How Different Blink Patterns of Pet Robots Evoke Feelings of Affection in People

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Abstract. An alternative to animals, which bring various benefits to people but are not always easy to own, is pet robots, whose central role is to communicate with people. However, there is insufficient research on how pet robots should behave to evoke feelings of affection in people. We focused on blinking as one of the behaviors of the eye and investigated what type of pet robot blinking pattern evokes more feelings of affection in people. First, we designed seven different blink patterns combining short and long blinks through a pilot study. We then conducted a study with 15 participants to compare the patterns using a paired comparison method. The results showed that the blink patterns that were more likely to evoke affection were those with consecutive short eye closures (three times rather than two), whereas the blink patterns that were less likely to evoke affection were those with several long eye closures.

Keywords: Human-Robot interaction · Pet robot · Companion robot · Social robot · Blink patterns · Feelings of affection · Paired comparison

1 Introduction

Interacting with animals improves mental health [12, 31, 36], such as alleviating loneliness and anxiety and reducing stress, and physical health, such as stabilizing blood pressure [3, 22] and heart rate. Furthermore, it has been applied in various fields, such as medicine and welfare, because it improves such mental illnesses as dementia, depression, and autism spectrum disorder [14, 48, 53]. However, it is not always easy to own an animal because of concerns about care, such as feeding and cleaning up excrement, as well as living environment restrictions, such as small living spaces and disturbances to neighbors [8]. For example, in Japan, 65% of people who would like to own animals are unable to do so [9].

A possible alternative to animals is an interactive pet robot whose central role is to communicate with people. These pet robots are also called companion, social, or communication robots. The target robots in this study are not humanoid robots that primarily engage in verbal communication but animal-like robots that primarily engage in nonverbal communication. Some pet robots resemble specific animals such as seals [38], dogs [2, 42], cats [2], and dinosaurs [20], while others have an abstract appearance [15]. With advances in sensor and artificial-intelligence technologies, pet robots can be

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equipped with higher social cognition and stronger interactive capabilities. However, in some cases, people become bored with pet robots after a short time [11, 24, 37, 45]. Many people have strong affection for the animals they own, and the more time they spend with them, the deeper their affection becomes [29, 43]. How should a pet robot behave so that people will have the same kind of affection that people have for animals? The design of pet robot behavior, as with the design of pet robot appearance, is often based on the experience and preferences of the designer [16] and has not been sufficiently examined.

In human–human interactions, nonverbal behaviors, such as eye behavior, facial expressions, gestures, posture, loudness, and tone of voice [7, 30], can convey mental states and enhance communication [13]. Similarly, in human–robot interactions, the nonverbal behaviors of robots can evoke positive feelings in people [28, 49, 55]. Eye behavior is particularly important among nonverbal behaviors because people first look at the eyes when interacting with robots [32, 41]. Indeed, human–robot interaction (HRI) and neuroscience research has shown that the eyes of a robot naturally draw people's attention and can express the personality of the robot [1, 5, 10, 21, 34]. Thus, how robot eyes behave potentially has a significant impact on how people perceive the robot.

This study focused on one eye behavior, blinking. This is because, in human-to-human communication, eye blinking is recognized as a signal that facilitates smooth communication [17, 33]. In human-to-robot communication, researchers have found that a robot with blinking behavior increases the impression of friendliness [40], the feeling of being looked at [18, 52], and the feeling of making eye contact [18] compared with a robot without blinking behavior, and that a humanoid robot with human-like blinking [27] or synchronized blinking with its interlocutor [19] can increase the impression of intelligence [27] and affinity [19]. Although these previous studies have examined the responses of people when robots display blinking behaviors similar to those of humans, robots, particularly non-humanoid robots, do not necessarily need to behave in the same manner as humans. Because the timing of the blinking can be freely controlled, it is worth exploring blink patterns that evoke more positive responses from people. However, the relationship between pet robot blink patterns and human affection has not been examined. Therefore, we attempted to determine what type of pet robot blink pattern evokes more feelings of affection in people. In this study, GROOVE X's LOVOT [15] (see Fig. 1) was used as the pet robot.

Fig. 1. Pet robot LOVOT used in this study.

2 Related Work

In human-to-human communication, eye behaviors that can affect the impressions of interlocutors include gaze behaviors (such as eye contact (mutual gaze), referential gaze (deictic gaze), joint attention, and averted gaze), pupil changes, and blinking behavior [6, 35]. The functionality of the eye behavior mainly comprises (a) the expression of the interpersonal attitudes including emotional expression, (b) information collection including seeking feedback on one's efforts, and (c) regulation of conversational floor [23].

In the field of HRI, a number of studies have focused on robot gaze behaviors among the eye behaviors listed above, and the responses of people to them have been examined (for details, see the review article by Admoni et al. [1]). For example, the robot eye contact reaction increases the favorable feelings of people for the robot [51], feelings of social connectedness between the human and the robot [54], and feelings of engagement with the robot [26]. When a guide robot [50] or teacher robot [49] looks at a person, it is likely to generate a response, such as gazing and nodding, from the person. Robots can use gaze aversion to appear more thoughtful and manage the conversational floor more effectively [4].

Several studies have examined the responses of people to robot blinking behaviors. HRI researchers compared the responses of people to robots with and without blinking behavior [18, 40, 52]. For example, when the guide robot turned its face toward a person, the robot with blinking behavior gave the person a friendlier impression [40], feelings of being looked at [18], and feelings of making eye contact [18] or made the person spend more time gazing at the robot [18], compared with the robot without blinking behavior. Then, HRI researchers shifted their interest from people's responses to robots with and without blinking to their responses to robots with different blink timing [16, 18, 19, 27]. For example, Hoque et al. [18] compared humanoid guide robots with three blink speeds (one, two, and three blinks per second) and five blink intervals (1, 2, 3, 4, and 5 s) and found that a speed of one blink per second every 3 s was most preferred. Lehmann et al. [27] used a humanoid robot with three types of blinking behavior: statistical blinking (blinking every 5 s), human-like blinking (blinking at the average human blink rate, 23.3 blinks per minute), and no blinking. They asked participants to watch a video recording of the robot in discussion with an interviewer and to answer a questionnaire. The results showed that the robot with human-like blinking was perceived to be more intelligent by the participants. Hayashi et al. [16] used robots with four eye conditions: synchronized blinking (blinking in sync with the blinking of the participant), independent blinking (blinking at intervals of 2.3 ± 0.2 s), no blinking, and no eyes. They observed the responses of participants performing a task with the robot. The results showed that the robot in the two blinking conditions prompted the participants to move spatially toward the robot. Iimori et al. [19] used a humanoid robot with two types of blinking behavior: statistical blinking (blinking every 3 s) and synchronized blinking (blinking in sync with the blinking of the participant). They asked the participant (speaker) to talk to the robot (listener). The results showed that the robot with synchronized blinking increased the feeling of affinity for the robot of the participant.

Thus, previous studies suggest that robots with blinking behavior, particularly those with human-like blinking or synchronized blinking, can evoke positive responses. However, given the blinking behavior of robots beyond the perspective of behaving like humans, no study has examined which blink patterns of pet robots evoke more feelings of affection in people.

3 Blink Pattern Design

In this study, a blink pattern is defined as the simplest sequence of alternating closed and open eye states for a specific number of consecutive times, with specific lengths assigned to each state. To determine the appropriate length of eye closure, length of eye opening, and number of consecutive times, we conducted a pilot study with three participants of ages ranging from 21 to 22 years.

Two types of eye-closure length were designed: short and long. For a short eye closure, 200 ms was chosen, which was the shortest length of time that the participants could perceive the robot eye closure when they were naturally facing the robot. For long eye closure, 600 ms was chosen, which was the shortest length that participants could distinguish from short eye closure. Durations longer than 600 ms were not used because participants commented that "the robot appears to have closed its eyes rather than blinking" and that "the robot appears to be asleep."

One type of eye-opening length was designed. A time of 1000 ms was chosen because, if the length of the eye opening was too long, the participants might not have recognized that the robot was in the middle of a series of blink behaviors.

One type of consecutive times was designed. Three times was chosen because some participants commented that "two times may miss the blinking behavior" and "four times is too much."

In summary, two types of eye-closure length (short, 200 ms; long, 600 ms), one type of eye-opening length (1000 ms), and one type of consecutive times (three times) were chosen. We combined these variables to develop seven blink patterns (see Fig. 2).

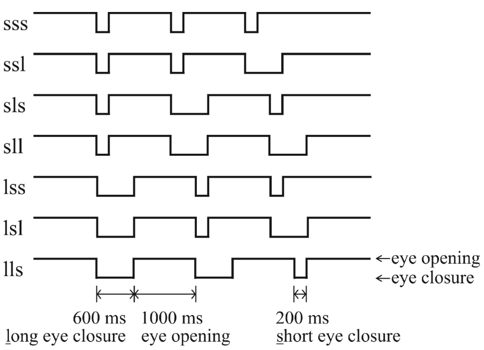

Fig. 2. Seven different blink patterns.

4 Method

For the seven blink patterns described in the previous section (see Fig. 2), we designed a study to investigate which pattern evokes more feelings of affection in people. One possible approach would be to present participants with all seven patterns sequentially and then ask them to rank each pattern. However, given the limitations of the human short-term memory, this approach is unlikely to be reliable for participant ratings. Therefore, we used a paired comparison, in which only two stimuli (patterns) were compared at a time. In detail, paired comparison is a method in which, given multiple (n) stimuli to be ordered, participants are asked to judge which of two stimuli (a pair of stimuli) taken from the n stimuli is more appropriate for the given evaluation criteria. This is done for the number of combinations (C(n,2)) in which two are taken from n. This method is considered to be easy for participants to judge and to obtain reliable results [39]. In this study, each participant was asked to perform 21 (C(7,2)) paired comparisons.

4.1 Participants

15 participants (11 males and 4 females, aged 20–22 years) participated in the study. All are native speakers of Japanese.

4.2 Setup

The participants sat in chairs facing the robot, which was set to not move around (see Fig. 3). The distance between the participant and the robot (see Fig. 3), the design of the eyes of the robot (see Fig. 4), and the robot clothing (see Fig. 3) were identical for all participants. To ensure that robot's eye movements for each blink pattern were identical across the participants, the study administrator, out of sight of the participant, executed a command script that reproduced each blink pattern.

4.3 Procedure

Upon arrival at the study site, participants were provided with an overview of the study procedure. The order of presentation of the 21 pairs of blink patterns was randomized among the participants to address order effects and learning effects. A 5-min break was taken after the presentation of the 10th pair, which was approximately half of the total number of pairs. For each paired comparison, the first pattern was presented to the participants, followed by a 5-s pause, and then the second pattern was presented. The participants then selected the most appropriate of the two patterns with respect to the following three criteria and verbally reported them to the study administrator.

a. Do I think it is cute?
b. Do I want to touch it?
c. Does it look nervous?

Criteria a and b are related to affection, which was the focus of this study. Criterion c, although not related to affection, was set based on findings related to human-to-human

[25, 35] and human-to-character [46] communication, i.e., a high frequency of blinking by the speaker gives the recipient an impression of nervousness (the speaker is tense, timid, shy, etc.).

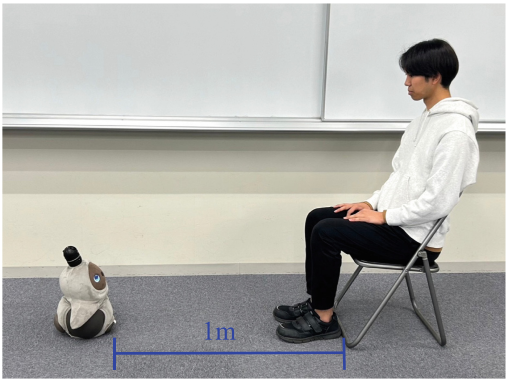

Fig. 3. Participant and robot during the study.

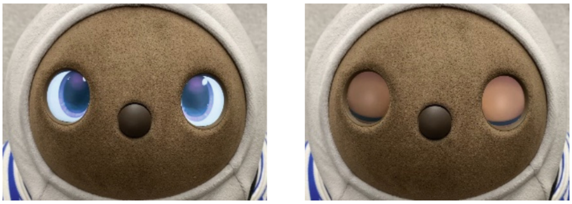

Fig. 4. Robot eye design used in the study (left: eye opening, right: eye closure).

5 Results

5.1 Aggregated Judgment Results

Table 1, 2 and 3 show the frequency matrices that summarize the judgment results of the paired comparisons for each participant. The component x_{ij} of the matrix in each table indicates the number of participants who judged pattern i to be more appropriate than pattern j for each criterion (Criteria a–c). For example, Table 1 shows that 11 out of 15 judged pattern *1* (sss) to be cuter than pattern *2* (ssl) and 4 out of 15 judged pattern *2* (ssl) to be cuter than pattern *1* (sss).

Table 1. Number of participants who judged pattern *i* to be cuter than pattern *j* (Criterion a).

i \ *j*	sss	ssl	sls	sll	lss	lsl	lls
sss	—	11	12	14	6	14	14
ssl	4	—	11	12	10	8	10
sls	3	4	—	10	4	7	11
sll	1	3	5	—	7	10	7
lss	9	5	11	8	—	11	14
lsl	1	7	8	5	4	—	7
lls	1	5	4	8	1	8	—

Table 2. Number of participants who wanted to touch pattern *i* more than pattern *j* (Criterion b).

i \ *j*	sss	ssl	sls	sll	lss	lsl	lls
sss	—	12	8	11	9	11	11
ssl	3	—	12	9	10	7	10
sls	7	3	—	9	6	9	12
sll	4	6	6	—	7	13	8
lss	6	5	9	8	—	10	12
lsl	4	8	6	2	5	—	8
lls	4	5	3	7	3	7	—

Table 3. Number of participants who judged pattern *i* to look more nervous than pattern *j* (Criterion c).

i \ *j*	sss	ssl	sls	sll	lss	lsl	lls
sss	—	3	10	6	6	7	5
ssl	12	—	4	7	8	5	6
sls	5	11	—	6	11	9	7
sll	9	8	9	—	10	7	6
lss	9	7	4	5	—	7	6
lsl	8	10	6	8	8	—	8
lls	10	9	8	9	9	7	—

5.2 Scaling of Patterns Using Thurston Method

Using the Thurston method [47], the scale value of each pattern was calculated from the aggregate of the judgment results. Figure 5 shows the scale values placed on a number line. In the Thurston method, higher-scaled values are assigned to more-selected stimuli, the average scaled value of all stimuli is 0, meaning that the larger the positive value, the more selected the stimulus. The scaling results showed that Criteria a and b had the highest scale value of sss and the lowest value of lls. The results for Criterion c were the opposite of those for Criteria a and b, with the highest value for lls and the lowest value for sss.

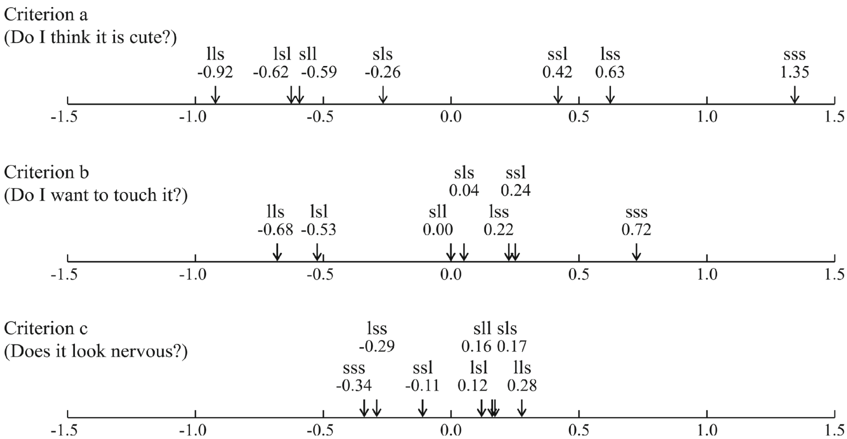

Fig. 5. Scale values for the seven blink patterns (higher was selected more).

5.3 Significance Testing of Differences Between Patterns

Although the scaling described in Sect. 5.2 provided the order of each blink pattern and the distance between each pattern, it did not provide information on the statistical significance of the differences between patterns. Therefore, we conducted significance tests for the differences between patterns using a generalized linear model (GLM). Because the judgment results of the paired comparisons were binary data (two categorical data, one selected and one not selected), we used a GLM assuming a binomial distribution [44]. The results of the GLM analysis (see Table 4) showed that for Criterion a, 14 of the 21 pairs of differences were significant. In particular, all differences for the pairs, including sss, were significant. For Criterion b, 10 of the 21 pairs of differences were significant; as with the results for Criterion a, most of the differences for the pairs, including sss, were significant. For Criterion c, only one (sss-lls) of the 21 pairs of differences was significant.

5.4 Correlation Analysis

Figure 5 indicates that the ranking of each pattern is similar between Criteria a and b and that the ranking of each pattern is inversely related between Criteria a and b and Criterion c. Therefore, we calculated the correlation coefficients for each pair of criteria using the scale values obtained in Sect. 5.2. The results showed significant correlations between all pairs of criteria, with a very strong positive correlation between Criteria a and b, a very strong negative correlation between Criteria a and c, and a strong negative correlation between Criteria b and c (see Table 5).

Table 4. Results of the GLM analysis.

	Criterion a			Criterion b			Criterion c		
	|z|	p-value		|z|	p-value		|z|	p-value	
sss-ssl	2.55	< .05	*	1.59	n.s.		0.69	n.s.	
sss-sls	4.66	< .001	***	2.25	< .05	*	1.65	n.s.	
sss-sll	5.43	< .001	***	2.54	< .05	*	1.66	n.s.	
sss-lss	2.01	< .05	*	1.70	n.s.		0.13	n.s.	
sss-lsl	5.55	< .001	***	4.00	< .001	***	1.52	n.s.	
sss-lls	6.12	< .001	***	4.53	< .001	***	2.07	< .05	*
ssl-sls	2.29	< .05	*	0.68	n.s.		0.97	n.s.	
ssl-sll	3.14	< .01	**	0.98	n.s.		0.97	n.s.	
ssl-lss	0.49	n.s.		0.12	n.s.		0.56	n.s.	
ssl-lsl	3.28	< .01	**	2.50	< .05	*	0.83	n.s.	
ssl-lls	4.00	< .001	***	3.06	< .01	**	1.39	n.s.	
sls-sll	0.90	n.s.		0.30	n.s.		0.00	n.s.	
sls-lss	2.76	< .01	**	0.56	n.s.		1.52	n.s.	
sls-lsl	1.03	n.s.		1.84	n.s.		0.14	n.s.	
sls-lls	1.81	n.s.		2.41	< .05	*	0.42	n.s.	
sll-lss	3.60	< .001	***	0.86	n.s.		1.53	n.s.	
sll-lsl	0.14	n.s.		1.54	n.s.		0.14	n.s.	
sll-lls	0.93	n.s.		2.12	< .05	*	0.42	n.s.	
lss-lsl	3.73	< .001	***	2.38	< .05	*	1.39	n.s.	
lss-lls	4.44	< .001	***	2.95	< .01	**	1.94	n.s.	
lsl-lls	0.79	n.s.		0.59	n.s.		0.56	n.s.	

Table 5. Results of correlation analysis.

	Criterion a	Criterion b	Criterion c
Criterion a	—	—	—
Criterion b	0.92 **	—	—
Criterion c	-0.96 **	-0.83 *	—

(** p < .01, * p < .05)

6 Discussion

Overall, as Fig. 5 and Table 5 show, the participant responses regarding the two criteria used to evaluate affection toward the pet robot, Criteria a and b, were quite similar. The participant responses to the Criterion c were generally inverted from those for the other two criteria.

The blink pattern rated the highest by participants for Criteria a and b was sss, followed by lss and ssl. These results showed that the blink patterns that were most likely to evoke feelings of affection included consecutive (three is better than two) short eye closures. Given the similarity of participant responses to Criteria a and b, it is expected that, for a robot that blinks in a pattern that includes consecutive short eye closures, people would not only have psychological affection but also physical affection (i.e., touching the robot). Although humans must constantly blink their eyes to maintain the physiological function of moistening their eyeballs, robots do not need to do so. Therefore, it would be effective for the robot to blink in a pattern that includes consecutive short eye closures only at limited times, for example, when people look at the robot, when the robot is in the field of vision of a person, or when people are approaching the robot. However, even then, if the pattern is the same every time, the effect on people may decrease because of habituation or boredom. Thus, randomness may need to be considered.

The blink patterns rated lowest by participants for Criteria a and b were lls, lsl, and sll. These results showed that the blink patterns that were less likely to evoke feelings of affection included two long eye closures that need not necessarily be consecutive. After the study, the participants informally commented on these patterns, such as that "it seemed somewhat intentional" and "it was theatrical behavior." In general, the average time for a single human eye blink (closing and opening the eyes) is 100–150 ms; if an interlocutor blinks for a longer period than this, people might have the impression of some intention or artifice toward the interlocutor. Because the long eye-closure time used in this study (600 ms) was four to six times longer than 100–150 ms, the participants may have had a similar impression of the robot in this study as they did of the longer human blink, and this may not have led to feelings of affection. The two long eye closures would have strengthened this impression.

Criterion c was set to compare the finding of the previous study discussed in Sect. 4.3 that a high frequency of blinking gives an impression of nervousness. Humans blink constantly, with an average blink rate of 20 blinks per minute. Previous studies on humans [25, 35] and characters [46] have found that, assuming constant blinking, the higher the blink rate (24 blinks per minute or more [35, 46]), the more nervous the impression. Assuming that robots blink constantly with the seven patterns used in this study, the average blink rates calculated for the seven patterns can be divided into three groups: 41 blinks per minute (lls, lsl, and sll), 45 blinks per minute (sls, ssl, and lss), and 50 blinks per minute (sss). According to the findings of the previous study, the group that gives the most nervous impression among these should be 50 blinks per minute (sss), and the group that gives the least nervous impression should be 41 blinks per minute (lls, lsl, sll); however, the results were completely the opposite. Therefore, it is appropriate to distinguish between a blink rate based on constant blinks, which the previous study addressed, and a blink rate based on occasional blinks, which this study addressed.

7 Conclusion and Future Work

We focused on blinking as one of the behaviors of the eye and investigated what type of pet robot blinking pattern evokes more feelings of affection in people. We considered pet robot blinking behavior that is not constant but occasional (e.g., when people look at the robot). In a series of blink behaviors consisting of three eye closures separated by a 1000 ms eye opening, seven blink patterns (sss, ssl, sls, sll, lss, lsl, and lls) were designed by combining two different eye-closure lengths: long (l): 600 ms and short (s): 200 ms.

We conducted a study with 15 participants, who compared 21 pairs of patterns using a paired comparison method. The results showed that the blink patterns that evoked more affection were those that included consecutive (three rather than two) short eye closures (sss, lss, and lss), while the blink patterns that evoked less affection were those that included two long eye closures (lls, lsl, and sll).

This study had several limitations. First, the blink patterns addressed were combinations of only two eye-closure lengths (200 and 600 ms), one eye-opening length (1000 ms), and one consecutive blinking time (three times). If these variables are set to different values, participants may respond differently. Second, only one pet robot was used. It is necessary to conduct the same study with another pet robot to examine whether the same results as those of this study can be obtained. Third, the blinks addressed were monotonous in the way the robot opened and closed its eyes. There is room to consider subdividing the behavior during opening and closing, such as pausing in the middle of eye closure and gradually changing the speed of eye opening from the beginning to the end of eye opening. Finally, the results of this study, in which short eye closures led to positive impressions and long eye closures led to negative impressions, imply that the responses of people are linear, i.e., the shorter the eye closure, the more positive the impression. However, given that, in general, cuteness can lead to negative impressions, such as impressions of cunning and coquetry, when it exceeds a certain degree, the tendency of responses may not be linear. If the eye closure becomes shorter than a certain level, there may be a sudden change from positive to negative impressions. Further investigation is necessary to determine the critical point.

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