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Gradual Rhythm Change of a Drumming Robot Enhances the Pseudosenese of Leading in Human–Robot Interactions

HIDEYUKI TAKAHASHI¹, TOMOYO MORITA^{2,3}, MIDORI BAN¹, HIROKA SABU⁴, NOBUTSUNA ENDO⁵, AND MINORU ASADA^{2,3,6}, (Life Fellow, IEEE)

¹Graduate School of Engineering Science, Osaka University, Osaka 565-0871, Japan

²Institute for Open and Transdisciplinary Research Initiatives, Osaka University, Osaka 565-0871, Japan

³Center for Information and Neural Networks (CiNet), National Institute of Information and Communications Technology (NICT), Osaka 565-0871, Japan

⁴Graduate School of Engineering, Osaka University, Osaka 565-0871, Japan

⁵School of Science and Technology for Future Life, Tokyo Denki University, Tokyo 120-8551, Japan

⁶International Professional University of Technology in Osaka, Kita-ku, Osaka 530-0001, Japan

Corresponding author: Hideyuki Takahashi (takahashi@irl.sys.es.osaka-u.ac.jp)

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This work involved human subjects or animals in its research. Approval of all ethical and experimental procedures and protocols was granted by the Ethics Committee at the Graduate School of Engineering, Osaka University under Application NO. # 28-1-0.

ABSTRACT In order to achieve symbiosis between humans and social robots, it is not enough to simply design a robot with excellent functionality, but it is necessary to give humans a friendly impression of the robot. Rhythmic synchronization is the foundation of social interaction and unity, and it is expected that research on synchronization between humans and robot will contribute to the design theory of robot that can build intimate relationships with humans. Specifically, the sense of leading a rhythm evokes a pleasant emotion. If a communication robot is behaviorally synchronized with humans, a strong sense of unity with the robot could occur in keeping with their sense of leading. However, in rhythmic interactions, having the sense of leading the rhythm often differs from the actual rhythm leading. We conducted three kinds of experiments to examine whether a pseudosenese of leading occurred in human-robot or human-human drumming interactions. At the experiment 1, we used an interaction task of human-robot drumming to examine whether participants experienced a strong sense of leading when interacting with a robot drumming with gradual rhythm fluctuations and whether the sense of leading the rhythm induced a positive impression of the robot. As a result, we found that a pseudosenese of leading the rhythm and the pleasant emotion of drumming occurred even from the artificial robot's rhythm, notably when the rhythm of the robot changed gradually. At the experiment 2, we also showed that the pseudosenese of leading was not likely to occur in the drumming between humans. Finally, at the experiment 3, we found that the pseudosenese of leading would induce anthropomorphic impressions of the robots. These findings may contribute to designing interactive robots' rhythmic behavior to realize symbiosis between humans and robots.

INDEX TERMS Pseudosenese of leading, drumming interaction, anthropomorphic impression.

I. INTRODUCTION

The recent development of robotics and artificial intelligence technologies predicts the arrival of a society in which social robots will support human lives as partners [1]–[3]. In order

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to realize such a society, it is not enough for robots to be highly functional; they must also be friendly to the human mind and give humans a strong sense of unity. In other words, research that considers the psychological characteristics of human is essential in building a design theory for robots that can coexist with humans. Therefore, research on the psychology of humans facing artifacts has been actively conducted

in engineering research fields such as human computer interaction.

The psychological effects of synchronization on the movements between individuals have been attracting attention as an important means of building an intimate relationship between humans and robots [4]. The timings of utterances and gestures are generated based on rhythm in interpersonal interactions (e.g., conversation). The rhythmic aspects of the interaction implicitly affect our communicative attitudes. For example, if the rhythms of utterance timing are synchronized between two individuals during a conversation, they tend to have friendly feelings [5]. Hence, in many traditional rituals, there are occasions in which many individuals share the same rhythm through various embodied activities (e.g., dancing, praying in primitive religious activities, playing instruments, and singing) to create strong unity among them [6]–[10]. Therefore, if a communication robot can synchronize with humans, a strong sense of unity with the robot might occur.

In most rhythmic interactions (e.g., music ensemble), someone initiates a rhythm in interaction as a “leader,” and others follow that rhythm. Previous neuroimaging studies have suggested that the sense of leading (and that of being followed by other individuals) evokes a pleasant emotion and activates the reward-related brain regions [11]–[14]. Interestingly, participants often report a sense of leading, even though they do not actually do it. Thus, the sense of being the leader does not always correspond to the actual situation. However, few studies have quantitatively extracted details regarding the factors that induce it.

In psychological experiments involving nonsocial situations, similar phenomenon has been observed [15], [16]. Many animals, including humans, sometimes learn about pseudo-association between their actions and an external event unrelated to the action in the psychology of learning, whereby the action is reinforced based on the pseudo-association, as if it initiated the external event. Such behavior is called “superstitious behavior,” which tends to occur when the presentation timing of external events is periodic and can be predicted easily [16].

In the previous studies [15], [16], “superstitious behavior” has been mentioned only in nonsocial contexts. However, in this study, we hypothesized that “superstitious behavior” can be also observed in social contexts: learning about the pseudo-association between one’s behavior and other agents’ independent behavior occurs when the latter’s behavior can be easily predicted. Pseudo-association learning between one’s behavior and another agent behavior could induce a sense of leading in social interactions and evoke a positive emotion.

In this study, we conducted three kinds of experiments to examine whether a pseudosen of leading occurred in human-robot or human-human drumming interactions. In the experiment 1, we used a human-robot drumming interaction task, where we manipulated the robot’s drumming rhythm fluctuations independent from the human’s rhythm. We expect that participants experienced a strong sense of leading when



FIGURE 1. Experimental setting in Experiment 1 (human-robot interaction).

interacting with a robot drumming with gradual rhythm fluctuations. In the experiment 2, we also sought to examine factors that induced a sense of leading in human-human drumming interactions and compared the results of human-human and human-robot interactions. Furthermore, in the experiment 3, we examined whether differences in the robot’s drumming rhythm fluctuations affected not only the sense of leading but also the impression of the robot’s mental attributes, such as emotions. Such impressions are called “anthropomorphic” minds (an inanimate object being ascribed human characteristics) and can be measured by mind perception questionnaires [17].

II. EXPERIMENTS

A. EXPERIMENT 1 HUMAN-ROBOT DRUMMING INTERACTION

1) AIMS OF THIS EXPERIMENT

Using a human-robot drumming interaction task, we examined whether participants experienced a strong sense of leading (i.e., being followed by the robot) when interacting with a drumming robot having gradual rhythm fluctuations. Further, we investigated whether the sense of leading the rhythm induced a positive impression of the robot (i.e., pleasantness, favorability, and closeness).

2) PARTICIPANTS

Fourteen healthy adults (10 women and four men, 20.0 ± 0.78 years, recruited from Osaka University) participated in Experiment 1 (human-robot drumming interaction). The protocol used in the study was approved by the Ethics Committee at the Graduate school of engineering, Osaka University. All participants provided written informed consent before the experiment. The experiment was conducted following the principles and guidelines of the Declaration of Helsinki (1975).

3) EXPERIMENTAL SETTINGS

FIGURE 1 shows the experimental setting where each participant sat on the chair facing the drumming robot to engage in drumming interaction.

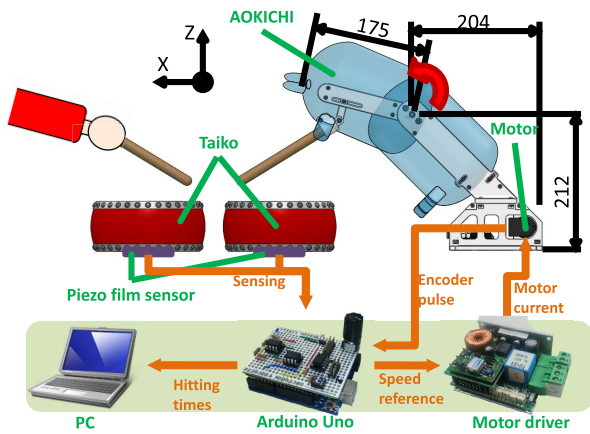


FIGURE 2. System configuration for the drumming robot.

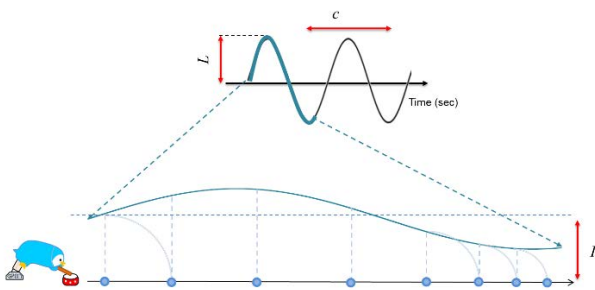


FIGURE 3. Illustration of the hitting timings fluctuating according to sin wave function.

We used the drumming robot system [18] shown in FIGURE 2. It had one degree of freedom and could hit a drum (Japanese taiko, 18 cm in diameter) using an attached drumstick. The timing of the drumming was controlled using an Arduino Uno board and a motor driver (TITECH PC-0120-2). To increase the agency of the robot, we covered the metal skeleton with a stuffed penguin.

A digital video camera (Panasonic HC-W870M) was set up in the room to record the participants’ and robots’ drumming behaviors. The recorded data were converted into Advanced Video Codec High Definition format to analyze the drumming sound.

4) EXPERIMENTAL PROCEDURES

The experiment proceeds as follows:

[1] The robot initiates the interaction by hitting its drum with a wooden stick.

[2] The participant is instructed to hit his/her drum (similar to the robot’s) after the robot first hits the drum and then alternatively hitting the drum for 40 seconds.

[3] The experimenter stops the session, and the participant is asked to answer five questions about her/his impressions concerning the above mentioned interaction. The questions are related to the subjective feelings of being followed by the robot, being a follower, pleasure for the interaction, favor for the robot, and closeness to the robot.

[4] Go to [1] (repeat 12 times).

a: DESIGN OF HITTING TIMINGS

The following equation specifies the hitting timing at time $t + 1$, where I , L , and C indicate the average interval between the robot’s drumming (1,000 ms), the amplitude (200 ms), and the period of the sine wave (5 s, 10 s, and 20 s), respectively (FIGURE 3). Three different C s manipulate how rapidly the tempo at which the robot hit the drum changed. That is, if C is shorter (longer), the robot’s drumming tempo quickly (slowly) changed. As a reference, a constant interval (1,000 ms) condition is added; therefore, we have four conditions. Each participant completed the sessions three times for each of the four conditions. The order of conditions was counterbalanced across the participants. The number of conditions and the differences in their drumming parameters were not open to participants in advance.

$$h_{t+1} - h_t = I + L \sin\left(\frac{2\pi h_t}{C}\right)$$

b: RATING SCHEME

During the rating period, the participants were asked to provide subjective ratings of their impressions regarding the preceding interactions, using a sheet of paper containing five questions in Japanese.

- (1) To what degree was the robot following you? (sense of being followed)
- (2) To what degree were you following the robot? (sense of being a follower)
- (3) To what degree did you favor the robot? (favorability)
- (4) To what degree was the interaction with the robot pleasant? (pleasantness)
- (5) How close did you feel with the robot? (closeness)

The participants answered the first four questions using a visual analog scale (VAS [19]), in which the left endpoint of the scale corresponded to “not at all (0)” and the right endpoint corresponded to “fully (1).” We normalized the value to the range from 0 to 1 for each answer based on this scale.

For the fifth question, we measured the closeness of their relationships with the robot using a pictorial tool, the Inclusion of the Other in the Self (IOS) Scale developed by Aron *et al.* [20]. The participants were asked to select the pair of circles that best described their relationships with the robot out of seven pairs of increasingly overlapping circles. In each pair of circles, one circle represented the participant, and the other represented the robot. For example, if participants felt unrelated to the robot, they were likely to select the first pair of disjointed circles; if participants felt a strong sense of unity with the robot, they were likely to choose the almost completely overlapping set of circles.

5) DATA ANALYSIS

Based on the recorded drumming sound data, we extracted the time clocks of each drumming session for both the robot and the participants. From these time clocks, we calculated two

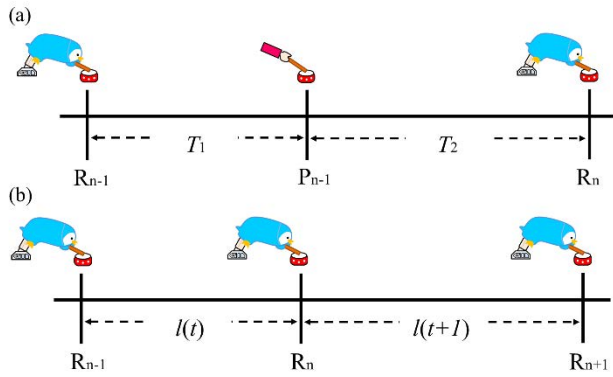


FIGURE 4. Illustration of the hitting point spacing used to calculate followability and variability.

objective indices representing the physical characteristics of the drumming interactions.

One index was “followability” (F), which represented the extent to which the robot followed the participant’s hitting rhythm (previous time interval), calculated using the following formula:

$$F = - \left(\log_2 \frac{T_1}{T_1 + T_2} \right) * \frac{T_1}{T_1 + T_2} - \left(\log_2 \frac{T_2}{T_1 + T_2} \right) * \frac{T_2}{T_1 + T_2}$$

in which T_1 corresponds to the time interval between the robot’s drumming (R_{n-1}) and the subsequent participant’s drumming (P_{n-1}), and T_2 corresponds to the time interval between the participant’s drumming (P_{n-1}) and the robot’s subsequent drumming (R_n) (FIGURE 4(a)). If the robot’s interval time was the same as that of the participant in the previous drumming interaction, F will be 1. On the other hand, if the robot beats the drum irrespective of the participant’s hitting interval, the value of F approaches 0. We calculated F values for the robot’s drumming, and the average F value was computed for each interaction.

The other index was “variability” (v), which represented the extent to which the drumming tempo of each robot varied within each interaction. We calculated the degree of variability in the time intervals between the robot’s drumming using the following formula:

$$v = \text{abs} \left(1 - \frac{I(t+1)}{I(t)} \right)$$

where $I(t)$ indicates the interval between the robot’s drumming (R_{n-1}) and the subsequent drumming (R_n) (FIGURE 4(b)). We computed the average within a time window of 5 s. We took the maximum average value within all eight-time windows as the variability in the robot’s drumming in each session. v becomes large when the robot’s hitting rhythm changes drastically from point to point while it approaches zero when the change is gradual.

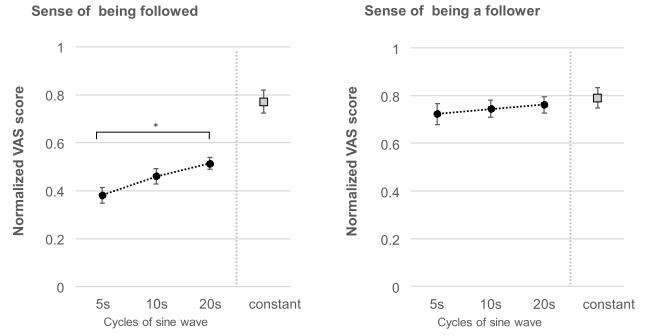


FIGURE 5. Subjective ratings of the drumming interactions for each condition.

6) PATH ANALYSIS

We conducted a path analysis to clarify how the two aspects of the physical characteristics of drumming interactions affected the participant’s impressions of the partner robot. In this analysis, two objective indexes (followability and variability) of drumming interactions were defined as explanatory variables. Further, each of three subjective ratings for the participant’s impressions of the robot (favorability, pleasantness, and closeness) was used as the dependent variable. In the full model, we included one additional mediating variable, “sense of being followed.” SPSS Amos 24 (IBM Corp., Armonk, New York) was used to perform the path analysis.

7) RESULTS AND DISCUSSION

a: BEHAVIORAL RESULTS

To examine how rapidly the robot’s drumming tempo changes (5s, 10s, and 20s) affected the subjective ratings of the drumming interactions among three conditions (FIGURE 5), we performed a one-way ANOVA (condition: 5 s, 10 s, 20 s for each of two ratings, “sense of being followed” and “sense of being a follower”). This analysis revealed a significant main effect in “sense of being followed” [F (2, 26) = 4.90; p = 0.016, η² = 0.274]. The posthoc t-test revealed that the sense of being followed in the 20-s (gradual) condition was significantly stronger relative to that in the 5-s (rapid) condition [p = 0.031 corrected with Bonferroni’s multiple comparisons], but there was no significant difference in the extent of the sense of being a follower between the three conditions [F (2, 26) = 0.64; p = 0.54, η² = 0.047].

b: RESULTS OF THE PATH ANALYSIS

The results of the path analysis of participants’ “sense of being followed” by the robot using favorability as an explanatory variable are shown in FIGURE 6(a). The goodness-of-fit index (GFI) for the model was.93. The information quantity reference value indicating the stability of the model, the Akaike information criterion (AIC), was 40.21. The path analysis for human-robot drumming interaction showed that the variability of the robot’s drumming exerted a significant negative effect on participants’ “sense of being followed” (β = -.28, p = .001), and participants’ “sense of being

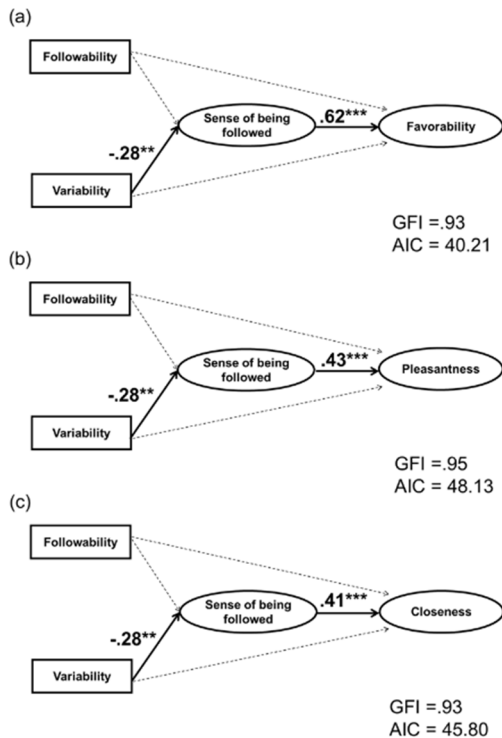


FIGURE 6. Results of the path analysis of the human-robot drumming interactions (a) Favorability (b) Pleasantness (c) Closeness; values indicate the normalization factor). The squares in the figure represent the physical characteristics of the drumming interactions, and the ovals represent the psychological characteristics of the drumming interactions, and the ovals represent the psychological.

followed” exerted a positive effect on favorability ($\beta = .62$, $p = .001$). The direct paths from both variability ($\beta = .00$, n.s.) and followability ($\beta = -.03$, n.s.) to favorability were nonsignificant. The followability of the robot did not exert a significant effect on subjective “sense of being followed”.

Similar results were observed when using subjective ratings of pleasantness and closeness as dependent variables. For pleasantness ratings (FIGURE 6(b)), the variability of the robot’s drumming exerted a significant negative effect on participants’ “sense of being followed” ($\beta = -.28$, $p = .001$). Further, the participants’ “sense of being followed” significantly positively affected pleasantness ($\beta = .43$, $p = .001$). The direct paths from both variability ($\beta = -.13$, n.s.) and followability ($\beta = -.01$, n.s.) to pleasantness were nonsignificant.

For closeness ratings (FIGURE 6(c)), the variability of the robot’s drumming exerted a significant negative effect on participants’ “sense of being followed” ($\beta = -.28$, $p = .001$). Further, the participants’ “sense of being followed” exerted a significant positive effect on closeness ($\beta = .41$, $p = .001$). The direct paths from both variability ($\beta = .00$, n.s.) and followability ($\beta = -.04$, n.s.) to closeness were nonsignificant.

These results indicated that robot drumming with lower levels of variability increased participants’ sense of being



FIGURE 7. Experimental setting in Experiments 2 (human-human interaction).

followed by the robot, which increased their impression that the interaction with the robot was pleasant. They felt a strong sense of unity with the robot.

B. EXPERIMENT 2 HUMAN–HUMAN DRUMMING INTERACTION

1) AIM OF THE EXPERIMENT

We sought to examine physical factors associated with a sense of leading the rhythm in drumming interactions between humans in a free situation and compared the results with those from Experiment 1 (human-robot interaction).

2) PARTICIPANTS

Twenty healthy adults (10 females and 10 males, mean age: 21.6 ± 1.0 years, range 20–24 years) participated in Experiment 2 (human-human drumming interaction). None of the participants had been diagnosed with neurological or psychiatric disorders. We followed the same ethical guidelines used in Experiment 1.

3) EXPERIMENTAL SETTING

The experiment was conducted in two adjoining soundproof rooms. One was used as an experiment room, and the other was a waiting room. We provided two chairs for participants in the experiment room, with a table (size: 70 cm × 140 cm) between them (Figure 7). Unlike in Experiment 1, we placed a screen (whiteboard) at the center of the table in Experiment 2. This was used to prevent the transmission of information other than drumming sounds between the participants during the experiment. In the human-human interaction, individuals’ impressions of their partners can be strongly influenced by appearance. Therefore, to investigate how the exchange of rhythms in the interaction affected participants’ impressions of their partners, we limited the information transferred between the participants to drumming sounds. The size of the screen was 102 cm (width) × 70 cm (height), which was large enough to prevent the participants from seeing each other. The drumming behaviors and drumming sound were recorded with the same video camera and microphone used in Experiment 1. In the waiting room, we created four booths. Each of which was spatially separated from the others by partitions at

the height of approximately 2 m. Each booth contained a chair for participants. As both rooms were soundproofed, people in the waiting room could not hear the drumming sounds from the experiment room.

4) EXPERIMENTAL PROCEDURE

We divided 20 participants into five groups of four (two males and two females). Each group of four participants participated in the experiment together. They were not familiar with each other, and we took care to ensure that they did not see each other before or during the experiment. We led the participants to different booths in the waiting room one by one. We strongly encouraged them not to look at or interact with each other during the experimental session or resting time. In each session, two participants engaged in a drumming interaction in the experiment room. The two participants were randomly chosen from four participants in the group. They were taken to the experiment room one by one before the session and led back to the waiting room one by one after the session.

Each experimental session consisted of a 40-s alternating drumming interaction followed by a rating period. The participants were instructed to hit the drum rhythmically, alternating with the opponent. Before the first session, each participant watched a prerecorded silent movie demonstrating an example of alternating drumming. This was intended to help them to understand the task. An experimenter provided instructions as to which participant should initiate the drumming and inform them of the times to begin and end the session.

During the rating period, the participants were asked to provide subjective ratings of their impressions of the preceding interaction. The items and procedures for the ratings were identical to those used in Experiment 1 (please see above). As there were six possible combinations for pairs of four participants in each group, and each pair performed the experimental session five times, a total of 30 sessions were completed by one group. The order of the pairs was predetermined in pseudorandom order, avoiding repetition of the same pair. We performed this for the five groups.

5) DATA ANALYSIS

We extracted the time of each drumming point for each participant based on the recorded sound data. We used these data to calculate two objective indices (followability and variability) representing the physical characteristics of drumming interactions. These indices were the same as those estimated in Experiment 1.

6) PATH ANALYSIS

We performed a path analysis to clarify how the two physical characteristics of drumming interactions affected participants' impressions of their partners in the human-human drumming interactions. In this analysis, we used all data obtained from both participants in each pair. The other procedures used in the analysis were identical to those used in

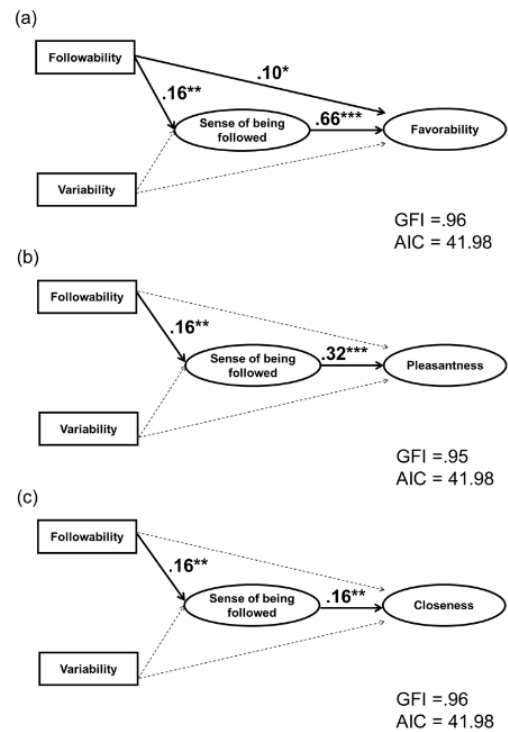


FIGURE 8. Results of the path analysis of the human-human drumming interactions ((a) Favorability (b) Pleasantness (c) Closeness; values indicate the normalization factor). The squares in the figure represent the physical characteristics of the drumming interactions, and the ovals represent the psychological characteristics. The paths with significant effects are shown with solid lines, and those without substantial effects are shown with dotted lines.

Experiment 1. The objective variables were followability and variability, and the explanatory variables were favorability, pleasantness, and closeness.

7) RESULTS AND DISCUSSION

a: RESULTS OF THE PATH ANALYSIS

FIGURE 8(a) shows the results of the path analysis with favorability as the explanatory variable. The GFI for the model was .96, and the AIC was 41.98. The path analysis showed that followability in human drumming exerted a significant positive effect on participants' "sense of being followed" ($\beta = .16, p = .001$), and participants' "sense of being followed" exerted a positive effect on favorability ($\beta = .66, p = .001$). The direct path from followability to favorability was significant ($\beta = .10, p = .002$), and the variability of the drumming variability did not significantly affect favorability ($\beta = .06, n.s.$).

Similar results were observed using subjective ratings of pleasantness and closeness as dependent variables. For the pleasantness ratings (FIGURE 8(b)), followability in human drumming interactions exerted a significant positive effect on participants' "sense of being followed" ($\beta = .16, p = .001$), and participants' "sense of being followed" exerted a positive effect on closeness ($\beta = .32, p = .001$). The direct paths



FIGURE 9. Experimental setting in Experiment 3.

both from followability ($\beta = .07$, n.s.) and variability ($\beta = .09$, n.s.) to pleasantness were nonsignificant.

For the closeness ratings (FIGURE 8(c)), followability in human drumming interactions exerted a significant positive effect on participants' "sense of being followed" ($\beta = .16$, $p = .001$), and participants' "sense of being followed" exerted a positive effect on closeness ($\beta = .16$, $p = .01$). The direct paths both from followability ($\beta = .07$, n.s.) and variability ($\beta = .10$, n.s.) to closeness were nonsignificant.

These results showed that the participants' sense of leading increased when they sensed followability with partner drummers. Interactions with others increased their feelings of comfort and created a strong sense of unity with partner drummers.

C. EXPERIMENT 3 THE ANTHROPOMORPHIC IMPRESSION OF DRUMMING ROBOTS WITH TWO DIFFERENT CYCLE PARAMETERS

1) AIM OF THE EXPERIMENT

We aimed to investigate whether the pseudosen of leading would induce anthropomorphic impressions of robots. We prepared two drumming robots, one that could induce a higher pseudosen of leading and one that could not, based on Experiment 1. We examined the extent to which participants viewed the robots as anthropomorphic, using a "mind perception" questionnaire [17].

2) PARTICIPANTS

Fourteen healthy adults (8 females and 6 males, mean age: 23.35 ± 2.17 years, range: 20–27 years) participated in Experiment 3. None of the participants had been diagnosed with neurological or psychiatric disorders. We followed the same ethical guidelines used in Experiment 1.

3) EXPERIMENTAL SETTING

FIGURE 9 shows the experimental setting in Experiment 3. We placed a table (140cm \times 140cm) and chair in an experiment room. We covered the two drumming robots with stuffed animals (i.e., blue penguin used in Experiment 1 and yellow chick) and set them up on the table facing the participants. The intervals of the robot's drumming were determined

using the sine wave function, as in Experiment 1. One cycle of tempo change (C in Figure 3) was 5 s for one robot and 20 s for the other robot. Other parameters were the same as those used in Experiment 1. The combination of stuffed animals and the duration of cycles was counterbalanced across participants.

4) EXPERIMENTAL PROCEDURE

Each participant sat on the chair facing the drumming robot. The participants performed drumming sessions, alternating with the two robots, and each participant completed three drumming sessions per robot. The robot with which each participant undertook the initial session was randomly assigned. Each session was composed of a 20-s drumming interaction followed by a rating period.

The actual content of the drumming task was the same as that of Experiment 1. During the rating period, participants were asked to rate the sense of being followed, which represented the extent to which they felt that the robot followed their drumming, using a seven-point Likert scale ranging from 1 ("Not at all") to 7 ("fully").

After completing all six sessions, participants were asked to answer a "mind perception" questionnaire [17] to measure their anthropomorphic impressions for each of the two robots. The questionnaire consisted of two dimensions ("intelligence" and "emotion") and contained 21 pairs of two opposing adjectives (e.g., mechanical-humanlike, cold-warm). Participants responded using a 7-point Likert scale ranging from 1 (a left side adjective is well-matched) to 7 (a right side adjective is well-matched) to express their impressions of the robots.

We examined how rapidly the robot's drumming tempo change affected the pseudosen of being followed by the robot, using a paired t-test (condition: 5 s and 20 s). We also examined how participants' anthropomorphic impressions of the robots differed between the two conditions.

For the analysis, we integrated raw data of a previous online survey on mind perception for several entities (500 people \times 7 target characters) with data acquired in this experiment (14 people \times 2 conditions). We performed a principal component analysis for the integrated data to extract two dimensions for mind perception: intelligence and emotion. Through this procedure, we could compare the anthropomorphic impression of two robots with that for other entities measured in the previous study, such as humans, frogs, and gods.

5) RESULTS

The results of the paired t-test revealed a significant difference of "the sense of being followed" between the two conditions with different cycles of tempo change ($t(13) = 3.47$, $p < .01$). Therefore, the results of Experiment 1 could be replicated in Experiment 3.

The results of the principal component analysis showed two factors reported in the previous study. "Emotion" (eigenvalue = 11.55) accounted for 55.00% of the variance, and

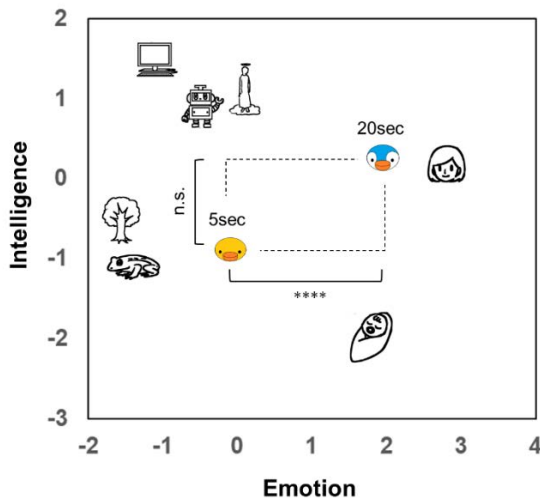


FIGURE 10. Anthropomorphic impression of each agent.

“intelligence” (eigenvalue = 3.02), accounted for 14.37% of the variance.

We quantified the scores of both emotion and intelligence for the anthropomorphic impressions of the two robots from the factor loadings. We compared these scores between conditions (FIGURE 10). The score for emotion for the robot with the 20-s tempo change was significantly higher relative to that observed for the 5-s tempo change ($t(13) = 3.45$, $p < .01$). There was no significant difference in intelligence scores between the two conditions (paired t-test, $t(13) = -1.53$, $p = .152$). These results indicated a gradual rhythm fluctuation in robot drumming induced anthropomorphic impressions of the robots, particularly concerning emotion.

III. DISCUSSION

In this study, although the robot actually hit the drum according to simple mechanical law (sine wave) and did not monitor human drumming, the sense of leading (being followed) occurred, notably when the rhythm of the robot changed gradually. In addition, the path analysis revealed that pleasant emotions were induced by the pseudosen of leading in human-robot drumming. Furthermore, anthropomorphic impressions of robots were formed when the pseudosen of leading occurred. We also performed a similar investigation in human-human drumming interaction. As a result, we found that the sense of leading the rhythm also evoked pleasant emotions in human-human drumming interactions. However, compared to human-robot interaction, the pseudosen of leading was not likely to occur in the drumming between humans, and actual following behavior in the drumming partner induced the sense of leading in the interactions between humans.

We considered why the sense of leading occurred in the gradual rhythm fluctuation from the perspective of the easiness of prediction. Our results suggested that even with the

same amount of variation between conditions, long cycles of rhythm fluctuation induced the sense of leading. In contrast, when participants were adapting to rapid change, this sense decreased. Our interpretation of this result was as follows. It is known that humans unconsciously predict and adjust to gradual environmental change [21]. Therefore, in this experiment, the participants could have predicted and adapted to the gradual rhythm fluctuation without being conscious of adjusting to the robot’s rhythm. As a result, participants could have mistakenly believed that the robot followed their rhythm because their rhythm was in synchrony with that of the robot without awareness of following the robot’s rhythm. In contrast, in the case of rapid rhythm fluctuation, the participants had to consciously adjust to the rhythm, which may have reduced their pseudosen of leading the rhythm.

The interesting finding shown in Experiment 3 was that the sense of leading and higher-order anthropomorphic impressions of the robot occurred with the non-interactive mechanical robot’s movement. Numerous previous studies have attempted to assign psychological properties such as emotion to artificial robots. The studies have suggested that the physical characteristics of robots’ appearances and motion affected anthropomorphic impressions of the robots. Many of these previous studies have focused on the independent physical properties of robots. However, the current study is unique because it focused on the interaction of two agents rather than examining independent agents’ properties. Even though the robot’s motion was artificial and far from being a biological property, the interaction between humans and the robot created psychological impressions of the robot. We believe that the impressions of other agents are formed not only based on the agent’s independent characteristics but also on the characteristics of the interaction with the agent.

Some studies have examined robots’ behaviors in synchrony with humans [22], [23]. However, most of these studies focused on how robots functionally followed the rhythm of humans. In comparison, our results suggested that participants’ subjective impressions could be formed even if the robot does not have the functionality to follow the human rhythm. Our findings suggest that when designing robots in the future, it is essential to design the robot’s behavior and interactions between humans and the robots [24]. If robots’ behaviors are designed to change smoothly and predictably, humans tend to form biological and anthropomorphic impressions for the robots by unconsciously adjusting themselves to the robots’ behaviors.

We assume that the phenomenon reported in this study is not found only in human-robot interaction but also in interpersonal situations. In human-human drumming interactions (Experiment 2), we showed a moderate correlation between the sense of leading and the extent of the actual initiative. Meanwhile, in more realistic social situations (e.g., a collaboration between a married couple to complete housework), people have been found to overestimate their leading and contribution [25]. Hence, if we redesigned the task, the pseudosen of leading could also be observed in human-human

drumming interactions. Generally speaking, humans more or less have a motivation to be a leader, which might cause any social conflicts. Therefore, this pseudo-sense may contribute to mitigating such conflicts [26], [27].

The findings obtained in this study will provide an important foundation for the future consideration of social robot behaviors that create a friendly impression to humans. On the other hand, it is difficult to demonstrate how universally the results of this study can be applied to people because of the only a limited number of samples obtained in this study. However, we expect the knowledge obtained in this study useful to design the movements of robots interacting with humans, and to examine how universally the knowledge obtained in this study can be applied to various social situations [28].

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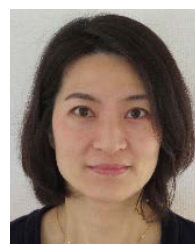
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HIDEYUKI TAKAHASHI received the M.E. and Ph.D. degrees in information science from Hokkaido University, in 2005 and 2008, respectively. He is currently a Specially-Appointed Associate Professor in engineering science with Osaka University. Since 2020, he has also been a Visiting Researcher with the Tamagawa University Brain Science Institute. His research interests include human-robot interaction, human-agent interaction, and cognitive science.



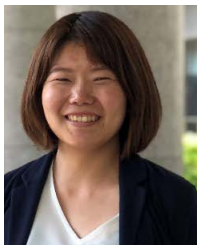
TOMOYO MORITA received the M.E. and Ph.D. degrees in human environmental studies from Kyoto University, in 2000 and 2003, respectively. She is currently a Senior Researcher with the Center for Information and Neural Networks (CiNet), National Institute of Information and Communications Technology (NICT). Her research interests include the development of the human-brain, cognitive, and emotional processes.



MIDORI BAN received the M.E. degree in child education from Hirosaki University, in 2008, and the Ph.D. degree in psychology from Doshisha University, in 2015. She is currently a Specially-Appointed Lecturer in engineering science with Osaka University. Her research interests include cognitive development in toddlers and human agent interaction of children.



NOBUTSUNA ENDO received the B.E., M.E., and Ph.D. degrees in mechanical engineering from Waseda University, Tokyo, Japan, in 2006, 2008, and 2013, respectively. He is currently an Associate Professor with the Department of Robotics and Mechatronics, School of Science and Technology for Future Life, Tokyo Denki University, Japan. His research interests include robotics, teleexistence, and human–robot interaction.



HIROKA SABU received the B.E. and M.E. graduate school of engineering from Osaka University, Osaka, Japan, in 2016 and 2018. Her research interest includes human–robot interaction.



MINORU ASADA (Life Fellow, IEEE) received the B.E., M.E., and Ph.D. degrees in control engineering from Osaka University, Osaka, Japan, in 1977, 1979, and 1982, respectively. In April 1995, he became a Professor with Osaka University, where he was a Professor with the Department of Adaptive Machine Systems, Graduate School of Engineering, from April 1997 to March 2019. He has been a Specially-Appointed Professor with the Symbiotic Intelligent System Research Center, Open and Transdisciplinary Research Initiatives, Osaka University, since 2019. Since 2021, he has been the Vice President of the International Professional University of Technology in Osaka. He is a Former President of RoboCup (2002–2008).

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