expert Systems*, 2004, pp. 424–434.

[10] J. Goetz, S. Kiesler, and A. Powers, “Matching robot appearance and behavior to tasks to improve human-robot cooperation,” in *Proceedings of the IEEE Workshop on Robot and Human Interactive Communication*, 2003.

[11] S. Nakaoka, A. Nakazawa, K. Yokoi, H. Hirukawa, and K. Ikeuchi, “Generating whole body motions for a biped humanoid robot from captured human dances,” in *Proceedings of the 2003 IEEE International Conference on Robotics and Automation*, 2003.

[12] A. Gale, E. Kingsley, S. Brookes, and D. Smith, “Cortical arousal and social intimacy in the human female under different conditions of eye contact,” *Behavioral Processes*, vol. 3, pp. 271–275, 1978.

[13] F. H. Previc and S. J. Murphy, “Vertical eye movements during mental tasks: A reexamination and hypothesis,” *Perceptual & Motor Skills*, vol. 84, no. 3, pp. 835–847, 1997.

[14] A. McCarthy, K. Lee, and D. Muir, “Eye gaze displays that index knowing, thinking and guessing,” in *the Annual Conference of the American Psychological Society*, 2001.

[15] A. McCarthy and D. Muir, “Eye movements as social signals during thinking: Age differences,” in *Biennial Meeting of the Society for Research in Child Development*, 2003.

[16] I. Daibo and T. Takimoto, “Deceptive characteristics in interpersonal communication (in Japanese),” *Journal of Japanese Experimental Social Psychology*, vol. 32, pp. 1–14, 1992.