Evaluating Humanlikeness by Comparing Responses Elicited by an Android and a Person

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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 presence, charm, or intelligence. However, this impression is influenced by behavior and the complex relationship between appearance and behavior. As Mori [1] observed, a humanlike appearance does not necessarily give a positive impression. 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.

1 Introduction

Our everyday impressions of intelligence are a subjective phenomena arising from our interactions with other people. The development of systems that can 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 developing and integrating behavioral models, implementing them in humanoid robots, analyzing their faults, and then improving and reimplementing them, repeatedly [2, 3].

By following this constructivist approach in a bottom-up fashion, we [4] have developed a humanoid robot "Robovie" [5] that has hundreds of situation-dependent behavior modules and episode rules to govern their combination. This has allowed us to study how Robovie's behavior influences human-robot

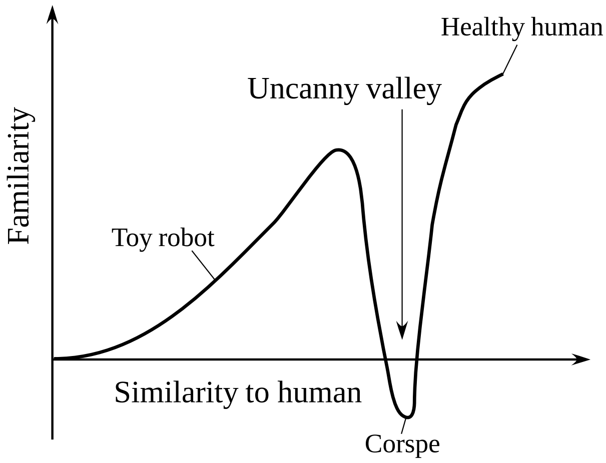


Figure 1: Uncanny valley.

communication. 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 [6, 7]. 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 communication through the development of androids.

Our android research has two aspects:

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

The two aspects interact with each other closely. That is to say, *to make androids humanlike, we must investigate human activity (e.g., behavior, cognition), and to investigate human activity, we need to implement processes to support it in androids.*

Research on the development of communication robots has benefited from insights drawn from the social and life sciences [8, 9, 10, 11, 12, 13]. 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 test bed 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 to mechanical looking robots 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. This paper proposes a direction for android research based on our hypothesis on the relationship between appearance

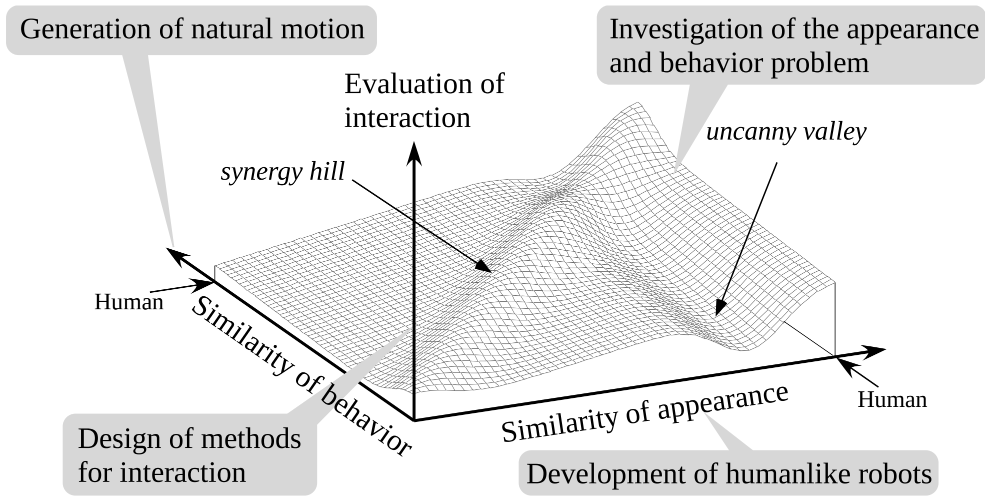


Figure 2: The extended uncanny valley and a map for investigating it.

and behavior. It also reports a study that evaluates the humanlikeness of an android based on human gaze fixations.

2 A Research Map based on the Appearance and Behavior Hypothesis

2.1 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 [14]). 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 [15, 16], an alternative goal would 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 [1]. 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. A robot in the uncanny valley may seem like a moving corpse or zombie. 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 broken down 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 [17]. Figure 2 superimposes graphs derived from Mori's "uncanny valley" hypothesis [1] and the hypothesis that there is a synergistic effect on interaction when appearance and behavior are well-matched [18]. Simply put, we hypothesize that an android's uncanniness can be mitigated by its behavior, if the behavior closely resembles that of a person.

Figure 3: The android *Repliee R1.*

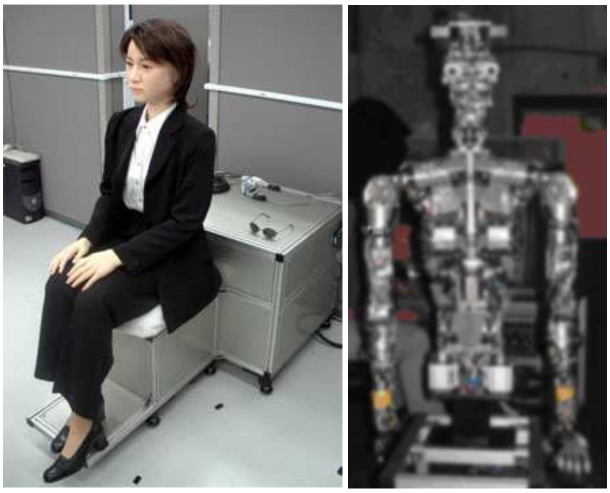


Figure 4: The android *Repliee Q1.*

2.2 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? Mori may have been mistaken in labeling his original dependent axis *familiarity* since the corpse of a loved one can be at once familiar and unsettling; therefore, we relabel it *evaluation of interaction.* There are three main research issues to define the axes.

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.

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 to design a sequence of control commands. This, however, is difficult because the android has many degrees of freedom. Another method is to implement in the android 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 and calculate the joint angles using the robot's kinematics [19]. 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 motion we see at the surface of the robot resembles those of a human being.

Human motion may be decomposed into dominant motions and fine motions that are contingent on dominant motions. While a dominant motion may often be consciously initiated, it will result in fine motions that are largely nonconscious. For example, when raising a hand, a person's shoulder and waist may also move to keep balance. Breathing may become more rapid during physical exertion. These motions are considered important if an android is to closely resemble a person. We are studying methods to decompose human motion into dominant, contingent, and autonomic motions and, furthermore, methods to map human motions to the android by means of an appropriate decomposition.

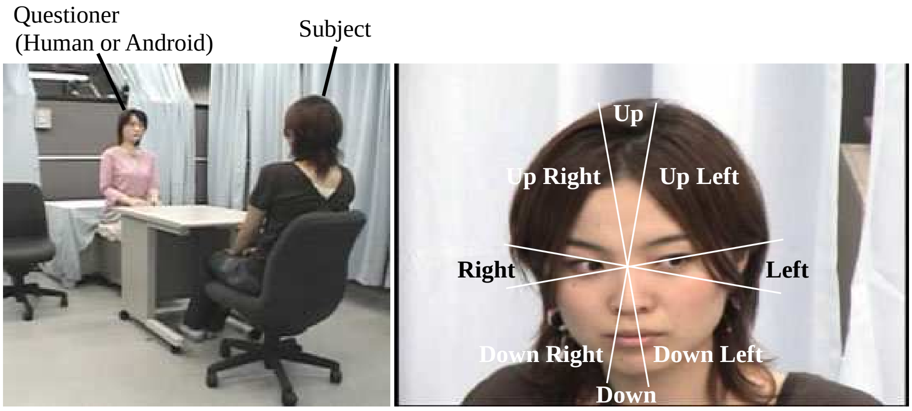
The development of humanlike robots. We have developed two androids that we are currently using for experimentation. *Repliee R1*, shown in Fig. 3, is based on an actual five-year-old girl who wanted to preserve her likeness in android form. We took a cast of her body to mold the android's skin, which is composed of a kind of silicone that has a humanlike feel. The silicone skin covers the android's whole body. The android has nine degrees of freedom in the head (five for the eyes, one for the mouth, and three for the neck) and many free joints to make a posture. The actuators (electrical DC motors) are all embedded within the body. The main problems are as follows:

- Repliee R1's range of motion is limited by the low elasticity of the silicone skin.
- The eye and eyelid mechanisms are not perfectly realized, which is an issue because people are generally sensitive to imperfections in the eyes.

These problems must be overcome to achieve a humanlike appearance.

To realize more humanlike motion, we developed *Repliee Q1*, shown in Fig. 4. Repliee Q1 currently has 31 degrees of freedom in the upper body, which we are extending to 41. The android can generate various kinds of micro-motions such as the shoulder movements typically caused by human breathing. Silicone skin covers only the head, neck, hands, and forearms with clothing covering other body parts so that a wide range of motion can be realized. Air actuators are used in place of DC motors. The compliance of the air actuators makes for a safer interaction with movements that are generally smoother. Highly sensitive tactile sensors mounted just under the android's skin enable contact interaction. As mentioned above we are investigating how to implement natural behavior in Repliee Q1. Furthermore, we are upgrading Repliee Q1 so that the android can make facial expressions and finger motion.

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



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

Figure 5: Experiment scene and eight averted gaze directions.

3 A study of the appearance and behavior problem

3.1 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. 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. This paper examines subjects' gaze behavior and, in particular, the breaking eye contact. 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 [20].

- The differential cortical activation hypothesis

  This hypothesis suggests that brain activation induced by thinking tasks lead individuals to shift their gaze away from the central visual field [21].

- 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 [22, 23]. We report an experiment that compares subjects' breaking of eye contact with a human and android interlocutor.

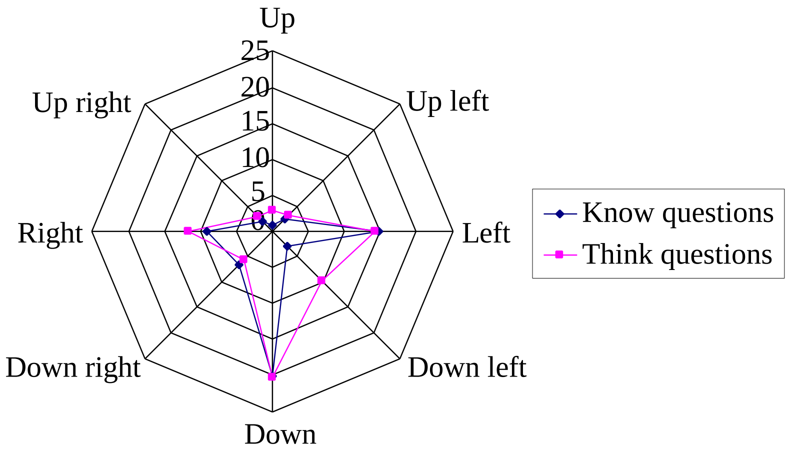


Figure 6: Average duration in percentage of gaze in eight averted directions for a human questioner.

3.2 Experiment

3.2.1 Existing result in human-human conversation

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*. 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."). It has been reported of Canadian subjects that eyes are averted for longer when answering think questions with a preference for the upper-right direction. However, there was not a directional bias for know questions. The preference for the upper-right direction is considered to be the effect of a social signal. Although differential cortical activation is considered to cause downward averting, people look up and to the right during interaction with others to avoid looking downward, which is considered to be negative behavior in Canada [22, 23].

Japanese, however, tend to avert eyes downward for both know and think questions. Figure 6 lists the duration of gaze in the eight directions shown in Fig. 5 (b). The questioner and subjects were all Japanese. 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. From the figure, the duration of averting eyes is longer for think questions. There is, however, almost no directional bias. The social signal theory is not supported by the comparison between the know and think questions, unless the signal was not present in Japanese culture.

3.2.2 An experiment with human-android conversation

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.

We conducted an experiment almost identical to the one described in the previous section except that we substituted Repliee Q1 for the human questioner. A speaker embedded in the android's chest produced a prerecorded voice. Micro-behaviors such as eye and shoulder movements were implemented

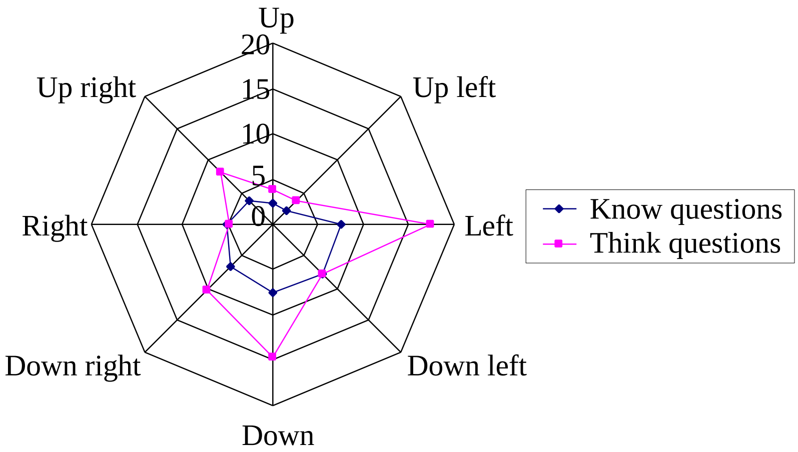


Figure 7: Average duration in percentage of gaze in eight averted directions for the autonomous android questioner *Repliee Q1*.

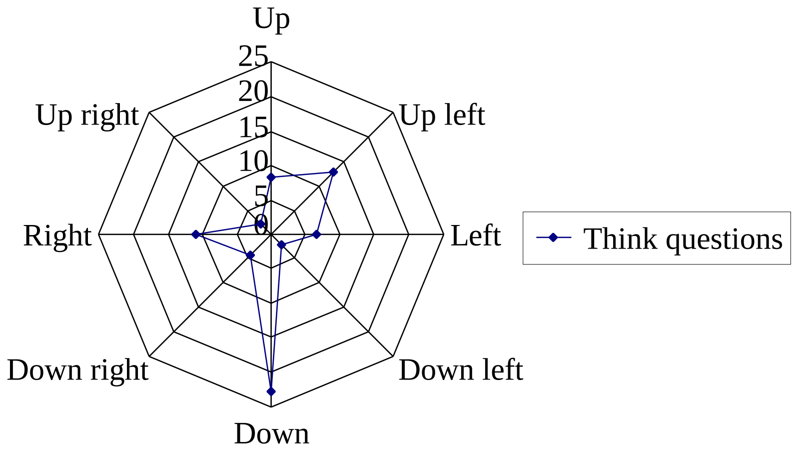


Figure 8: Average duration in percentage of gaze in 8 averted directions for a human questioner.

in the android to make it seem more 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 a humanlike 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.

Eight subjects participated, and the results are shown in Fig. 7. We also performed an experiment with a human questioner for comparison, enlisting five subjects. The results are shown in Fig. 8 (only think questions). In Fig. 7 the duration of averting eyes for think questions is still larger, but the downward directional preference decreases compared to Fig. 8.

If we assume that, if the downward directional preference in human-human interaction is a social signal, the weaker preference in human-android interactions may suggest that the subjects were not treating the android as an interactive agent. To check this reasoning, we conducted another experiment in which the subjects were taught that the android is not autonomous and that an experimenter triggers the android

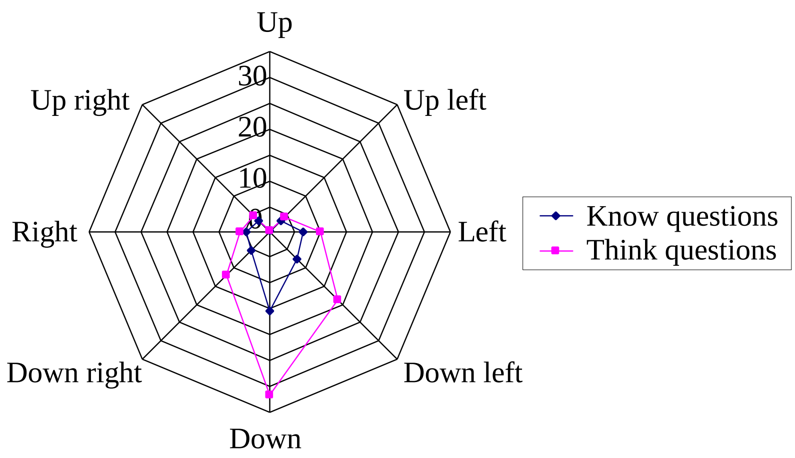


Figure 9: Average duration in percentage of averting gaze in eight directions for an android questioner that subjects know to be operated by a human.

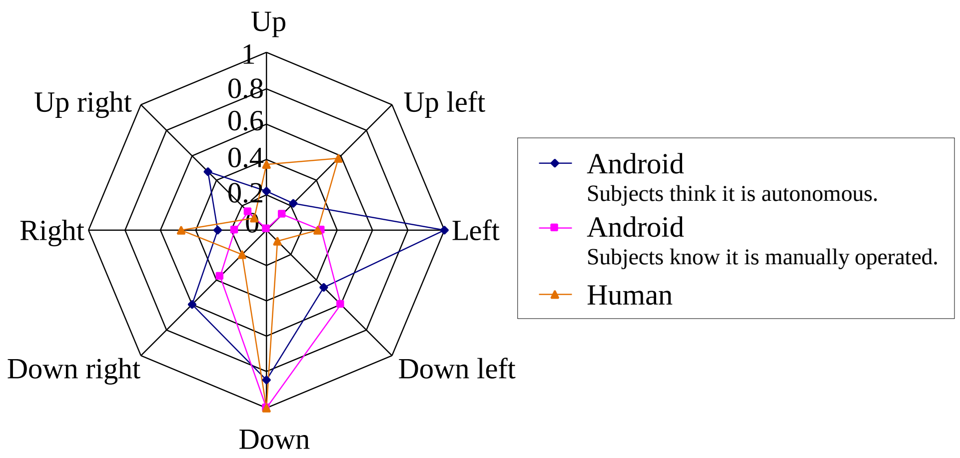


Figure 10: Comparison between baises of gaze direction.

to ask questions. We predict that the downward directional preference decreases because subjects no longer consider the android to be interactive.

Figure 9 shows the result, enlisting seven subjects. Contrary to our expectation, the downward perference increases. This may be because the subjects were sending a social signal to the experimenter. Figure 10 superposes the results of the think questions in the three experiments. The duration is normalized by the maximum percent of each question to compare the degree of preference. From the figure we can see the downward preference tends to decrease from a human questioner to a human-operated android to an android believed to be autonomous. The difference in the gaze bias with respect to the different questioners suggests that that breaking eye contact depends on the interlocutor. It also suggests that the sociality of the android is lower than the human questioner for the subjects. Conversely, breaking eye contact can be an evaluation of the android's appearance and behavior. We must investigate which aspects of appearance and behavior influence human gaze behavior.

Under the condition that the subject believes the android to be human operated, it is considered that the subjects interacted with the experimenter through the android and the relation between the experimenter and subject is different from that between the human questioner and subject. The difference may indicate that breaking eye contact has meaning as a social signal.

4 Conclusion

This paper proposed a hypothesis about how appearance and behavior are related and maps 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 and behavior problem. In the study, we used the android to investigate the social signal theory and obtained evidence that differs from previous psychological experiments in human studies. Furthermore, it was found that the breaking of eye contact can be an evaluation of an android's humanlikeness.

This study is only preliminary, and the statistical significance of the results is insufficient. A more comprehensive study is needed to explain the results in order to contribute to human psychology.

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