Two is Better Than One: Verification of the Effect of Praise from Two Robots on Pre-school Children’s Learning Time

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This paper reports the effects of praise from two robots on children's learning time, their performance, and their acceptance of the robots. Since praise from a single robot provides positive effects for children as educational support, we hypothesized that praise from two robots will increase such effects because two robots will enhance the social influences. To verify this hypothesis, we developed an English learning system that consisted of an e-learning application, a depth sensor for human-tracking, a tabletop humanoid robot, a doll-type robot, and an operator. We designed the robots to interactively praise children during their learning situations and experimented with a with-in participant design to compare the effects of praise from two robots and just one. 22 children participated in an experiment whose results showed that children learned more when two robots praised them than just one, even with an identical amount of praise. These results suggest the effectiveness and empirical evidence of using two robots for educational support.

Keywords: Human-Robot Interaction, Education support, Children, Social reward, Praise

1. Introduction

Building educational-support systems with social robots for children is a burgeoning research topic in human-robot interaction [1]. One main difficulty for educational support is keeping children to learn. To solve this problem, several studies in human science literature have focused on model-based approaches, e.g., the Attention, Relevance, Confidence, and Satisfaction (ARCS) model of motivation from an educational technology perspective [2] and the Dick and Carey Model [3] from an instructional system perspective for designing e-learning contents. Researchers are already using these models to design educational-support robot systems and have reported their effectiveness for educational support and designing e-learning contents [4-6].

To keep children motivated to learn, robotics researchers have focused on model-based approaches and the interaction styles of social robots used in educational support. For example, several studies developed a social robot to promote rest times and increase the growth mindsets for children during self-teaching to maintain their learning motivation [7-9]. Other studies used multiple robots to play roles during storytelling to attract children's attention [10-12]. Several studies focused on the actual settings in learning situations, i.e., installing social robots in elementary schools to support English learning and stimulating interest in Science, Technology, Engineering, and Mathematics (STEM) contexts [13-15].

In this study, we focused on the effect of praise because it is an essential social reward to increase children's learning time. Several studies have investigated the effect of praise from teachers on children [16-18]. For example, a past study conducted an experiment with more than one hundred children from the classes of Grades IV and VI at USA and reported that praise from teachers positively affected the learning attitudes of children [19]. In past studies related to robot educational-support systems, some researchers incorporated praise contents in robot behavior design [9, 20, 21]. These studies described the positive elements of praise, even if they did not exclusively investigate its effects on educational support for children.

We are interested in how the number of robots affects such praise to increase the praise effects in the context of encouraging children to learn. More robots generally increase the social influence on people's feelings and their behavioral changes [22-24]. A recent study reported that children are more influenced by the number of robots than adults [25]. Another described the effectiveness of praise from multiple robots in the context of offline motor skill improvements [26]. Based on these results, we hypothesized that such effects will occur in the context of educational support: praise from two robots will exert more influence on children's learning time than praise from a single robot.

Therefore, we investigated the effectiveness of using two robots that praise children in the context of educational support by developing a system whose robots praise children during learning. We employed an English learning system because learning English as a second language is a popular activity in Japan. We conducted experiments where children learned English with a GUI-based learning support system to investigate whether their learning increased due to the number of robots (Fig. 1) and investigated the following research question:

- Does praise from two robots increase children's learning time more than praise from just one robot?

Fig. 1 Child learns English with two robots

2. RELATED WORKS

Past studies have broadly investigated the effectiveness of educational-support robot systems [1]. Several investigated the effects of praise from an artificial agent and two or more robots. In this section, we overview related works about educational support and focus on two topics that are related to this study's aims: praise effects and using two robots. Finally, we summarize the positions of our study.

2.1 Educational-support robot systems

Due to the importance of educational support for children, various robotics researchers have investigated the effectiveness of social robots [1]. One advantage of using them for educational support is that children can physically communicate with them. For example, gestures are critical in educational support because they elicit speech and improve performances [14, 15]. The physicality of robots creates advantages for providing more information than computer-graphics-based agents [27]. Other studies focused on the physicality of robots in the context of direct manipulation for such educational support as handwriting [28], shooting free throws [29], or encouraging physical exercise during breaks from learning [7, 8]. From another perspective, implementing the perceptions of such human activities as gestures is also essential for educational robots [14, 30]. These studies described the effectiveness of social robots for educational purposes based on laboratory experiments.

Field trials in actual environments, i.e., installing social robots in kindergartens and elementary schools, are also active research approaches in human-robot interaction research fields. For example, some studies placed social robots in schools to investigate whether they increase children's motivation and performance to support the learning of English [31, 32]. Another study installed a social robot to stimulate children's interest in science in STEM education contexts [33]. Robotics researchers are interested in how a social robot influences the behaviors of children. Another past study placed a social robot in a kindergarten and described how children treated it on long field trials [34].

However, these studies focused less on the effects of praise from two or more robots in an educational-support context. Below we discuss related works on the effects of praise and using two or more robots. Table 1 lists the typically related works by considering the educational-support context.

Table 1 Summary of related works that correspond to two or more categories

Author	Ages of participants	Educational support	Praise effects	Two or more robots
Komatsubara et al., 2014 [20]	10-11	✓	✓ (a part of)	-
Leite et al., 2014 [21]	8-9	✓ (playing games)	✓ (a part of)	
Park et al., 2017 [9]	5-9	✓	✓ (a part of)	-
Davison et al., 2020 [51]	6-10	✓	✓ (a part of)	
Leite et al., 2015 [11]	6-8	✓ (storytelling)		✓
Tamura et al., 2017 [12]	3-5	✓ (storytelling)		✓
Iio et al., 2017 [23]	Visitors to museum (10-50)	✓ (a part of)		✓
Khalifa et al., 2018 [53]	University students	✓		✓
Shiomi et al., 2020 [26]	University students	-	✓	✓
This study	**4 to 6**	**✓**	**✓**	**✓**

2.2 Praise effects from artificial agents

Praise is a fundamental social reward in human-human interaction [35]. Human science literature has reported a wide variety of positive effects, including self-efficacy

[36], improving motivation [37, 38], raising academic self-concepts [39], promoting pleasure [40], improving skill and task performance [38, 39], raising academic performances [17, 19, 41], and honing motor skills [42, 43]. Such social beings as robots and computer agents can also praise humans [44-46]. Past studies described the positive impressions and performance improvements from social beings [47-50].

As shown in Table 1, several studies reported praise effects through experiments with social robots for educational support [11, 20, 21, 51]. Although they used praise from robots as an element of conversational contents, they focused on such different topics as the robot's existence and concluded that it was less effective [51]. These studies varied the effectiveness of the praise from robots/computer agents and provided rich knowledge about the possibilities that praise can influence people's behaviors and increase the perceived positive impressions from them. However, these studies focused less on the effects of praise from two or more robots in the context of encouraging children to learn.

2.3 Effects of multiple social robots in human-robot interaction

People's behaviors are often influenced by the opinions of others, and the strength of such effects often increases due to the particular number of others. Robotics researchers investigated the effects of the number of robots on behavior changes, i.e., conformity effects from multiple robots [24, 52] and effective information-providing tasks in real environments [22]. A recent study revealed that children are more influenced by the number of robots than adults [25].

Several studies investigated the positive effects of two or more robots in such education contexts as storytelling for children [11] [12], educational support for science [23], and an educational-support robot system for university students [53]. These studies gathered essential knowledge about social effects and the power of multiple robots. Unfortunately, they insufficiently focused on the praise effects from two or more robots.

2.4 Praise effects from multiple robots

To the best of our knowledge, only one past study has focused on the effects of praise from two robots [26]. In a context of offline motor skill improvements, that study conducted a two-day experiment to investigate whether praise from two robots enhanced the consolidation process of adult participants. It concluded that praise from two robots has more positive effects than praise from one robot. However, the effect of the number of robots who praise remains unknown in the context of educational-support contexts for children.

2.5 Position of this study

As summarized in Table 1, previous studies on educational-support robot systems reported their effectiveness in various experiments with children. Such studies on praise from agents described how it changed behaviors and impressions. Still, these studies focused less on praise from two or more agents in the context of educational support. The unique point of our study is its investigation of the effectiveness of praise from two robots in the context of an English learning system for children.

Another unique point is to focus on both motivation improvement and performance improvements for younger children participants, because we thought that the main difficulty in younger children's learning compared to adults' learning is motivation improvement. For example, past studies with adults [26, 53, 54] and relatively older children [20, 55, 56] mainly focused on task performance improvement within a certain learning time period (e.g., during experiment sessions or school classes). Therefore, the developed systems in these studies are designed to increase performance effectively and implicitly assume that participants can keep learning during the limited time period.

For young children, on the other hand, it is relatively difficult to maintain their motivation to learn. For this reason, past studies with younger children [7-9] have also focused on motivation improvement for studying because it is directly related to task performance improvement. Our study focused on praise effects from multiple robots to both increase motivation and improve performance.

3. Proposed system

Figure 2 shows the architecture of our developed system, which consists of an English e-learning application, a human-tracking system with a depth sensor, a tabletop-sized humanoid robot, a doll-type robot, and an operator as a speech recognizer. The application sends the correct/wrong information about the children's answers to the behavior controller to decide the praise contents from the robots. The tracking system and the speech recognizer send the children's position information and their recognized speech to the behavior controller to control the behaviors of the humanoid robot. The following are the details of each system.

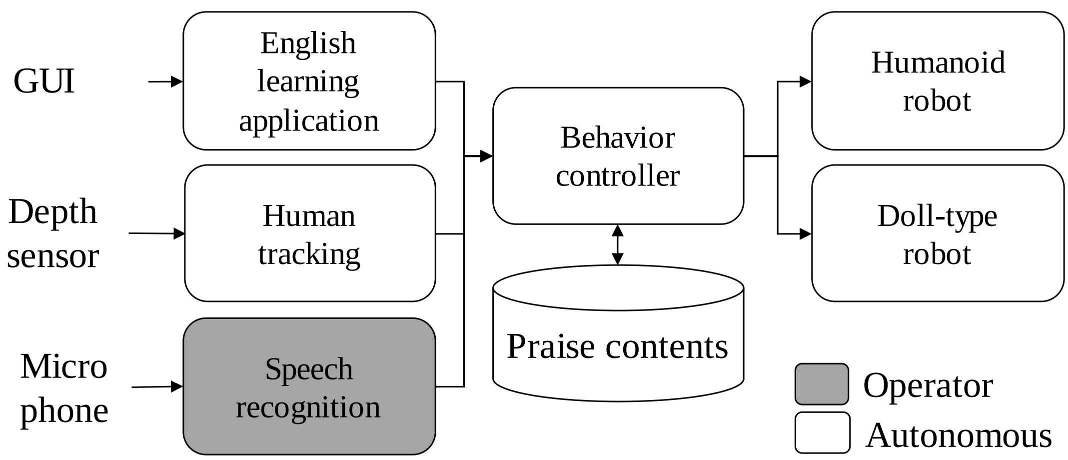

Fig. 2 System configuration

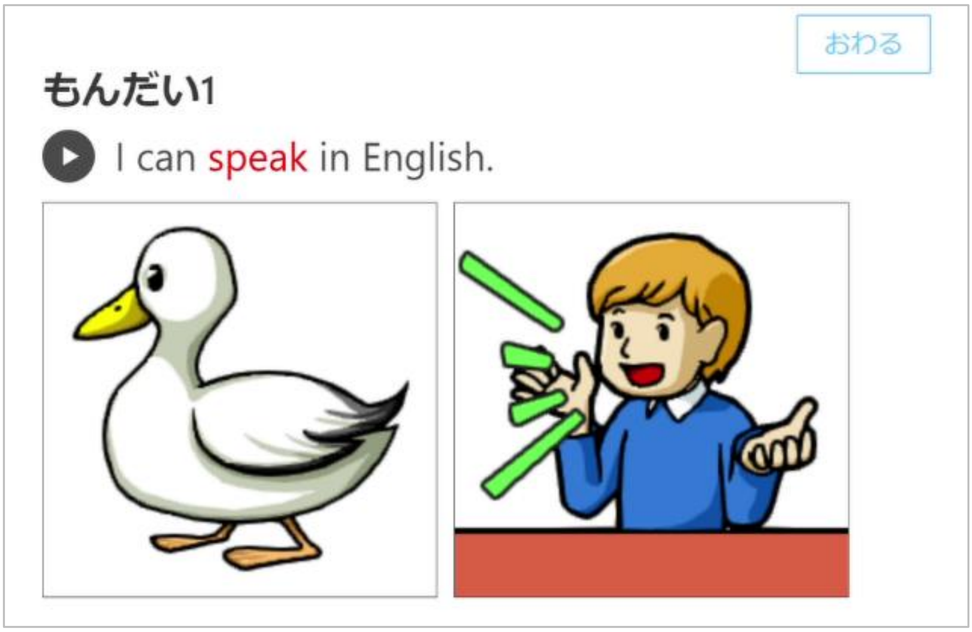

Fig. 3 Touch-based GUI for our e-learning system. Children can hear English questions by repeatedly pressing the play button. They answer by touching the image. Blue button in upper-right corner ends the system.

3.1 English e-learning application

We implemented a simple touch-based GUI to select English words by listening and reading English text (Fig. 3) using JavaScript. Children answer questions by touching the image shown on a screen. We prepared 60 questions, each of which consisted of speech content, a text, and two images. The speech contents and the images are part of an English e-learning system named ATR CALL, which was developed to examine the learning process of second language speech and has been used in several studies [57-60] and supports listening, talking, reading, and writing. The system records the touch logs of children and their working times for analysis.

3.2 Human-tracking system

We used a Kinect V2 sensor to track the head positions of the children in the experiment. The tracking system sends their position information to the humanoid robot to control its face and body orientation, because such non-verbal information is important for smooth and natural interactions between robots and people [61].

3.3 Tabletop-sized humanoid robot

The humanoid robot explains the experiment to the children and praises them. We used such a humanoid robot as host because it has minimum capabilities for such gestures as pointing and eye-contact, which are essential to maintain joint attention in human-robot interaction [62].

We used Sota (Fig. 4), which has three DOFs in its head, two DOFs in its shoulders, two in its elbows, and one in its base. It is 28 cm tall with both network connection and voice synthesis functions. It has a function that links its mouth's LED based on the sound level to indicate when it is talking. The robot always faces the children using position information from the human-tracking system.

3.4 Doll-type robot

In this study, we used a different-type robot to investigate praise effects from multiple robots due to below reasons: 1) the children can easily understand that different robots are present and which is speaking, and 2) if using an additional robot that praises children for education support robot systems is a promising approach for existing education support systems, a cheap and simple robot, such as a simper doll-type robot and an additional wireless speaker, would be reasonable. For this reason, we used a teddy-bear robot with one DOF in its head and another in its mouth (Fig. 5). It has a microphone and a speaker. Its head and mouth automatically move due to the sound level to indicate when it is talking. In our system, the server system sends speech contents to its speaker by a network. We used *VOICEROID + TohokuZunko*[1] (AHS Co. Ltd.) as a speech synthesis function.

3.5 Operator

We used a human operator who assumed control of the timing of the starting/ending system and interrupting by following pre-determined rules (Wizard of Oz [63]) because accurate speech recognition for children's speech remains difficult [64]. The operator controlled the timing of the following conditions: 1) the robot's introduction at the beginning of the experiment; 2) the goodbye information at its conclusion; and 3) suggestions that the children touch an image to answer questions if they are inactive or reluctant during the experiment.

Fig. 4 Tabletop-sized humanoid robot

Fig. 5 Doll-type robot

[1] https://www.ah-soft.com/vocaloid/zunko/top.html

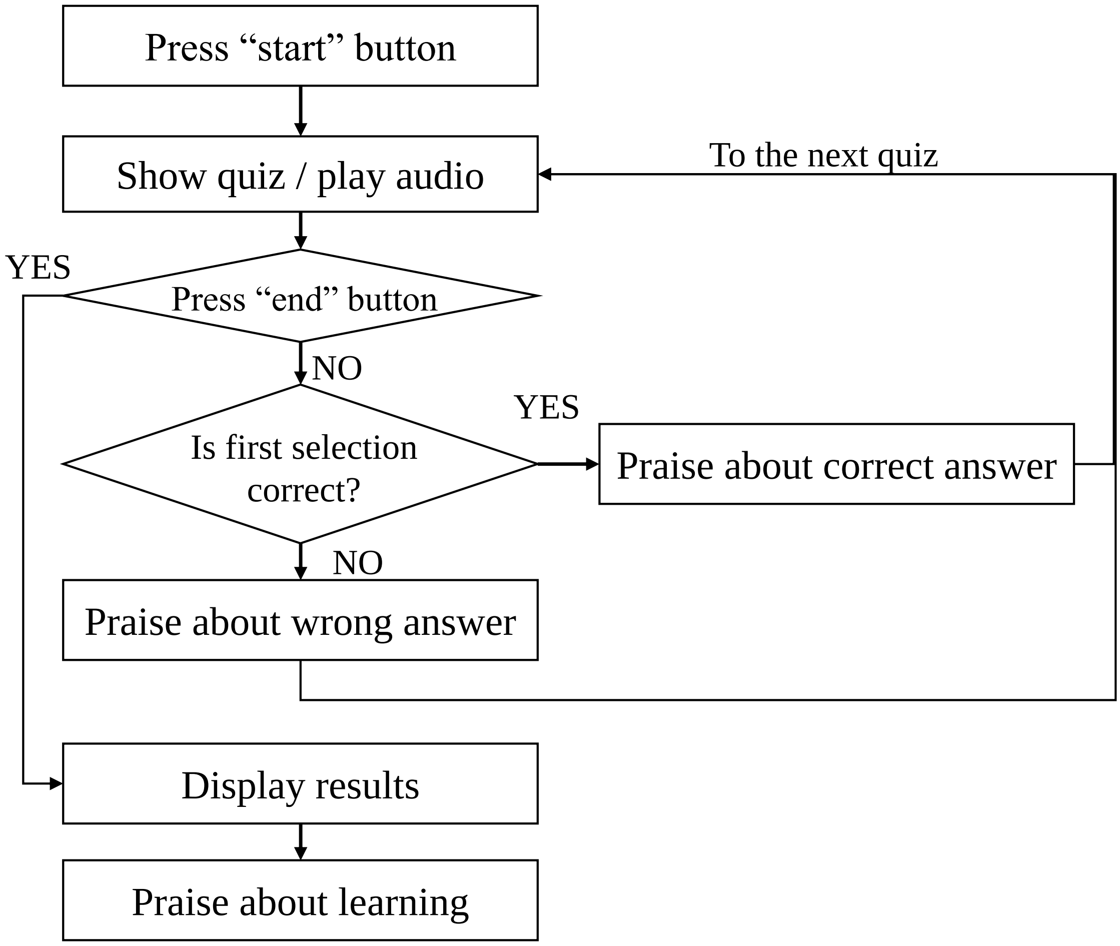

Fig. 6 Praise timing and the basic flow of the system during experiment

3.5 Praise contents

The robots praised the children when they 1) answered correctly, 2) answered incorrectly, and 3) completed the application as shown in Fig. 6. All the praise consisted of two sentences: "You're getting used to English, aren't you? You're working very hard" (when children answered correctly); "Don't worry about mistakes. Keep trying" (when they answered incorrectly); and "I think your answers are better than they were at the beginning. Your hard work is paying off" (when they completed the application). We prepared 40 praise sentences (20 for answering correctly, 10 for answering incorrectly, and 10 for finishing) and integrated two praise sentences into one praise comment. To avoid repeating the same sentence set, we changed the combinations of the sentences and their order when the robots praised the children. Thus, during the experiments, the robots and the English e-learning system are basically autonomous while the children are answering the questions.

4. Experiment

4.1 Hypotheses and predictions

Past studies reported that the effectiveness of social rewards produces such beneficial effects as motor skill improvements [26, 47-50]. People's behaviors are influenced by the number of interacting targets, i.e., since many people and agents have stronger social influence [22, 23]. Another study reported that children are more influenced by the number of robots than adults [25]. However, such effects in the context of educational-support robot systems haven't been scrutinized yet.

Based on these considerations, we hypothesized that praise from two robots will encourage more learning in children than praise from a single robot. As a result, children who are praised by two robots will use the English e-learning applications longer than children who are just praised by a single robot. In addition, we expected that more learning time will increase the number of correct answers. Therefore, we made the following predictions:

Prediction 1: Praise from two robots will increase the learning time of children more than praise from just a single robot.

Prediction 2: Praise from two robots will increase the scores of children more than praise from just a single robot.

4.2 Environment

Figure 7 shows our experimental environment. The room is about 40 m^2. We set the touch-panel display, placed the robots around it, and set a Kinect V2 behind it. The children sat on the floor to look at the display.

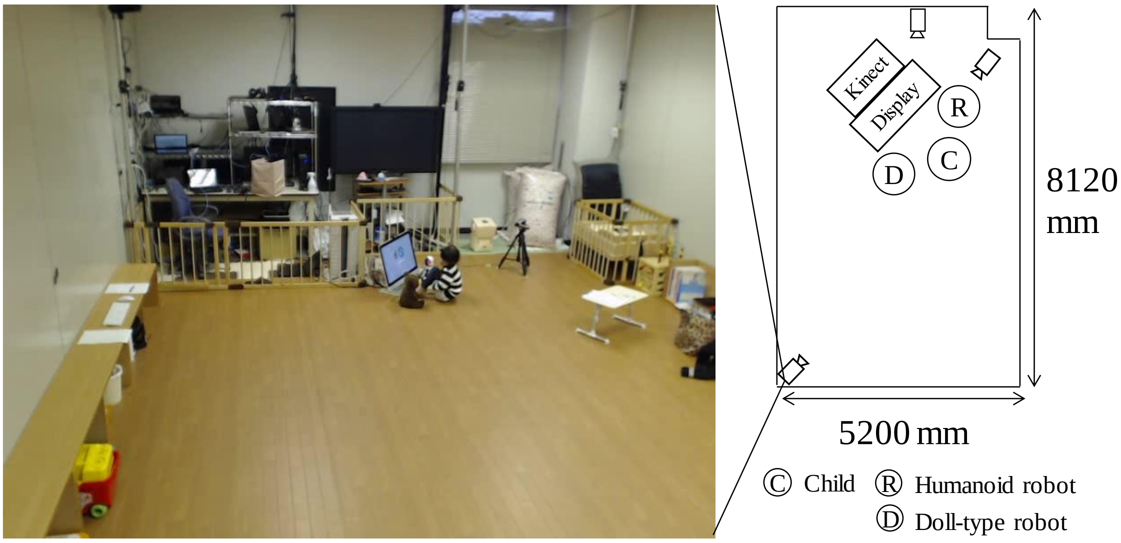

Fig. 7 Experiment environment

4.3 Conditions

This study had a within-participant design. All the participants experienced two trials: *single-robot* and *two-robot* conditions. We separated 60 questions into two sets of 30 and used a different question set for each condition. The experiment had two sessions; the order of the conditions and the question sets for each session was counterbalanced.

1) Single-robot condition: we only used the humanoid robot, i.e., the robot praised the children with two sentences. It praised them based on pre-defined rules as described in section 3.5.

2) Two-robot condition: we used both the humanoid and doll-type robots. All comments including two sentences were separately made by both robots. The speaking sequence was the same. The humanoid robot spoke first, followed by the doll-type robot.

4.4 Participants

Twenty-two children (11 girls and 11 boys from four to six years old, average age of 5.23, and S.D is 0.79) participated in our experiment. Their mothers observed in a separate room.

4.5 Procedure

Before the experiment session, the mothers received a brief description of our experiment's purpose and procedure. Its protocol was approved by our institutional review board, and all the mothers signed consent forms. First, the children practiced with the English e-learning system by answering three questions. After the practice session, the experimenter and the mothers left the experiment room, and the robot requested the children to click on the "start" button. They were free to finish the experiment at any time by clicking on the "end" button. At the end of the first session, the mothers and experimenter returned to the room, the children and their mothers were given a five-minute break. Then the experimenter and mothers again left the experiment room, and the second session began. They observed their children in the experiment room by cameras and microphones.

4.6 Measurements

In this experiment, we objectively measured the amount of learning time, the number of answered questions, the number of correct answers, and the rate of correct answers to measure their performances. The definition of the learning time is from when the children clicked "start" button and "end" button. We note that the time of utterances from the robots was the same between conditions. The children can answer the questions or finish the session by clicking buttons regardless of the robot's utterances; therefore, the time of utterance did not influence the learning time in a comparison between the conditions.

5 Results

5.1 Verification of prediction 1

Figure 8 shows the average learning time for the children in each condition, and Table 2 shows the average and median values. We performed the Kolmogorov-Smirnov test to check the normality of the results. Since the results were not normally distributed, we conducted a Wilcoxon signed-rank test instead of a paired t-test and found a significant difference among the conditions (z=2.191, p=0.028, r=0.47). Thus, prediction 1 was supported.

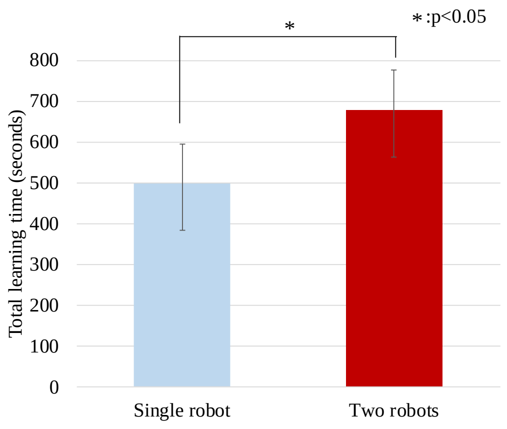

Fig. 8 Average learning time of children

Table 2 Average and median values of learning time

	Learning time (seconds)	
	Average	Median
Single robot	497.7	356.5
Two robots	678.3	479.5

5.2 Verification of prediction 2

Figures 9 and 10 show the number of answered questions and correct answers. We performed a Kolmogorov-Smirnov test to check the normality of the results. Since the results were not normally distributed, we conducted a Wilcoxon signed-rank test instead of a paired t-test and identified significant trends among the conditions for both the number of answered questions ($z=1.947$, $p=0.051$, $r=0.42$), the number of correct answers ($z=1.843$, $p=0.065$, $r=0.39$), and the rate of correct answers ($z=1.025$, $p=0.305$, $r=0.22$), but the differences were not significant. Thus, prediction 2 was not supported.

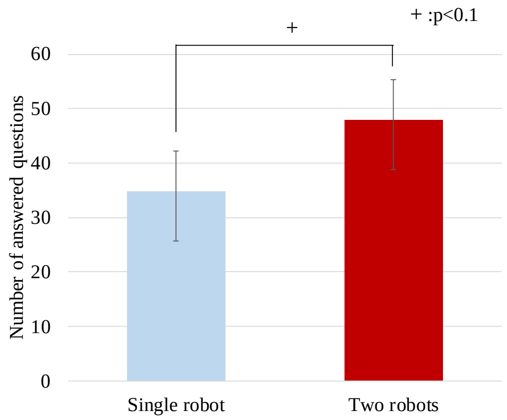

Fig. 9 Answered questions

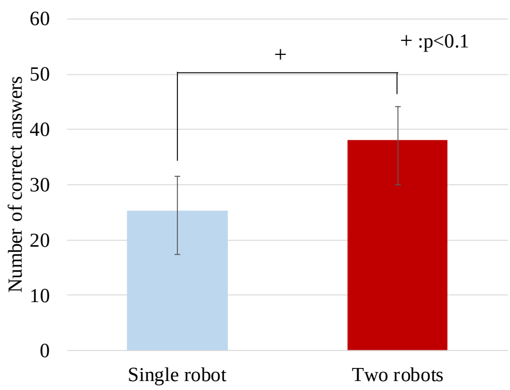

Fig. 10 Correct answers

Table 3 Average and median values of answered questions, correct answers and rate of correct answers

	Answered questions		Correct answers		Rate of correct answers (%)	
	Average	Median	Average	Median	Average	Median
Single robot	34.9	22.5	25.4	12.5	69.3	64.2
Two robots	48.0	33.5	38.0	26	74.7	81.2

5.3 Observations of children's behaviors

Based on increasing learning times and preferences, using an additional robot that praises children for education support robot systems is a promising approach to increase learning effects. In this sub-section, we described the results of observations of children during the experiment and the interview results with them and their parents.

In both conditions, the children's behaviors were basically similar. They quietly listened to the humanoid robot's explanations and answered the questions (Fig. 11). They often paid attention to the robots when they were talking and smiled when they were praised. A few children touched the heads of the humanoid robot and/or the doll-type robot when they praised the children (Fig. 12, left). Some hugged the doll-type robot during the experiment (Fig. 12, right).

In addition, we asked children and parents about their impressions of the robots. Most children preferred the doll-type robot (e.g., they said "The bear is cute," and "I felt lonely without the bear."), as well as their parents, For example, parental responses include "my child seemed to feel nervous in the front of the robot, but the bear robot is a doll, making it more acceptable;" "a trialogue style seems better for children than a one-to-one style." One child said, "I felt more praised when the bear was there," and a mother said, "my child was more motivated by praise from the two robots than from just a single robot." They felt this way even if the amount of praise was identical between the conditions.

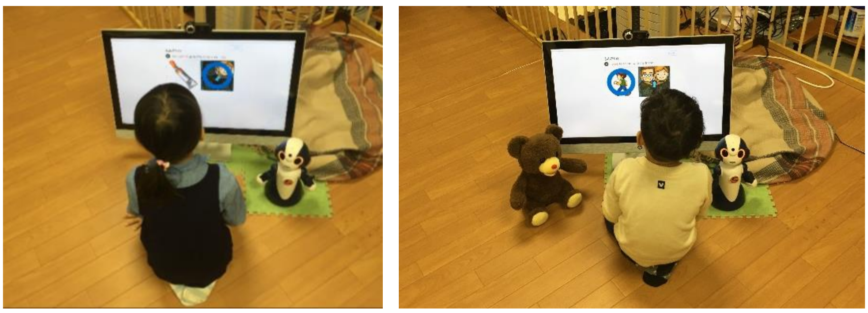

Fig. 11 Single-robot condition and two-robot condition

Fig. 12 Child pats humanoid robot and child hugs doll-type robot

6 Discussion

6.1 Application for schools

Our system enables children to learn more by praise from two robots. With this approach in school settings, e.g., if both a teacher and a robot praise children, they will learn more. A past study reported that social comparison is deleterious for children [17], and they prefer individual praise compared to praise in front of their peers [65]. Therefore, praise content should be carefully designed in such settings. Since related past studies mainly focused on praise situations for school-aged children at school, it is unknown whether toddlers also have similar feelings.

Our experiment has a self-study setting, and it didn't focus on praise contents in a social-comparison fashion. Our setting avoided such problems because the children were alone in the room with the robots. Although we believe that praise from two robots is effective for self-study settings with school-age children, its use should be scrutinized in different settings, such as classrooms.

6.2 Gender effects

This study did not investigate the gender effects because this paper investigates the praise effects and a past study that investigated the gender effects in praise effects, which reported no significant effects for gender [66]. In fact, past similar studies also did not evaluate gender effects, although the gender ratios of the participant children are not biased [9, 11, 21, 51]. As a reference, we conducted an ANOVA to investigate the gender effects for all measurements (learning time, answered the question, correct answers, and the ratio of correct answers), but all comparisons did not show any significant effects in gender effects.

However, several studies reported the reported gender differences in the context of second language learning, in particular the advantages of females [56] [54]. We note that these studies mainly focused on longer learning effects (i.e., not learning time and the number of answered questions) and relatively older people (i.e., children with more than nine years old or adults). Therefore, investigating the gender effects toward praises in the context of second language learning for younger children is not well investigated yet; it should be one interesting future work.

6.3 Robot group structure's effects

In this study, we only investigated the effects of the hetero robot group. Past studies that investigated the effects of multiple robots adopted both hetero and homo types (i.e., using the same robots or different robots), and they less focused on the effects of robot group structures [12][23][26]. We thought that both structures have different merits depending on target users and development perspectives. For example, using a hetero-style robot group would be effective in assigning different roles and behaviors for each robot because their appearances are different. Such merit would be useful for applications toward younger children by decreasing cognitive load. In addition, a variety of robot's appearance might have positive effects on such children to keep their motivation and interests.

On the other hand, using the homo-style of the robot group would be effective in expressing a sense of unity because their appearances are the same. For example, their synchronized behaviors would provide different effects in the praise context. Moreover, we thought that the praise from the homo-style of the robot group would provide similar positive effects because our past study showed the positive effects of the praise from two same robots.

On the other hand, using the homo-style of the robot group would provide different effects by expressing a sense of unity because their appearances are the same. For example, a past study showed that synchronized behaviors of the homo-style of the robot group provide different impressions and behavior changes compared to non-synchronized behaviors in the context of peer pressure [67]. Moreover, our past study showed the positive effects of the praise from two same robots in the context of offline motor improvement [26]. Therefore, the praise from the homo-style of the robot group also might provide different but positive effects in the context of education support, we think. Such effects are out of focus in this paper, but investigating the robot group structure effects would be one interesting future work.

6.4 Can the system be autonomous?

Our system involved a human operator controlling the timing of the robot's behaviors because we assumed that children behave unexpectedly. However, such situations really occurred in the experiment, only when a child cried up due to the absence of his mother. Moreover, the developed three rules are easily automated by connecting with the developed GUI. For example, the system autonomy can be enhanced by detecting when the "start" and "end" buttons of the GUI are pressed and long idle times. Therefore, the system can easily be autonomous.

We note that a minimum function to collaborate with a human operator will be important when the system detects the wrong situations like breaking the PC or detecting crying behaviors of children. In such situations, humans’ supports would be needed to solve the problems. In this context, if the system is mostly autonomous, the operator does not need to operate the system thoroughly. Moreover, past studies reported that one operator control more than four robots with more complex settings (conversational mobile robots in a real shopping mall) [68]. One possible application is for a professional teacher or a parent to operate several robots simultaneously to support children's learning in various locations such as a home, a kindergarten, and an elementary school.

6.5 Other possible factors that influence praise effects

In this study, the experiment results did not show significant differences in performance improvement. However, past studies reported the performance improvement effects of praises, which focused on a relatively long time period, such as a performance the next day [26, 42, 43]. If we conduct this experiment with a longer time period, such effects might appear in our settings. Moreover, our robots always praise children even though the children answer wrongly. If the robots provide praise and additional follow-up comments about the mistake, it might be more effective in improving the children's performance. Such long-time effects and different praise strategies are not investigated yet in this study.

Another possible factor is basic learning performance or activities for children's English learning. We did not measure children’s basic performances before the experiment, but we asked their daily activities about English learning of children, such as lessons. Therefore, we conducted an additional analysis by separating children into two classes: with (12 children) or without (10 children) daily activity. We used a repeated

ANOVA by using the daily-activity factor and number factor for learning time, the number of answered questions, the number of correct answers, and the rate of correct answers. But, all factors and metrics did not show significant differences.

6.6 Limitations

This study has several limitations. It was conducted with specific settings, such as one kind of humanoid robot (Sota) and a doll-type robot for investigating the effects of praise on pre-school children. As shown above, the effects of praise from different robots and roles have not been investigated yet. Since we only investigated praise from two robots, its effects from additional robots on children remain unknown. Of course, increasing the number of robots would eventually saturate such benefits, and such future work might be illuminating.

Note that since we fixed the roles of the robots, we don't know whether we can observe the same effects if their roles were switched. However, our approach seems reasonable because an MC robot needs sufficient capability to explain a system with understandable gestures. In fact, e-learning robot systems are already equipped with such abilities [1, 69-71]. On the other hand, additional robots that praise children only need speaking and connection capability.

We believe that our study provides valuable insight and knowledge for readers who are interested in child-robot interaction and praise effects from two robots for children.

7 Conclusion

We investigated whether the length of time children spend with an English e-learning application increases and whether their performances improve through praise from two robots more than praise from a single robot. We developed an English e-learning-support robot system using a tabletop humanoid robot and a doll-type robot and experimented with 22 children. The children's learning times were significantly longer when two robots praised the children than when just a single robot offered praise, even if the amount was identical. These results suggest that praise from two robots has several advantages for educational support purposes.

Acknowledgements

This research work was supported in part by JST CREST Grant Number JPMJCR18A1, Japan JSPS KAKENHI Grant Numbers JP18H03311 and JP19J01290, and JST, PRESTO Grant Number JPMJPR1851, Japan.

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