Robots as an Interactive-Social Medium in Storytelling to Multiple Children

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Abstract This paper investigates the effects of group interaction in a storytelling situation for children using two robots: a reader robot and a listener robot as a side-participant. We developed a storytelling system that consists of a reader robot, a listener robot, a display, a gaze model, a depth sensor, and a human operator who responds and provides easily understandable answers to the children's questions. We experimentally investigated the effects of using a listener robot and either one or two children during a storytelling situation on the children's preferences and their speech activities. Our experimental results showed that the children preferred storytelling with the listener robot. Although two children obviously produced more speech than one child, the listener robot discouraged the children's speech regardless of whether one or two were listening.

Keywords Storytelling, child-robot interaction, multiple robots, group interaction

1 Introduction

Interactive storytelling is a growing topic in education services for children because it plays an important role in language development and improves the complexity of their language [2, 3]. Interactivity is an essential factor for attracting children and supporting their education, regardless of the storytelling situations [4, 5]. Based on these contexts, agents (including robots) are often used in interactive storytelling systems [6-12], and these studies reported the effectiveness of various systems and how they encourage children's language development.

For more engagement with children, we focused on the interaction styles of a storytelling system. Past studies mainly used only one robot or an agent for storytelling, but several recent studies described how using a group of robots for information-providing services attracts people by showing conversations between robots in information-providing contexts [13, 14]. Such an information-providing style is defined as an interactive-social medium [15].

This paper is an extended version of previous work by Tamura et al. [1] and contains additional experiment results and more detailed discussions.

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Fig. 1 Storytelling for children with two robots

In interactive-social medium designs, one robot takes the speaker role, and the other plays the listener, and they talk together in front of an audience. In other words, the additional robot behaves as a *side-participant*, which is a *ratified participant* during conversations [16, 17]. The presence of such a listener robot enables a storytelling system to naturally provide additional information about the story contents by showing a conversation that directly questions the speaker robot. Of course, if the children directly question the robots, the speaker robot answers; the listener robot might also respond to show interactivities.

In this study, we investigate the effects of an interactive-social medium (i.e., a reader robot and a listener robot) in a storytelling situation for children (Fig. 1) by comparing an interactive medium (i.e., only a reader robot) to investigate how multiple robots shape interaction with children. We also investigated how the number of children (i.e., one or two) influenced their behaviors during the storytelling because understanding the interaction with multiple children is important for child-robot interaction settings. Therefore, this study focuses on the group interaction of children and robots in storytelling situations. We employ a semi-autonomous approach to accurately respond to children's questions during storytelling to avoid the difficulties of speech recognition [18] to develop a storytelling system with two robots. We also developed a gaze controller model for natural and autonomous gaze control of the reader robot. In this study, we address the following research question:

- How do the interaction style of a storytelling system and the number of children influence their activities?

We note that this paper is an extended version of previous work by Tamura et al. [1] and contains additional experiment results and more detailed discussions.

2 **Related Work**

2.1 Robot as an information-providing medium

Robots are often used as a medium for information-providing services because their physical existence attracts people in such actual environments as museums and shopping malls [19-22]. For natural conversational interaction with people based on robot behaviors in such environments with ordinary people, several researchers have developed both verbal/non-verbal interaction models, including gaze behaviors [23, 24], body gestures [25, 26] [27], spatial coordination [28, 29], approaching people [30], and distribution [31] [32].

Many such information-providing robots are used as interactive media, i.e., robots that directly interact with people to provide information [33, 34]. On the other hand, some recent studies focused on a different interaction style to provide information by showing the conversations of robots to people [35]. In this interaction style, the robots basically talk with each other to provide information (Fig. 2, middle) and sometimes interact with people based on the contexts of their conversations, such as asking about specific topics (note that social is defined as multiple robots interacting with each other). Sakamoto et al. concluded that using multiple interactive robots is better for conversational types of information providing than an interactive medium (i.e., just one single robot), and the passive-social medium approach (i.e., only showing conversations between robots to people without interactivity) is better for advertising contexts than using multiple robots [15]. Thus, these studies make clear about the styles of information-providing for social robots.

In this study, we focused on storytelling applications for children. Since past studies reported that interactivity is essential for effective storytelling (the details are described in the next section), we employed multiple robots for storytelling.

2.2 Interactive storytelling-robot systems for children

Recently robots are also being used as storytelling agents in education contexts [36] because their physical presence has advantages over virtual agents for spreading information [37, 38]. For example, Fridin developed a storytelling system with a robot that tells prerecorded stories to children and showed that it improved both cognitive and motor performances [9]. Kory et al. developed a storytelling system using a robot with preschool children to support their language development [10]. Another perspective used a storytelling-robot system to understand children's behaviors [13].

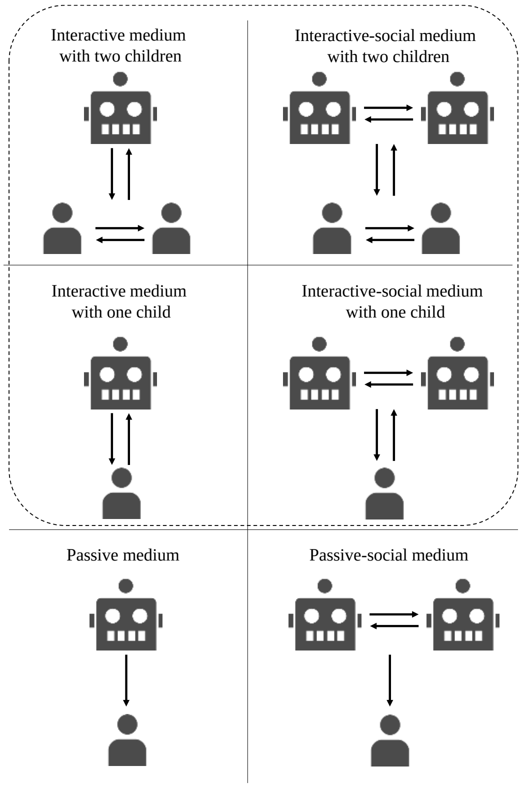

Fig. 2 Types of information media with robots based on previous work [15] (bottom and middle) and interaction style of this study (top and middle)

These research works identified the effectiveness of a storytelling system with robots and scrutinized the possibilities of using them in storytelling contexts. Unfortunately, they less focused on the interaction styles of storytelling. They employed interaction-medium [10] and/or passive-social medium styles (or limited interactive-social style, e.g., just a tablet to select storytelling contents) [9, 14] without comparing the effects of an interactive-social medium with other interaction styles.

By considering interactive-social medium styles, asymmetrical roles (i.e., reader and listener robots) are essential to show conversations between robots independently of the storytelling contents, including asking questions about the contents. If both robots play the same roles, i.e., two reader robots like in past studies, it is illogical for either reader robot to ask the other reader robot a question about the contents. A more natural context is where a listener robot asks the reader robot a question. One study about child-robot interaction employed an interactive-social medium setting [39] that focused on a situation where children tell a story to multiple robots, which is different from our study. Since previous studies identified the importance of interactivities in storytelling [4, 5], we compared interactive medium (hereinafter *single-robot*) and interactive-social medium (hereinafter *two-robots*) styles.

Several past works focused on a situation where a robot interacted with multiple people [9, 14, 40]. For example, Vázquez et al. developed a furniture-robot system that consisted of a mobile chiffonier robot and an animated lamp device and investigated how multiple children interacted with it [40]. Short et al. investigated social interaction between a social robot and family groups and their speech activities [41]. Similar to these works, we are interested in situations where multiple children participate in storytelling because it will influence their activities (Fig 2, top and bottom). If multiple children are present, they will interact with each other, and their activities will be different from a situation where only one child is there. But past studies less focused on group interaction between multiple storytelling robots and children. We believe that the observations of such interaction will provide interesting knowledge for child-robot interaction research fields. In other words, exploring multi-party storytelling between children and robots will contribute to our understanding of child-robot interaction in group settings as well as the effectiveness of both single/multiple robots and children during storytelling situations.

3 System Overview

Figure 3 shows an overview of our developed system that consists of the following components: a human-tracking system, a gaze model, a reader robot, a listener robot, and a human operator who controls the speech recognition and the behavior selector of the robots. The reader robot shows each page of the book on a display during the storytelling. The details of each component are described as follows.

3.1 Human-tracking system

For children-position tracking, we used one depth sensor (Kinect V2) and a laptop PC to process the sensor data. The range for person recognition was from 0.5 to 4.5 m, the field's horizontal angle was 70°, and its perpendicular angle was 60°. This system sends the estimated head positions of the children to the behavior selector using Kinect V2 libraries through a wired network connection.

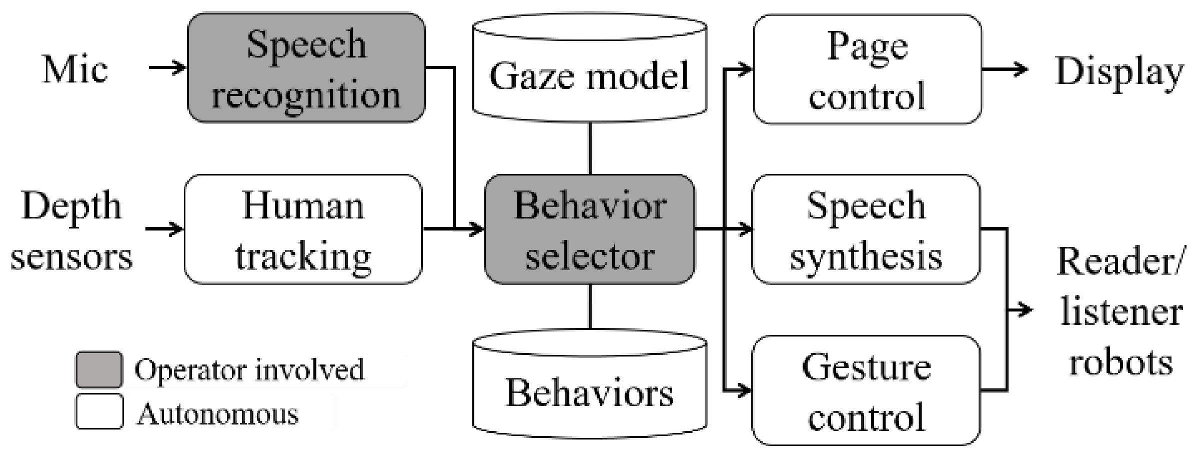

Fig. 3 An overview of the developed system.

3.2 Gaze model

Gaze behavior design in storytelling is an essential factor in attracting people's interest in a story's contents. Several gaze models have already been proposed in multi-party conversations [23, 25, 42, 43], but they mainly focused on situations where a speaker engages in storytelling with fewer than four persons. On the other hand, in our study, since the reader robot needs to consider not only multiple children but also the listener robot and a display for the images, we extended the current conversational gaze models [25].

The possible gaze targets were the listener robot, the display, an environment, and either of the children. Following a past study [25], the reader robot changes its gaze target ratio at the beginning of each speech sentence.

In the *two-robots* style, i.e., with a listener robot (Fig. 4), the gaze targets are the display, the children, the listener robot, and the environment. Following past research work, we set our reader robot to look at the display with a 70% ratio at the beginning of each sentence and at the listeners with a 73% ratio at the not-beginning of each sentence. Based on the previously defined gaze ratio probability [25], we set the ratios at the beginning of the targets to 70.0%, 22.8%, 2.52%, 2.52%, and 2.16%, and the ratios at the not-beginning of the targets to 10.28%, 16.74%, 25.55%, 25.55%%, and 21.9% for the display, the environment, child 1, child 2 and the listener robot. Thus, at the beginning of each sentence, the reader robot generally looked at the display; at the not-beginning of each sentence, it mainly looked at the children or the listener robot. When the gaze target is the environment, the gaze angle was randomly determined from the front of the robot to the display. Without a listener robot, the gaze target ratio is added to the children's ratios. When there is just one child, the gaze target ratio is also summarized. We changed the gaze target every three seconds. The listener's gaze is controlled with the same algorithm.

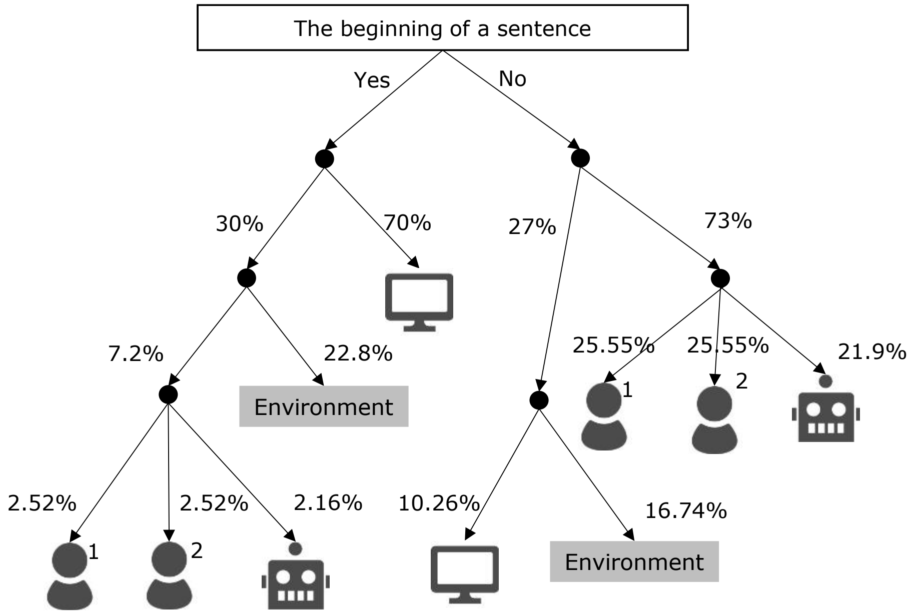

Fig. 4 Proposed gaze model for reader robot with listener robot and two children

3.3 Robot

Figure 5 shows Sota, a desktop-sized interactive humanoid robot characterized by its human-like physical expressions. We used two Sota robots as a reader and a listener. Sota has eight DOFs: three in its head, two for its shoulders, two for its elbows, and one in its base. It stands 28 cm tall and has a microphone, a camera, and a voice synthesis function. The LED on its mouth blinks depending on the sound level to indicate speaking. With the developed gaze model, the robot gazes are autonomously controlled. Its shoulders move slowly as an idling behavior during the storytelling. We did not use pointing or other gestures in this study.

Fig. 5 Sota

3.4 Details of implemented behavior

An overview of the dialogue flow is summarized in Fig. 6. After the storytelling begins, the reader robot looks at the children and the listener robot and starts to read. Both robots semi-autonomously interact with the children, except for the speech recognition and behavior selections (details are described in the next section).

For our storytelling-robot system, we used two picture books: *Etwas von den Wurzelkindern* by Sibylle von Olfers (*Nekko umare no kobito tachi* in Japanese) and *Zucchini of Zuzu* by Leo Rivas (*Zuzu no Zukki-ni* in Japanese). We chose these two relatively unknown books to provide novel situations to attract more of the children's attention in our experiment. We prepared 121 speech contents for the storytelling and chatting, and the average reading times by the robots are 5.5 for the Olfers book and 3.5 minutes for the Rivas book.

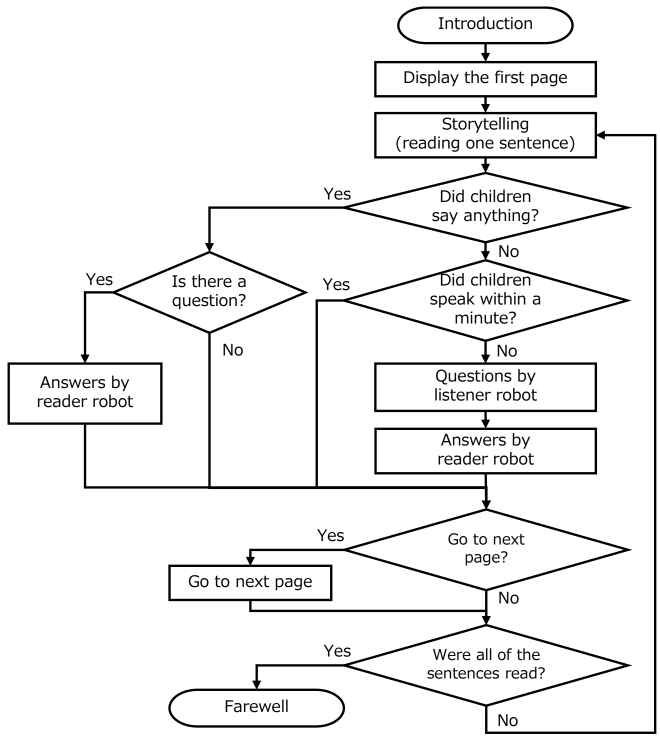

Fig.6 Dialog flow in our developed system

3.5 Operator

For this study, we employed a human operator who assumed control of the speech recognition and behavior selector functions with a tele-operated system (Wizard of Oz [44]) by following pre-determined rules because accurate speech recognition for children's speech remains difficult [18]. We also needed to avoid the effects of errors in speech recognition systems to investigate interaction styles in storytelling. Also, the human operator waits for a minute before stimulating the listener robot by using a timer to avoid the operator's biases

When the children asked questions to the robots, and if no appropriate answers were identified, the operator used Sota's text-to-speech function to answer them as quickly as possible. The operator also determined the timing of the utterances during the storytelling because we cannot predict when children will ask questions. For these reasons, we used a human operator as a speech recognizer. The operator exists in a different room, so all commands and sensor information were remotely transferred.

4 **Experiment**

4.1 Hypotheses and predictions about children's speech activities and the number of robots

We assume that the *two-robots* style will change the children's speech activities during the storytelling. However, since the phenomena related to the number of robots remain basically unexplored and accurately estimating young children's behaviors is difficult, we made two competing hypotheses about their effects based on different theories and considerations.

First, we assume that the *two-robots* style will stimulate children's speech activities and encourage them to ask more questions because showing conversations between robots enables the interacting people to understand their contents more easily [45]. Other studies suggest that using multiple robots attracts people's interest in their conversational content and might stimulate children's curiosity [46] [47]. Moreover, questioning behaviors during robot conversations might fuel children's curiosity in the story's contents. In fact, past work at an elementary school reported that when a child questioned a robot, others were encouraged to ask questions themselves [48]. If the children feel that the listener robot asks the reader robot questions, they might participate more actively during the storytelling.

However, one possible competing phenomenon might exist. Since the presence of a listener robot might change the role of the children from addressees to side-participants because the listener robot participates in the conversation by asking a question, a past study suggested that the roles in the conversation influence the speech activities of people [49]. Another study reported that the number of speaking turns and times fluctuates greatly due to their roles [50], which is also directly related to people's speech activities. If the children feel that the reader robot is mainly talking to the listener robot, they might participate less actively during the storytelling and focus more on the robots' conversations. Based on these considerations, we made the following competing predictions:

Prediction 1-a (stimulating speech activities): The *two-robots* style will encourage the speech activities of children: more statements and/or questions, regardless of the number of children.

Prediction 1-b (discouraging speech activities): The *two-robots* style approach will discourage children's speech activities, i.e., fewer statements and/or questions, regardless of the number of children.

4.2 Participants

In this experiment, 32 children (16 girls and 16 boys from three to five years old, average age 4.47, S.D 0.71) and their parents (30 mothers and two fathers) participated.

4.3 Conditions

Our experiment had a mixed participant design. The *robot's number* factor is a within-participant design (*single-robot* and *two-robots*), and the *children's number* factor is a between-participant design (*alone* and *pair*).

Single-robot condition: Just one robot conducted the storytelling with the children; this condition is a typical storytelling-robot system.

Two-robots condition: Two robots conducted the storytelling with the children.

Alone condition: Each child participated in the storytelling alone; 16 children participated in this condition.

Pair condition: A pair of children participated in the storytelling; 16 children who are friends (except one pair of twins) participated in this condition. They attend the same kindergarten or live in the same neighborhood. The paired-children ages and genders were the same. All participants are healthy children.

4.4 Environment

Figure 7 shows the experimental environment. The room is approximately 40 m^2. We placed the reader and listener robots in front of the display and a Kinect V2 behind it. The children sat on the floor to look at the displayed book.

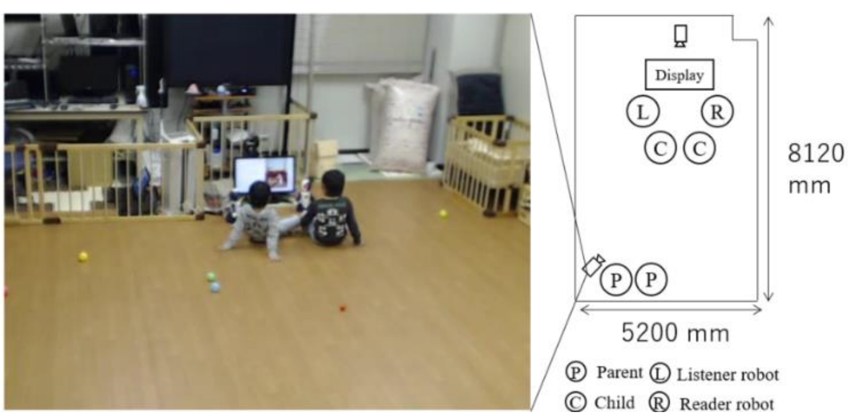

Fig. 7 The experimental environment in our study

4.5 Procedure

Before the first session, the parents were given a brief description of our experiment's purpose and procedure. We note that all parents signed the consent form. The first ten minutes were used to adjust the children to their environment and the robots; during this period, the reader and listener robots greeted each other and talked. Before the storytelling began, the children sat in front of the display, and their parents moved away from their child.

The children sat through two sessions of different conditions about the number of robots. The order of the conditions (*single-robot* or *two-robots*) and the books were counterbalanced. After each session, the parents filled out a questionnaire. After the experiment, the parents and children separately answered questions about their preferences to reduce bias.

The experimental protocol was approved by our institutional review board.

4.6 Measurements

In this experiment, we objectively measured the number of utterances using recorded videos to verify our hypothesis. We also subjectively investigated both the children and the parental impressions. We measured the preferences from the children and the parents (binary choice among conditions, one item for each). We also measured their impressions about the naturalness of the reader robot gaze from a third-person perspective. For this purpose, we prepared an item as "The degree of naturalness about robot's gaze behaviors" with 1-to-7 scale, 7 is most positive, one item.

5 **Results**

In this section, firstly, we describe observations of children's behaviors to explain how they interact with the robots during the experiment (Section 5.1). Next, we analyzed the behavioral results (Section 5.2) and the questionnaire results (Sections 5.3), as well as additional analysis based on the observation (Section 5.4).

5.1 Observations

In both the *single-robot* and *two-robots* conditions, typically, the children intently listened to the story from the reader robot (Fig. 8). The focus of their attention, i.e., their gaze, changed based on the timing of the storytelling situations. For example, when the reader robot started to talk, a child generally looked at it first and then at the display. In both conditions, children sometimes focused on a specific part on a page, e.g., approaching the display for a closer look or pointing at a ladybug or specific characters after the reader robot talked about them (Fig. 9).

From observations between the *single-* and *two-robots* conditions, the number of robots influenced not only the children's speech activities but also their physical activities during the storytelling. In the *two-robots* condition, the children quietly listened to the robot's conversations. Due to the increase in the number of robots, the children sometimes touched them, but such phenomena were rarely observed in the *single-robot* condition. For example, one girl stroked the heads of the robots or hugged them during the story (Fig. 10). Based on these observations, we conducted more analysis of the children's behavior (see Section 5.4 for more details). These behavior changes (i.e., children quietly listened to the storytelling and friendly interaction such as touches to the robots) would make positive impressions and then influenced their preferences.

From observations between the *alone* and *pair* conditions, the number of children influenced their speech activities during the storytelling, and we inferred that sitting next to a friend might relax them. For example, when the listener robot asked the reader robot a question, the children sometimes discussed it together (Fig. 11). Some children read the displayed contents with the reader robot. One boy warned his friend, who was talking about something unrelated to the story or touching the robot (Fig. 12), to focus on the reader robot. On the other hand, sometimes children played together without focusing on the storytelling. We also analyzed such positive/negative behaviors during the storytelling in Section 5.4.

Fig. 8 Child listening to story in single condition

Fig. 9 Child pointing at a specific part of the display

Fig. 10 Girl hugging robot during storytelling

Fig. 11 Girls talking during storytelling

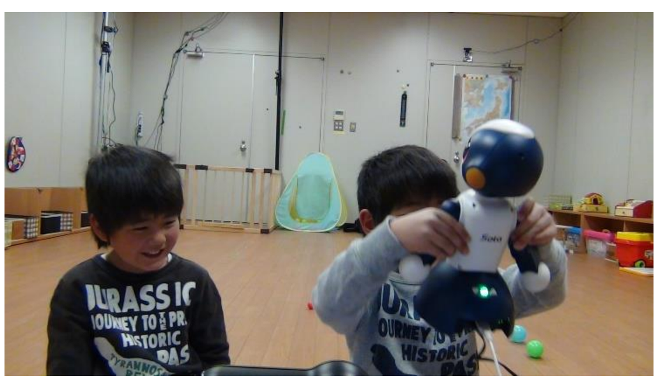

Fig. 12 Boy playing with a robot during storytelling

5.2 Verification of prediction: Speech activities based on the number of children and robots

During the experiment, the children made 336 utterances. First, we analyzed the utterances of the children during the storytelling by separating them into three categories: statements (e.g., "I see"), questions (e.g., "what's a zucchini?"), and conversations between children (e.g., talking about the contents by themselves) (Table 1). In the coding process, a coder classified them into 336 contents, and another coder coded 10% of these data [51]. After that, we investigated the coding's validity by calculating the kappa coefficient [52], which was 0.726, indicating substantial agreement between coders.

Figure 13 shows that the average number of children's utterances per minute depends on the number of children and robots. We conducted a two-factor mixed ANOVA for each factor on *robot's number* (within) and *children's number* (between) and identified significant main effects in the *robot's number* factor ($F(1, 30)=5.929$, $p=.021$, *partial* $\eta 2=.165$) and the *children's number* factor ($F(1, 30)=32.462$, $p<.001$, *partial* $\eta 2=.520$). No significance was found in the interaction effect ($F(1, 30)=1.209$, $p=.280$, *partial* $\eta 2=.039$). This result indicates that children spoke less in the *two-robots* condition than in the *single-robot* condition regardless of the number of children who were present. Thus, prediction 1-b was supported, i.e., the competing prediction (1-a) was not supported. This result also indicates that the speech activities of two children are larger than the speech activities of just one child.

Next, we explain the children's utterances, which were mainly statements in the alone condition, and in the pair condition, their utterances were mainly both statements and conversations regardless of the number of robots. For example, when one child saw a picture during the storytelling, she said, "a snail!" Another example about a conversation concerned a child who said, "a fish is eating zucchini." The other child answered, "you're right." Some children asked such questions as "what's a zucchini?" The operator answered with the prepared answering behaviors, which covered all the questions from the children. In the *pair* condition, the conversations and the questions to the robot were sometimes related; for example, when the characters in the story were making something with a large zucchini, the children asked the reader robot, "they're going to make a boat, right?"

Table 1 Categorization of children utterances in each condition	Single		Two	
	Alone	Pair	Alone	Pair
Statements	28	80	16	69
Questions	1	2	1	3
Conversations	-	70	-	66

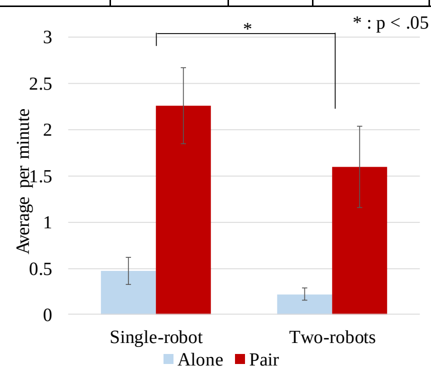

Fig. 13 Average number of children utterances in each condition

5.3 Additional analysis of subjective impressions

In this section, we analyzed both the children and the parental preferences and the perceived naturalness of the gaze behavior from the parent's perspective. Fig. 14 shows the number of children who preferred the *single-robot* or *two-robots* conditions. These results include both the *alone* and *pair* conditions. We eliminated three children who could not decide which condition they preferred and conducted a two-tailed binomial test that indicated that the proportion of the preferences for the *two-robots* condition of 0.72 was higher than expected 0.50, p=.024.

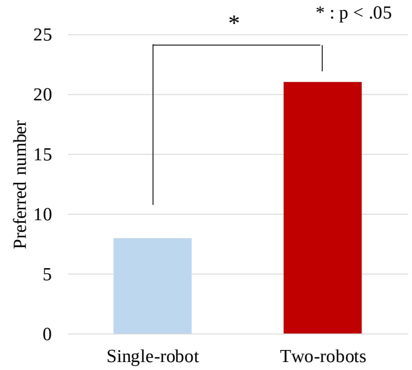

Fig. 14 Number of robots preferred by children

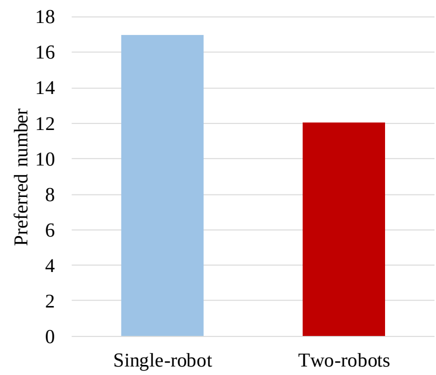

Fig. 15 Number of robots preferred by parents in each condition

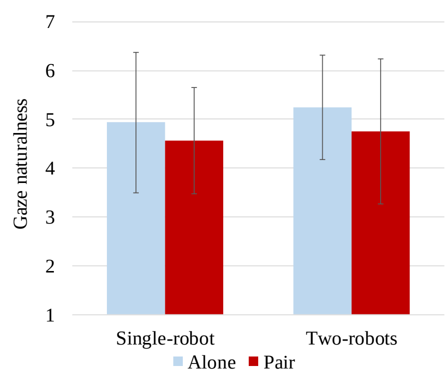

Fig. 16 The naturalness of reader robot's gaze in each condition

Figure 15 shows the parental preferences for the *single*- or *two-robots* conditions. We conducted a two-tailed binomial test, which indicated that the proportion of preferences for the *two-robots* condition of 0.41 was not as high as expected: 0.50, p=.458. Based on these three analyses, the number of robots and children did not significantly affect the parental impressions in our study.

We note that we did not share their preferences with their parents/children and their thought to avoid biases between children and parents. However, some parents thought that children are more attracted to the storytelling in the *two-robots* condition more than the *single-robot* condition, but they preferred the *single-robot* condition because the multiple robots might distract children's attention.

Figure 16 shows the questionnaire results for the naturalness of the gaze of the reader robot. We conducted a two-factor mixed ANOVA for each factor on the *robot's number* (within) and the *children's number* (between). No significance was found in the *robot's number* factor ($F(1, 30)=1.114$, $p=.300$, *partial* $\eta 2=.036$), the *children's number* factor ($F(1, 30)=1.277$, $p<.267$, *partial* $\eta 2=.041$), or the interaction effect ($F(1, 30)=0.070$, $p=.794$, *partial* $\eta 2=.070$). Since the average values of this item at least exceeded the middle (four) in all conditions, our developed gaze model seems to work satisfactorily regardless of the number of robots.

5.4 Children's behaviors analysis

5.4.1 Behavior category of children

Based on our observations, we analyzed the children's behaviors using recorded videos. First, we analyzed the types of behavior during the interactions between the children. We categorized their behaviors during the storytelling into three types: positive (e.g., trying to listen to the story), negative (e.g., inviting another child to play with toys instead of hearing the story), and other. Note that we categorized the children's behaviors that are unrelated to storytelling, such as a discussion about the robot's behaviors (e.g., gaze target) or adjusting their sitting positions as other categories.

In the coding process, a coder classified them into 218 behaviors, and then another coder coded these data. We calculated the kappa coefficient, which was 0.780, indicating satisfactory agreement between the coders. Table 2 shows each behavior category. We conducted a chi-square test, but it did not show any significant differences among the conditions.

Even though the numbers of behaviors are not significantly different, the behaviors types are slightly different between the *alone/pair* conditions. For instance, the positive behaviors in the *alone* condition are mainly reactions to the storytelling, such as approaching the display to look at pictures, clapping their hands at the end of the storytelling, and so on. On the other hand, in the *pair* condition, a typical behavior is to talk about the storytelling between children. For instance, after the page is changed, a child says, "that's a bug," and when the other child asks where the child points to it. When the storytelling is almost finished, a child gives his/her impression, and the other child agrees. In another situation, when a child asks the robot a question about the story, the other child also manifested interest in the question. Another example included suggesting that a child pay attention to the story; if a child was distracted during the storytelling (e.g., playing with a toy), the other child asked him/her to put the toy down and focus on the story. Moreover, one child's behaviors often led the other child to perform similar behaviors; for example, if a child read aloud (i.e., repeating the story content) by following the reader robot, the other child simultaneously did the same behavior.

Concerning the negative behaviors, their behavior types are also different between the *alone* and *pair* conditions. For instance, typical negative behaviors in the *alone* condition are playing with a toy alone and going to their parents during the storytelling. Instead, in the *pair* condition, they did not approach their parents but played together because both children asked the other child to play.

5.4.2 Conversation topics of children

Next, we categorized the children's conversation topics in the *pair* condition into seven types: robot (e.g., talking about robot's characteristic), story (e.g., talking about the contents by themselves), toy (e.g., talking about the around toys), advice (e.g., asking to turn other child's attention to the story), parents (e.g., talking about their parents' behaviors), and other (Table 3).

In the coding process, a coder classified them into 58 conversations, and then another coder coded these data. We calculated the kappa coefficient, which was 0.934, indicating satisfactory agreement between the coders. Note that the total number of conversation types and utterances (Table 1) is different because one conversation includes several utterances, and the total amount of utterances in the conversation category is not very different between the *single* and *two* conditions as shown in Table 1. The chi-square test did not show any significant differences, but the presence of the listener robot increased the variety of conversation topics.

Table 2 Number of each behavior category

Condition	Robot	Positive	Negative	Other
Alone	Single	25	19	22
	Two	12	20	17
Pair	Single	17	11	18
	Two	21	19	17

Table 3 Number of each conversation category in pair condition

	Robot	Story	Toy	Advise	Parent	Chat
Single	1	7	2	2	0	7
Two	7	11	5	6	2	8

5.4.3 Touch behaviors between robots and children

Finally, we analyzed the children's touch interactions during the storytelling because we noticed that the children often touched the robot more in the *two-robot* condition than in the *single-robot* condition. We counted the number of touch interactions between the children and the robots, and Fig. 17 shows the average number of touches in each condition. Only one coder counted them because identifying them is quite simple.

We conducted a two-factor mixed ANOVA for each factor of *robot's number* (within) and *children's number* (between) and identified a significant main effect in the *robot's number* factor ($F(1, 30)=7.354$, $p=.011$, *partial* $\eta 2=.747$). No significance was found in the *children's number* factor ($F(1, 30)=1.053$, $p=.313$, *partial* $\eta 2=.169$) or the interaction effect ($F(1, 30)=0.681$, $p=.416$, *partial* $\eta 2=.681$). These results indicate that the number of robots increased the touch interactions from the children, regardless of the number of children.

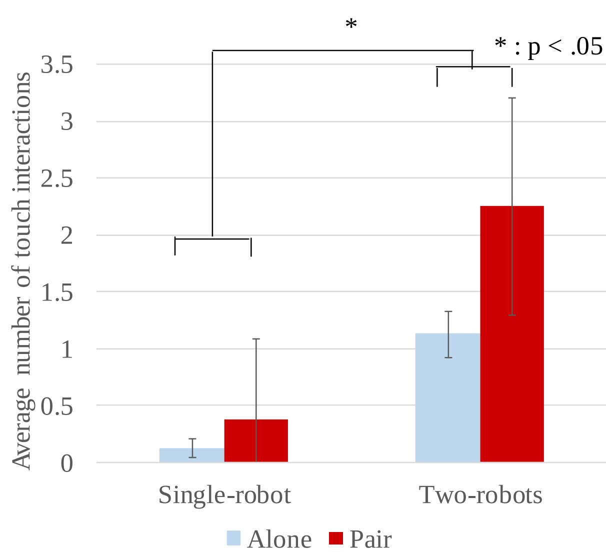

Fig. 17 Number of observed touches between children and robots in each condition

6 DISCUSSION

The following are the two main contributions of our paper: the investigation of the effects of an interactive-social medium (i.e., *two-robots* style) in a storytelling setting and the development of a gaze control model for a storytelling robot by considering multiple targets. Our experiment results showed how children's activities changed due to the number of robots, and our developed gaze control system works satisfactorily regardless of the number of targets. In this section, we discuss the children's behaviors based on observations, implications, and other topics.

6.1 Implications of experiment results

In this study, we prepared competing predictions toward children's activities during storytelling, and the experiment results supported the prediction about discouraging speech activities. This effect happened regardless of the number of children, although multiple children more talked to each other.

One of the possible reasons why children decreased their speech activities is that the multiple robots changed children's roles via storytelling, as discussed in the above section. Children basically observed and listened to the storytelling or conversations between the robots as side-participants; therefore, their speech activities would be decreased.

On the other hand, the number of robots significantly increased the children's preferences and their touch behaviors toward the robots. Physical interaction did not disturb storytelling in our setting then they could touch the robots during storytelling. Such physical interaction might have positive effects on their preferences. Still, it is difficult to estimate why children touched the robots more in the *two-robots* style. Their roles in the storytelling (i.e., side-participant) may be related to their behavior changes. For example, becoming a side-participant role may decrease their cognitive load to understand the story, and then it may increase their additional playful behaviors. Such behavior changes in children during interaction would be one interesting future work.

6.2 Design implications for application perspective

This study provides several design implications for the application perspective. First, the *two-robots* style was preferred significantly more than the *single-robot* style. In other words, the children preferred storytelling with two robots more than with just one. Our results and those of past work indicate that the *two-robots* style attracts people's interest in a robot's contents, regardless of the ages of the participants.

Second, our experimental results showed that the *two-robots* style discouraged the children's speech activities more during the storytelling regardless of the number of children than in the *single-robot* style. From a storytelling perspective, this phenomenon has both positive and negative effects. Decreasing the speech activities of children might focus more on their interest in the storytelling itself. On the other hand, this effect might discourage active participation in storytelling, relegating the children to passive participants.

Related to discouraging speech activities, their touch interaction activities showed an interesting phenomenon. One possible explanation for fewer speech activities is because of the perceived tension caused by the number of robots, but the children showed more touch interactions with two robots than just one; if they felt the tension, they might touch the robots less. Investigation about the relationship between touch and speech activities would be one interesting future work, which is not covered in this study.

Based on these considerations, the appropriate interaction style for storytelling should reflect a particular purpose. If a user wants children to participate actively, the *single-robot* style might be more appropriate. If a user wants children to listen quietly, perhaps during a kindergarten event, the *two-robots* style might be better. But in such situations, the robots need to respond to touch interactions from the children during the storytelling to avoid disturbing the storytelling due to continuous touches.

6.3 Toward (semi-) autonomous storytelling

In this study, we employed a semi-autonomous storytelling-robot system due to the difficulties of smooth and natural conversations in real environments with young children: speech recognition and unpredictable questions. For the former, past studies reported that the success rate of current speech recognition systems is only 21.3% [53] in real environments, and children's speech recognition also remains difficult [18]. For the latter, children often ask a wide range of questions to test the capabilities of robots [48]. Even if their questions are not related to the storytelling contents, ignoring or dismissing them is generally unacceptable and will discourage their interest. To improve the performance of speech recognition for the wide range of questions asked by children, more data collection and training are needed.

In addition, storytelling robots need the capability of detecting touches from children. In the first stage, we did not assume that children would touch the robots during the storytelling, but our experimental results showed that they often touched them when the number of robots was two. Using a touch sensor to cover the robot's body might be useful, and past studies already proposed various approaches to detect touches from people using whole-body touch sensors [54, 55]. Another approach is acceleration sensors that detect the body movements of the robots. This approach was also used to understand the physical interaction between robots and people [56] and robots and their environments [57].

Another perspective is to involve a human operator actively to realize semi-autonomous storytelling with multiple places. In this study, a human-operator only controlled one storytelling robot system. However, past studies reported that the semi-autonomous system could decrease the workload of an operator [58], and such an approach can enable them to control multiple robots simultaneously [53, 59]. Therefore, if this storytelling system can call the operator when only the system needs help, the operator's workload can be decreased too. If one operator can control multiple storytelling systems simultaneously, the cost-effectiveness and robustness toward child-robot interaction compared to a fully autonomous system would have advantages.

6.4 Limitations

This study has several limitations since it was conducted with our robot system and its specific settings, e.g., only using one kind of robot (Sota) to investigate the effects of storytelling with our gaze control models. Since we only investigated the participation of one or two children, adding more children might increase speech activities. Moreover, even though measuring subjective impressions from young children is difficult, more objective analysis is needed.

In our study, we used a listener robot that asks the reader robot questions, and so the total amount of information provided during the storytelling was different between the conditions. In addition, we only compared the effects of different roles using robots without focusing on people and/or virtual agents.

Another limitation is the roles of the robots. In this study, we assigned a reader and a listener for robots, but we did not investigate the effects of multiple readers and listeners. Adding more robots might decrease children's speech activities more by following our results, but it is not investigated yet. In addition, we did not investigate the effects of a role-playing style, e.g., robots behave as characters of the story. In reality, such a storytelling style is available to human readers. Investigating such a style would provide rich knowledge in the context of developing a storytelling robot system, although it is out of scope in this study.

However, we believe that our setting is satisfactory to offer knowledge to readers who are interested in child-robot interaction and storytelling in a *two-robots* style.

7 **Conclusion**

Understanding the effects of interaction styles during storytelling for children is essential for child-robot interaction. We investigated the effects of an interactive-social medium design of storytelling for children. We developed a semi-autonomous storytelling-robot system and experimentally investigated the effects of the numbers of robots on children's activities during storytelling.

Our experiment results showed that the number of children significantly affected the speech activities, i.e., their speech activities significantly decreased with two robots compared to just one. On the other hand, using two robots encouraged touch-based interaction activities from the children. Taken together, these experimental results suggest that the appropriate interaction style for storytelling should reflect different storytelling purposes and situations.

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References

[1] Y. Tamura, M. Kimoto, M. Shiomi, T. Iio, K. Shimohara, and N. Hagita, "Effects of a Listener Robot with Children in Storytelling," in Proceedings of the 5th International Conference on Human Agent Interaction, Bielefeld, Germany, pp. 35-43, 2017.

[2] R. Isbell, J. Sobol, L. Lindauer, and A. Lowrance, "The effects of storytelling and story reading on the oral language complexity and story comprehension of young children," *Early childhood education journal,* vol. 32, no. 3, pp. 157-163, 2004.

[3] F. Collins, "The use of traditional storytelling in education to the learning of literacy skills," *Early Child Development and Care,* vol. 152, no. 1, pp. 77-108, 1999.

[4] F. Van Gils, "Potential applications of digital storytelling in education," in 3rd twente student conference on IT, pp., 2005.

[5] M. Roussou, "Learning by doing and learning through play: an exploration of interactivity in virtual environments for children," *Computers in Entertainment (CIE),* vol. 2, no. 1, pp. 10-10, 2004.

[6] M. U. Bers, and J. Cassell, "Interactive storytelling systems for children: Using technology to explore language and identity," *Journal of Interactive Learning Research,* vol. 9, no. 2, pp. 183, 1998.

[7] H. Alborzi, A. Druin, J. Montemayor, M. Platner, J. Porteous, L. Sherman, A. Boltman, G. Taxén, J. Best, and J. Hammer, "Designing StoryRooms: interactive storytelling spaces for children," in Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques, pp. 95-104, 2000.

[8] J. A. Fails, A. Druin, and M. L. Guha, "Interactive storytelling: Interacting with people, environment, and technology," *International Journal of Arts and Technology,* vol. 7, no. 1, pp. 112-124, 2014.

[9] M. Fridin, "Storytelling by a kindergarten social assistive robot: A tool for constructive learning in preschool education," *Computers & education,* vol. 70, pp. 53-64, 2014.

[10] J. Kory, and C. Breazeal, “Storytelling with robots: Learning companions for preschool children's language development,” in Robot and Human Interactive Communication, 2014 RO-MAN: The 23rd IEEE International Symposium on, pp. 643-648, 2014.

[11] G. Gordon, S. Spaulding, J. Kory Westlund, J. J. Lee, L. Plummer, M. Martinez, M. Das, and C. Breazeal, “Affective Personalization of a Social Robot Tutor for Children’s Second Language Skills,” in Thirtieth AAAI Conference on Artificial Intelligence, pp., 2016.

[12] N. Fourati, A. Richard, S. Caillou, N. Sabouret, J.-C. Martin, E. Chanoni, and C. Clavel, "Facial Expressions of Appraisals Displayed by a Virtual Storyteller for Children," *Intelligent Virtual Agents: 16th International Conference, IVA 2016, Los Angeles, CA, USA, September 20–23, 2016, Proceedings*, D. Traum, W. Swartout, P. Khooshabeh *et al.*, eds., pp. 234-244, Cham: Springer International Publishing, 2016.

[13] I. Leite, M. McCoy, M. Lohani, D. Ullman, N. Salomons, C. Stokes, S. Rivers, and B. Scassellati, “Emotional Storytelling in the Classroom: Individual versus Group Interaction between Children and Robots,” in Proceedings of the Tenth Annual ACM/IEEE International Conference on Human-Robot Interaction, Portland, Oregon, USA, pp. 75-82, 2015.

[14] I. Leite, M. McCoy, M. Lohani, D. Ullman, N. Salomons, C. Stokes, S. Rivers, and B. Scassellati, “Narratives with robots: The impact of interaction context and individual Differences on story recall and emotional Understanding,” *Frontiers in Robotics and AI*, vol. 4, pp. 29, 2017.

[15] D. Sakamoto, K. Hayashi, T. Kanda, M. Shiomi, S. Koizumi, H. Ishiguro, T. Ogasawara, and N. Hagita, “Humanoid Robots as a Broadcasting Communication Medium in Open Public Spaces,” *International Journal of Social Robotics*, vol. 1, no. 2, pp. 157-169, 2009.

[16] E. Goffman, *Forms of talk*: University of Pennsylvania Press, 1981.

[17] H. H. Clark, *Using Language*: Cambridge University Press, 1996.

[18] J. Kennedy, v. Lemaignan, C. Montassier, P. Lavalade, B. Irfan, F. Papadopoulos, E. Senft, and T. Belpaeme, “Child Speech Recognition in Human-Robot Interaction: Evaluations and Recommendations,” in Proceedings of the 2017 ACM/IEEE International Conference on Human-Robot Interaction, Vienna, Austria, pp. 82-90, 2017.

[19] I. R. Nourbakhsh, C. Kunz, and T. Willeke, “The mobot museum robot installations: A five year experiment,” in IEEE/RSJ International Conference on Intelligent Robots and Systems, 2003.(IROS 2003). , pp. 3636-3641, 2003.

[20] M. Shiomi, K. Shinozawa, Y. Nakagawa, T. Miyashita, T. Sakamoto, T. Terakubo, H. Ishiguro, and N. Hagita, “Recommendation Effects of a Social Robot for Advertisement-Use Context in a Shopping Mall,” *International Journal of Social Robotics*, vol. 5, no. 2, pp. 251-262, 2013.

[21] H.-M. Gross, H. Boehme, C. Schroeter, S. Müller, A. König, E. Einhorn, C. Martin, M. Merten, and A. Bley, “TOOMAS: interactive shopping guide robots in everyday use-final implementation and experiences from long-term field trials,” in Intelligent Robots and Systems, 2009. IROS 2009. IEEE/RSJ International Conference on, pp. 2005-2012, 2009.

[22] M. Shiomi, T. Kanda, H. Ishiguro, and N. Hagita, “Interactive Humanoid Robots for a Science Museum,” *IEEE Intelligent Systems*, no. 2, pp. 25-32, 2007.

[23] B. Mutlu, T. Kanda, J. Forlizzi, J. Hodgins, and H. Ishiguro, “Conversational gaze mechanisms for human-like robots,” *ACM Transactions on Interactive Intelligent Systems (TiiS)*, vol. 1, no. 2, pp. 12, 2012.

[24] A. Yamazaki, K. Yamazaki, Y. Kuno, M. Burdelski, M. Kawashima, and H. Kuzuoka, “Precision timing in human-robot interaction: coordination of head movement and utterance,” in Proceeding of the twenty-sixth annual SIGCHI conference on Human factors in computing systems, Florence, Italy, pp. 131-140, 2008.

[25] B. Mutlu, J. Forlizzi, and J. Hodgins, “A storytelling robot: Modeling and evaluation of human-like gaze behavior,” in The 6th IEEE-RAS international conference on Humanoid robots, pp. 518-523, 2006.

[26] Y. Hato, S. Satake, T. Kanda, M. Imai, and N. Hagita, “Pointing to space: modeling of deictic interaction referring to regions,” in Human-Robot Interaction (HRI), 2010 5th ACM/IEEE International Conference on, pp. 301-308, 2010.

[27] T. Komatsubara, M. Shiomi, T. Kanda, and H. Ishiguro, “Can Using Pointing Gestures Encourage Children to Ask Questions?,” *International Journal of Social Robotics*, vol. 10, no. 4, pp. 387-399, 2017.

[28] F. Yamaoka, T. Kanda, H. Ishiguro, and N. Hagita, “A model of proximity control for information-presenting robots,” *IEEE Transactions on Robotics*, vol. 26, no. 1, pp. 187-195, 2010.

[29] C. Shi, M. Shiomi, T. Kanda, H. Ishiguro, and N. Hagita, “Measuring Communication Participation to Initiate Conversation in Human–Robot Interaction,” *International Journal of Social Robotics*, vol. 7, no. 5, pp. 889-910, 2015.

[30] S. Satake, T. Kanda, D. F. Glas, M. Imai, H. Ishiguro, and N. Hagita, “A robot that approaches pedestrians,” *IEEE Transactions on Robotics*, vol. 29, no. 2, pp. 508-524, 2013.

[31] M. Gharbi, P. V. Paubel, A. Clodic, O. Carreras, R. Alami, and J. M. Cellier, “Toward a better understanding of the communication cues involved in a human-robot object transfer,” in Robot and Human Interactive Communication (RO-MAN), 2015 24th IEEE International Symposium on, pp. 319-324, 2015.

[32] C. Shi, M. Shiomi, C. Smith, T. Kanda, and H. Ishiguro, “A Model of Distributional Handing Interaction for a Mobile Robot,” in Robotics: Science and Systems, pp., 2013.

[33] M. K. Lee, S. Kiesler, and J. Forlizzi, "Receptionist or information kiosk: how do people talk with a robot?," in Proceedings of the 2010 ACM conference on Computer supported cooperative work, Savannah, Georgia, USA, pp. 31-40, 2010.
[34] S. Satake, K. Hayashi, K. Nakatani, and T. Kanda, "Field trial of an information-providing robot in a shopping mall," in The IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2015) pp. 1832-1839, 2015.
[35] T. Iio, Y. Yoshikawa, and H. Ishiguro, "Pre-scheduled Turn-Taking between Robots to Make Conversation Coherent," in Proceedings of the Fourth International Conference on Human Agent Interaction, Biopolis, Singapore, pp. 19-25, 2016.
[36] L. P. E. Toh, A. Causo, P. W. Tzuo, I.-M. Chen, and S. H. Yeo, "A Review on the Use of Robots in Education and Young Children," *Educational Technology & Society,* vol. 19, no. 2, pp. 148-163, 2016.
[37] A. Powers, S. Kiesler, S. Fussell, and C. Torrey, "Comparing a computer agent with a humanoid robot," in Human-Robot Interaction (HRI), 2007 2nd ACM/IEEE International Conference on, pp. 145-152, 2007.
[38] K. Shinozawa, F. Naya, J. Yamato, and K. Kogure, "Differences in effect of robot and screen agent recommendations on human decision-making," *International Journal of Human-Computer Studies,* vol. 62, no. 2, pp. 267-279, 2005.
[39] H. W. Park, M. Gelsomini, J. J. Lee, and C. Breazeal, "Telling stories to robots: The effect of backchanneling on a child's storytelling," in Proceedings of the 2017 ACM/IEEE international conference on human-robot interaction, pp. 100-108, 2017.
[40] M. Vázquez, A. Steinfeld, S. E. Hudson, and J. Forlizzi, "Spatial and other social engagement cues in a child-robot interaction: Effects of a sidekick," in Proceedings of the 2014 ACM/IEEE international conference on Human-robot interaction, pp. 391-398, 2014.
[41] E. S. Short, K. Swift-Spong, H. Shim, K. M. Wisniewski, D. K. Zak, S. Wu, E. Zelinski, and M. J. Matarić, "Understanding social interactions with socially assistive robotics in intergenerational family groups," in Robot and Human Interactive Communication (RO-MAN), 2017 26th IEEE International Symposium on, pp. 236-241, 2017.
[42] T. Komatsubara, M. Shiomi, T. Kanda, H. Ishiguro, and N. Hagita, "Can a social robot help children's understanding of science in classrooms?," in Proceedings of the second international conference on Human-agent interaction, Tsukuba, Japan, pp. 83-90, 2014.
[43] H. Arai, M. Kimoto, T. Iio, K. Shimohara, R. Matsumura, and M. Shiomi, "How Can Robot's Gaze Ratio and Body Direction Show an Awareness of Priority to the People with whom it is Interacting?," *IEEE Robotics and Automation Letters,* vol. 4, no. 4, pp. 3798-3805, 2019.
[44] N. Dahlbäck, A. Jönsson, and L. Ahrenberg, "Wizard of Oz studies: why and how," in Proceedings of the 1st international conference on Intelligent user interfaces, Orlando, Florida, USA, pp. 193-200, 1993.
[45] T. Kanda, H. Ishiguro, T. Ono, M. Imai, and K. Mase, "Multi-robot cooperation for human-robot communication," in Robot and Human Interactive Communication, 2002. Proceedings. 11th IEEE International Workshop on, pp. 271-276, 2002.
[46] N. Karatas, S. Yoshikawa, P. R. S. De Silva, and M. Okada, "Namida: Multiparty conversation based driving agents in futuristic vehicle," in International Conference on Human-Computer Interaction, pp. 198-207, 2015.
[47] T. Iio, Y. Yoshikawa, and H. Ishiguro, "Retaining Human-Robots Conversation: Comparing Single Robot to Multiple Robots in a Real Event," *Journal of Advanced Computational Intelligence Intelligent Informatics,* vol. 21, no. 4, pp. 675-685, 2017.
[48] M. Shiomi, T. Kanda, I. Howley, K. Hayashi, and N. Hagita, "Can a Social Robot Stimulate Science Curiosity in Classrooms?," *International Journal of Social Robotics,* vol. 7, no. 5, pp. 641-652, 2015.
[49] Y. Matsuyama, I. Akiba, A. Saito, and T. Kobayashi, "A Four-Participant Group Facilitation Framework for Conversational Robots," in Proceedings of the SIGDIAL 2013 Conference, pp. 284-293, 2013.
[50] B. Mutlu, T. Shiwa, T. Kanda, H. Ishiguro, and N. Hagita, "Footing in human-robot conversations: how robots might shape participant roles using gaze cues," in Proceedings of the 4th ACM/IEEE international conference on Human robot interaction, pp. 61-68, 2009.
[51] M. Lombard, J. Snyder‐Duch, and C. C. Bracken, "Content analysis in mass communication: Assessment and reporting of intercoder reliability," *Human Communication Research,* vol. 28, no. 4, pp. 587-604, 2002.
[52] J. Cohen, "A coefficient of agreement for nominal scales," *Educational and psychological measurement,* vol. 20, no. 1, pp. 37-46, 1960.
[53] M. Shiomi, D. Sakamoto, T. Kanda, C. T. Ishi, H. Ishiguro, and N. Hagita, "Field Trial of a Networked Robot at a Train Station," *International Journal of Social Robotics,* vol. 3, no. 1, pp. 27-40, 2010.
[54] S. Yohanan, and K. E. MacLean, "The role of affective touch in human-robot interaction: Human intent and expectations in touching the haptic creature," *International Journal of Social Robotics,* vol. 4, no. 2, pp. 163-180, 2012.
[55] G. Huisman, "Social Touch Technology: A Survey of Haptic Technology for Social Touch," *IEEE Transactions on Haptics,* vol. 10, no. 3, pp. 391-408, 2017.
[56] R. Matsumura, M. Shiomi, T. Miyashita, H. Ishiguro, and N. Hagita, "Who is Interacting With me?; Identification of an Interacting Person Through Playful Interaction With a Small Robot," *IEEE Transactions on Human-Machine Systems,* vol. 44, no. 2, pp. 169-179, 2014.
[57] R. Matsumura, M. Shiomi, T. Miyashita, H. Ishiguro, and N. Hagita, "What kind of floor am I standing on? Floor surface identification by a small humanoid robot through full-body motions," *Advanced Robotics,* 2015.

[58] K. Wada, D. F. Glas, M. Shiomi, T. Kanda, H. Ishiguro, and N. Hagita, "Capturing Expertise: Developing Interaction Content for a Robot Through Teleoperation by Domain Experts," *International Journal of Social Robotics,* vol. 7, no. 5, pp. 653-672, 2015.

[59] D. F. Glas, T. Kanda, H. Ishiguro, and N. Hagita, "Teleoperation of multiple social robots," *IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans,* vol. 42, no. 3, pp. 530-544, 2011.

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