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Robot-Mediated Intergenerational Childcare: Experimental Study Based on Health-Screening Task in Nursery School

Junya Nakanishi[1] · **Jun Baba**[2] · **Wei-Chuan Chang**[3] · **Aya Nakae**[3] · **Hidenobu Sumioka**[3] · **Hiroshi Ishiguro**[1,3]

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Abstract

Intergenerational interactions between children and older adults are gaining broader recognition because of their mutual benefits. However, such interactions face practical limitations owing to potential disease transmission and the poor health of older adults for face-to-face interactions. This study explores robot-mediated interactions as a potential solution to address these issues. In this study, older adults remotely controlled a social robot to perform a health-screening task for nursery school children, thereby overcoming the problems associated with face-to-face interactions while engaging in physical interactions. The results of this study suggested that the children responded favorably to the robot, and the rate of positive response increased over time. Older adults also found the task generally manageable and experienced a significant positive shift in their attitude toward children. These findings suggest that robot-mediated interactions can effectively facilitate intergenerational engagement and provide psychosocial benefits to both the parties to the engagement. This study provides valuable insights into the potential of robot-mediated interactions in childcare and other similar settings.

Keywords Intergenerational interaction · Teleoperated social robot · Childcare · Nursery school

1 Introduction

Interactions between children and older adults are gaining popularity as an intergenerational outreach to benefit both parties (see review papers [1, 2]). For children, such interactions provide an opportunity to grow emotionally and socially and achieve a variety of educational and community goals. Simultaneously, these promote good mental health for the older adults by improving their self-esteem, increasing their well-being, and reducing their suffering. Thus, events that promote interaction between children and older adults have been prevalent in several countries for more than four decades [1].

✉ Junya Nakanishi
nakanishi@irl.sys.es.osaka-u.ac.jp

1 Graduate School of Engineering Science, Osaka University, 1-3 Machikaneyama, Toyonaka, Osaka 560-8531, Japan

2 AI Lab, CyberAgent,inc, 40-1 Abema Towers,Udagawa-cho, Shibuya, Tokyo 150-0042, Japan

3 Hiroshi Ishiguro Laboratory, Advanced Telecommunications Research Institute International, 2-2-2, Hikaridai, Seika-cho, Soraku-gun, Kyoto 619-0237, Japan

However, the face-to-face interaction, which is the predominant form of interaction between children and older adults [2], presents the following drawbacks: (1) Epidemics or pandemics (e.g., COVID-19 in 2020) can interrupt interactions, because both children and older adults possess relatively inferior immune functions when compared with those of other age groups. Hence, they are most likely to be restricted in their activities by infectious disease control authorities and policies. (2) A decline in the physical health of older adults can prevent them from attending social events for intergenerational interaction.

Therefore, we propose robot-mediated interactions as an alternative to overcome these drawbacks of face-to-face interactions and enhance the experiences of the parties involved. Robot-mediated interactions between children and older adults assume the form in which an older adult remotely controls a social robot and children interact with the robot face-to-face. Such an interaction between children and older adults can help minimize the risk of infections and address the limitations attributable to the physical health of older adults. Furthermore, the robot-mediated interaction offers advantages such as allowing in-person interaction, which is not possible with screen-based remote interactions such as a computer-generated agent or video conferencing.

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Robot-mediated interactions are expected to facilitate the understanding of spatial instructions. Furthermore, the robot being physically similar to a child will increase children's affinity for it [3, 4].

The objective of this study was to evaluate the feasibility and benefits of robot-mediated intergenerational interactions from the perspectives of children who interacted with the robot and older adult teleoperators who controlled the robot. This study is based on an experiment on a robot-mediated intergenerational childcare task in a nursery school, extending a previous pilot study [5]. In this experiment, older adults teleoperated a social robot to screen the health of pupils attending the school. The intention of conducting this experiment at nursery school is to combine intergenerational interaction and support for nursery schools by implementing some of nursery school childcare tasks as intergenerational interaction. Among the activities providing support to nursery schools, the choice of the health-screening task was made as a result of discussions with the nursery school, taking into consideration the capabilities of the robotic system, the burden on the nursery school, and the burden and risk to the pupils. The research objectives of this study were as follows.

- Investigate the reactions of pupils during their task completion via a social robot at the time of their arrival at the school.
- Investigate the psychological and physiological benefits of this system for the older adults, who teleoperated the robot to interact with the children.
- Monitor and evaluate the progress of the experiment on robot-mediated intergenerational childcare over a period of 20 days.

2 Related Work

2.1 Child–Robot Interaction

Many studies have introduced autonomous or teleoperated social robots in educational settings to support child development. Social robots are recognized as being more likely to form social relationships with children than adults or objects, which benefits the learning, social behavior, and emotional well-being of the children [3, 4]. For example, repeated exposure to an autonomous social robot helps improve the basic social interaction skills (e.g., imitation, turn-taking, and role-switching) in children with autism [6]. An autonomous social robot served as a teacher assistant by telling stories to small groups of children while incorporating song and motor activities in the process, which resulted in an improvement in the cognitive/motor performance of the children [7]. However, autonomous robots are constrained to specific use because of their limited perceptual and intellectual capabilities. Teleoperated social robots have relatively fewer limitations in their interactions with children and are expected to achieve a wider range of beneficial effects. For example, teleoperated robots joined the children's group work and made them more active and spontaneous [8]. Teachers in other countries have conducted English classes using teleoperated robots [9]. The current study aims to make a contribution to the field of childcare by utilizing the features of the robotic medium for the health-screening task.

2.2 Teleoperator in Robot-Mediated Interaction

Unlike an autonomous robot, a teleoperated robot involves a teleoperator, in addition to a user who interacts face-to-face with the robot. In many cases, the user interacting with the robot is the service recipient, and the teleoperator engages in several tasks to provide the service. Thus, research on teleoperators has focused on the teleoperation design of robotic systems to improve task performance [10]. An active field of research in this regard is the minimization of the workload of the teleoperator by enabling the program to automatically perform some of the actions of the robot [11, 12] or provide feedback to the teleoperator for appropriate task execution, which can lead to improved task performance [13].

Some studies have suggested that interacting with others through a social robot benefits the teleoperator more than do the face-to-face interactions. For example, by becoming the teleoperator of a robot, children may feel less reluctant to interact with others (e.g., older adults and foreigners) and become more interested in talking to them [14–16]. This study investigates the benefits that arise when older adults interact with children through teleoperating social robots.

2.3 Intergenerational Interaction and Social Robots

Many studies report that intergenerational interactions benefit both parties involved in such interactions (see review papers [1, 2]). For children, it is an opportunity to grow emotionally and socially and achieve a variety of educational and community goals. Furthermore, such interactions promote good mental health in older adults by improving their self-esteem, increasing their well-being, and reducing their suffering. The methods of such interactions vary and include computer-based learning [17], exercise programs [18], storytelling [19], and music therapy [20].

A few studies on intergenerational interactions have reported the use of robots. A study on pet robots suggested the importance of interaction design, such as spatial proximity to the robot and intermittent behavior, in creating opportunities for increased engagement between children and older adults [21]. Furthermore, Furthermore, there is a report of social robots being used to promote intergenerational interactions through games [22]. These studies use autonomous robots in a third-party position, which does not overcome the implementation limitations of face-to-face interactions between children and older adults.

In addition to teleoperated robots, telepresence robots and video calls enable remote interactions between children and older adults. They differ from teleoperated robots in that they make the presence of the teleoperator explicit; the image or name of the teleoperator is shown, and the user facing the robot or display is conscious of the teleoperator. Accordingly, in telepresence robots and video calls, the human relationship between communicators is carried over to the mediated interactions. If the communicators are already closely related, revealing the teleoperator would motivate the initiation of remote interactions. In fact, past studies on telepresence robots and video calls for interaction between children and older adults have focused on interactions within families [23–25]. However, if the communicators are meeting for the first time, revealing the teleoperator would be an obstacle to initiating remote interactions. For example, one study reported that initiating remote interactions is easy when a teleoperator acts as an autonomous robot rather than as a teleoperator in a mall [26]. Another study claims that robots are more likely to attract people than are humans in a mall [27]. Thus, people may have a motive to talk to robots but may have difficulty finding a motive to talk to strangers. In this study, because the child and older adult were meeting for the first time, the robot (i.e., teleoperator) behaved as an autonomous robot; that is, a “teleoperated” robot was used.

In a shorter version of this experimental study, five older adults were engaged to teleoperate a robot for one day each to greet children on their arrival at a nursery school [5]. The results showed that teleoperated robot achieved comparable performance for the greeting task to that of the nursery staff. Furthermore, the results suggested that even if a teleoperator is replaced, the next teleoperator can maintain the relationship established by the previous teleoperator. In the present study, we extended the course of robot-mediated intergenerational interactions over a longer period than in that previous study. In addition, we attempted to monitor the physiological changes in older adult teleoperators using blood tests.

3 Experimental

This experiment was performed at a nursery school in Japan. The experiment used a health-screening task as the interaction between children and older adults to evaluate the benefits of the teleoperated intergenerational interaction for both parties. The study was approved by the Ethics Committee of Advanced Telecommunications Research Institute International.

3.1 Teleoperated Social Robot System

The teleoperation system used in this study is depicted in Fig. 1. Although teleoperators could control the speech and movements of the robot using their own voice, as well as buttons on a web interface, and coordinate indications while watching real-time video footage from the camera behind the robot, the automatic generation of interactive behaviors, as described below, allowed the teleoperator to concentrate solely on speech, making it easy for older adults to teleoperate the system.

The teleoperator’s voice was emitted by the robot. Simultaneously, the teleoperator’s voice was recognized by voice recognition (Web Speech API, Google LLC[1]). It was used to automatically generate the speech gestures of the robot. For example, when the teleoperator used a word for greeting, the robot raised its arm; when the teleoperator used words such as “welcome” or “thank you,” the robot raised both of its hands. For this experiment, we registered approximately forty word–behavior pairs. If a word spoken by the teleoperator was not registered, the robot performed small, random arm and neck swings to express talking gestures whenever the voice recognition results were received.

It should be noted that the mismatch between robot’s appearance and voice has been shown to induce creepiness [28]. For that reason, in some studies of teleoperated social robots, manipulations have been taken to bring the teleoperator’s voice closer to match the robot’ appearance through voice conversion [5, 26, 29]. In our preliminary experiments, we also tried to use a voice conversion to produce robot-like speech, but the converted speech of some of the older adults was very difficult to hear (the older adults could not speak clearly). This is why the experimental design of this study did not use voice conversion. This is an issue for future study.

The teleoperation interface allowed the teleoperator to send behavior commands to the robot by pressing the relevant buttons and coordinating the indications. The teleoperator used buttons to generate robot motions in addition to the automatically generated speech gestures. For example, we prepared commands for “raising one hand,” “cute pose,” and “bye.” The direction of the face of the robot was commanded using the coordinate indications. By clicking directly on the image of the room on the teleoperation interface, the robot turned its face toward the selected coordinates for 10 sec. In the absence of any coordinate command, the robot used a pose estimation model to follow the face of the child closest to it on the image of the room (PoseNet[30]).

For the humanoid robot, we used Sota (Vstone Co., Ltd.[2]), which is a desktop-sized (approximately 0.3 ms tall) robot

[1] California, U.S.,https://about.google/intl/ALL_en/.

[2] Osaka, Japan, https://www.vstone.co.jp/english/index.html.

Fig. 1 Teleoperation interface and system

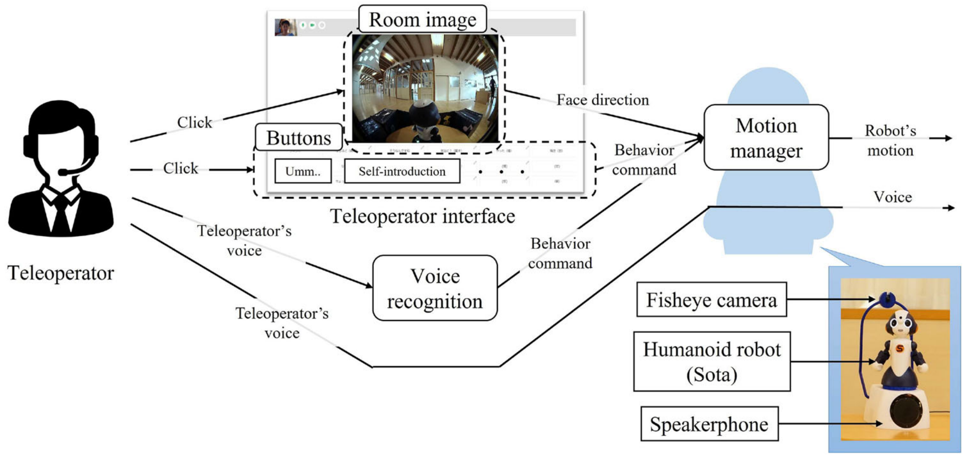
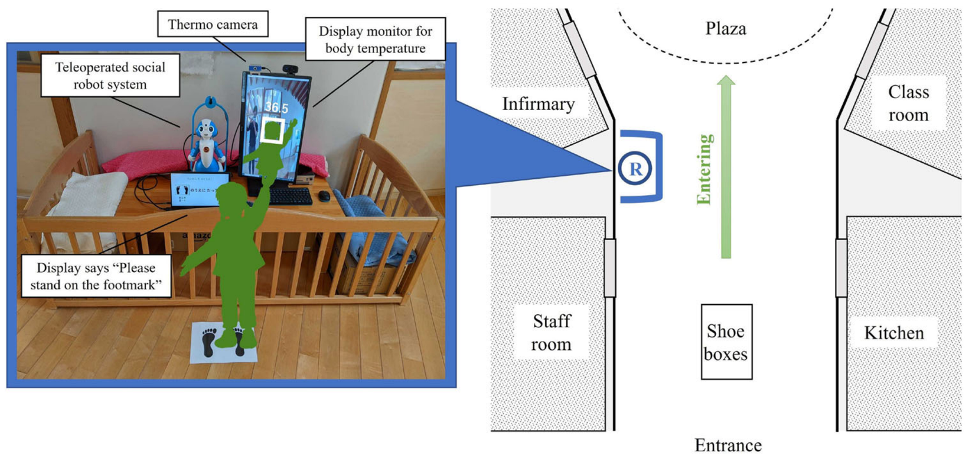


Fig. 2 Floor plan of the school with the robot at the school entrance



capable of interacting with a human using body movements and lights. It employs an 8-DOF (Degree of Freedom) design that allows movement of the arms, torso, and neck. The robot's eyes and mouth are embedded with LED lights, which enable it to express movement through blinking and changes in color. A fisheye camera was installed behind the robot to relay the scene in the room in real time to the teleoperator, and a speakerphone was embedded at the base of the robot to capture the sounds in the room. Next to the robot, a display monitor and a thermo-camera (Ami-T: Advanced Media, Inc.[3]) were installed to obtain the body temperature of the person in front of the robot (Fig. 2). The display showed the image of the user standing in front of the robot and his/her body temperature. It also could be viewed by the teleoperator (Fig. 3). A smaller display was installed in front of the robot to display instructions on where to stand.

3.2 Health-Screening Task

The health-screening task in this experimental study involved obtaining the body temperature of children while chatting with them when they arrived at the school. In a previous study, only the greeting task was performed [5]. The objective of incorporating the temperature check was to expand the scope of the childcare that can be provided by older adult teleoperators. Ordinarily, the staff at the nursery school would greet the children and measure their body temperature daily. While the staff greeted the children, they did not force the children to respond lest they become uncomfortable and dread the interaction. Approximately 60% of the children responded to greetings when using this method. However, body temperature measurements were mandatory for all the children. In this experiment, the teleoperated robot performed these tasks to help the staff. The children were given the option of refusing the health screening by the robot. The staff and experimenters discussed and set the above interactive tasks to be performed by the robot while carefully considering the risk of a negative impact on the pupils (e.g., possibility of mental and physical harm).

During the experiment, the robot was stationed at the entrance of the nursery school to greet and measure the body temperature of children coming to the school (Fig. 2). The robot was teleoperated between 8:00 and 9:00 in the morn-

[3] Tokyo, Japan, https://www.advanced-media.co.jp/english.

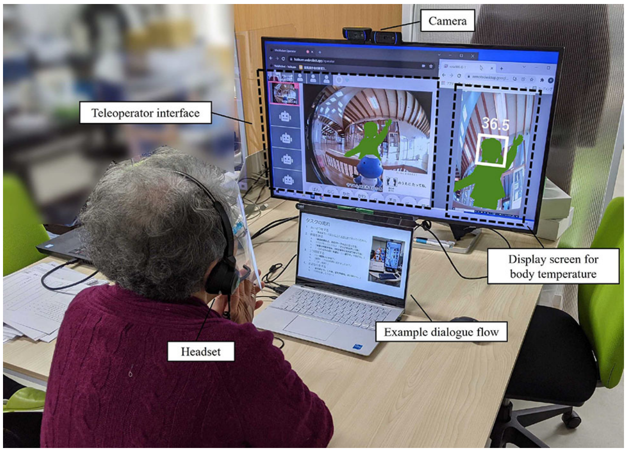


Fig. 3 Older adults teleoperating social robot

ing. A screen was erected around the robot to prevent any physical contact between the robot and children. One staff member maintained vigilance and was prepared to respond to any situations necessitating immediate intervention. Outside its teleoperational hours in the morning, the robot was kept covered.

3.3 Procedures and Participants

The experiment was conducted over a period of 20 days (partly in mid-January and partly late May to early June). The experiment had to be suspended midway owing to the coronavirus outbreak. On each day of the experiment, 20 older adult participants (nine males and 11 females; over 60 years old) teleoperated the social robot to perform the health-screening task. Older adults were recruited through staffing services. Table 1 lists the experimental procedures implemented by the teleoperators. Participants were adequately briefed about the experiment and gave their informed consent to participate. One day before the experiment, the participants received a 30-min briefing on how to teleoperate the robot. They were made to teleoperate the robot to deepen their understanding of the process. Figure 3 depicts participants teleoperating the social robot.

An example of the dialogue flow based on a previous pilot study [5] was also provided to them. The example consisted of the following four steps.

(1) Opening words
   (a) Say "Good morning" slowly but loudly.
(2) Obtained body temperature measurement
   (a) "I am going to take your temperature. Stand on the foot mark."
   (b) (If the pupil is wearing a mask) "Take off your mask."
   (c) "Wait a moment while I take the body temperature measurement."
   (d) "It is [X] degrees Celsius. You are fine."
   If the temperature exceeds 37.5 degrees Celsius, inform the nursery staff.
(3) Questions
   (a) "Can I ask you a question?"
   (b) "[The experimenter chooses a question from five questions in advance.]"
   (c) Keep chatting for a bit if the pupil shows interest.
(4) Closing words
   (a) "Thanks.", "I will see you next time.", "Bye-bye.", "Let's have fun today!".

First, given that the pupils might not have fully developed language skills and the nursery school environment could potentially be noisy, the teleoperator was instructed to speak slowly but loudly. For the temperature measurement task, the teleoperator explained the temperature measurement procedure to each pupil once. When a fever was present, the nursery staff were notified. For the questions part of the task, the teleoperator was instructed to use the question that the experimenter randomly selected from the five questions that the pupils were comfortable answering in the previous pilot study. Those five questions are as follows: "What time did you get up today?", "What did you eat for breakfast?", "What are you going to play today?", "What was the weather outside today?", and "What time did you go to bed last night?" Finally, the teleoperator was instructed to move to the closing part if another pupil was waiting for his/her turn. The teleoperators were instructed to use the example dialogue if they did not know what to talk about. In addition, they were instructed to interact with the pupils while pretending to be the robot. They were provided with a hard copy of the profile settings of the robot (e.g., favorite food, age, and birthplace) so that they could answer questions about it when asked by the pupils. They completed the evaluation tasks before and after the health-screening task (see 4 section).

Approximately 40 children, aged 0–5 years, attended the nursery school. Children who have difficulty engaging on the health-screening tasks alone are assisted by their parents. The parents of all the children were provided with adequate literature on the nature and scope of the experiment before they allowed their children to participate (i.e., informed consent). The children were informed in advance that a robot named "Sota" would be stationed in the nursery school. In other words, the children were informed that an autonomous robot, not a teleoperated one, would be installed. In addition,

Table 1 Experimental procedures for teleoperators

Time	Task contents
Training day	
10:00–10:30 a.m.	*Briefing*: An experimenter explained the experiment to participants and obtained their consent to participate in the experiment
10:30–11:00 a.m.	*Teleoperation training*: Participants were briefed on how to teleoperate the robot and given a demonstration to deepen their understanding of teleoperation
Experiment day	
7:00–7:30 a.m.	*Pre evaluation*: Participants completed questionnaires (i.e., mood state and attitude toward children) and blood tests
7:30–8:00 a.m.	*Teleoperation preparation*: Participants reviewed teleoperation method before starting
8:00–9:00 a.m.	*Teleoperation*: Participants engaged in the health-screening task
8:00–9:00 a.m.	*Post evaluation*: Participants completed questionnaires (i.e, mood state, attitude toward children, and willingness to work) and blood tests

they were informed that the robot could greet and measure their body temperature.

4 Evaluation

The benefits of the health-screening task for pupils by older adults were measured as follows: For pupils, we evaluated whether childcare had been established. The degree of task completion and the enjoyment of the interaction were measured through observational evaluation. Regression analysis was performed for each change during the experiment period. For older adults, we evaluated the mental and physiological health of them using questionnaires and blood tests. Comparisons were performed using the Wilcoxon signed-rank test, because it was not known whether the data were normal or not, and the sample size is too small to test for normality. The significance level was set at 5%.

4.1 Observations

Based on the recorded video data of the robot-mediated interaction, we evaluated the degree of task completion and enjoyment. Note that videography data were available only for 14 out of the 20 days. The pupils passed by the robot 932 times in the data. To measure the degree of completion of the task, two coders judged each interaction: whether the pupil stopped for the robot (inter-coder agreement score $\kappa = 0.87$), whether the temperature measurement was performed ($\kappa = 0.88$), and whether it was at the time of arrival at the school ($\kappa = 0.88$). Several pupils returned from the classroom and engaged in a second or third interaction, which was not for measuring their temperature. This is why we made the distinction between whether that was the interaction at the time of arrival at the school or not. When a health-screening task was not completed, the coders assigned one of the following 16 labels to each situation as the reason ($\kappa = 0.36$). This labeling was difficult to make a judgment on by the looks of the child, so any claims regarding this labeling must be accepted as unstable as such.

- The parent was in a hurry.
- The pupil was held by the parent.
- The pupil is not old enough to talk.
- The pupil did not like the interaction.
- The pupil was not interested in the robot.
- The pupil was shy to interact the robot.
- The pupil did not hear the teleoperator.
- The pupil could not answer the question.
- The pupil did not notice the robot.
- The pupil was distracted by other things.
- Other pupils were standing in front of the robot.
- Other pupils were waiting behind the pupil.
- The teleoperator could not hear the child.
- The teleoperator did not talk to the pupil.
- The teleoperator did not notice the pupil.
- I cannot guess the reason.

To measure the degree of enjoyment, the two coders judged how the pupils and older adults felt about the interaction based on their facial expressions during each robot-mediated interaction. The facial expressions of the pupils were observed in the video captured using the fish-eye camera of the robotic system. The facial expressions of the older adults were observed in the video captured using the camera attached to the teleoperating PC. The coders assigned one of the following labels to each facial expression: positive (happy, joyful, interested, and earnest), neutral (expressionless), or negative (confused, disappointed, discouraged, crying, and bored). The intercoder agreement score was $\kappa = 0.65$.

4.2 Questionnaires

For older adults, interactions with children are anticipated to promote their mental health [1]. With reference to previous studies on intergenerational interactions, mood state [18, 31, 32], attitudes toward children [20, 33], and continuous willingness to work [5, 17] were measured. Preliminary experiments have confirmed that the volume and difficulty of these questions are not a problem for older adults. In addition, we solicited feedback from nursery staff and parents.

Mood state: To measure changes in mood, the teleoperators were asked to respond to the Profile of Mood States 2nd Edition (POMS2) [34] before and after the experiment. This mood scale asked participants to rate their current mood on a five-point scale (0 = none at all, 1 = a little, 2 = moderately, 3 = quite a bit, 4 = extremely), with 65 items pertaining six factors: Anger-Hostility, Confusion-Bewilderment, Depression-Dejection, Fatigue-Inertia, Tension-Anxiety, and Friendliness. Anger-Hostility refers to feelings of intense discomfort or frustration, as well as animosity or aggression toward others. Confusion-Bewilderment refers to the state of not understanding what is happening and surprise when faced with unexpected situations or information. Depression-Dejection refers to a state of severe low mood accompanied by sadness, helplessness, disappointment, loss of motivation, and difficulty feeling interest or pleasure. Fatigue-Inertia refers to a state of physical or mental overwork and a feeling of energy starvation or lack of motivation or energy to take action. Tension-Anxiety refers to a psychological state resulting from stress or pressure, or worry or fear about future uncertainty or fear. Vigor-Activity refers to a state of mental and physical vitality and strength, and a willingness to take positive action. Friendliness refers to the characteristic of being approachable, cooperative, and warm toward others. The Cronbach's alpha coefficients were as follows: Anger-Hostility: 0.90, Confusion-Bewilderment: 0.75, Depression-Dejection: 0.90, Fatigue-Inertia: 0.91, Tension-Anxiety: 0.76, Vigor-Activity: 0.92, Friendliness: 0.53. It should be noted, however, that the value of Cronbach's alpha coefficient in Friendliness is lower than the adequate standard used in many studies ($\alpha < 0.7$) [35] and may not have been measured as intended.

Attitude toward children: To measure changes in the attitude of the older adults toward children, teleoperators were asked to respond to the Age Group Evaluation and Description (AGED) Inventory [36] before and after the experiment. This attitude scale asked participants to rate their impressions of children in general on a seven-point scale, with 28 adjective-pair items pertaining four factors: Goodness, Positiveness, Vitality, and Maturity. Goodness represents ideal qualities and attitudes to have toward others and society as a whole, such as consideration for others, honesty, and patience. Positiveness represents a consistent positive state of mind and attitude toward self and surrounding circumstances, such as optimism, flexibility, and sociability. Vitality represents a state of being full of energy, passion, and strength, such as independent, adventurous, and sexy. Maturity represents a state of spiritual, emotional, and social growth and development, such as trustworthiness, dignity, and modesty. Each factor corresponds to seven adjective-pair items. The degree of magnitude of the score indicates the degree of strength of the factor. The Cronbach's alpha coefficients were as follows: Goodness: 0.78, Positiveness: 0.80, Vitality: 0.77, Maturity: 0.86. Due to a form-filling error, one participant was excluded from this particular analysis.

Willingness to work: The teleoperators were asked to rate their willingness to work (see Table 6) on a five-point scale (1 = strongly disagree, 2 = slightly disagree, 3 = neither agree nor disagree, 4 = slightly agree, and 5 = strongly agree). The four questions are as follows: Q1: Do you think this job contributed to the community?, Q2: Did you enjoy this job?, Q3: Would you like to do this job again?, and Q4: Was this job difficult? Furthermore, they were asked about the reasons for their answers to the questionnaire in an effort to comprehend the factors underlying the results of Q2, Q3, and Q4 in the questionnaire. Because the experimenter explained to the teleoperators how this teleoperated robot contributed to the community in the briefing, we did not request a reason for Q1.

Feedback from nursery staff and parents: The other stakeholders (i.e., nursery staff and parents) in the robot-mediated childcare were asked for their feedback. They were asked to rate their satisfaction on a four-point scale (1 = unsatisfied, 2 = somewhat unsatisfied, 3 = somewhat satisfied, 4 = satisfied). They were also asked about areas of dissatisfaction and potential areas for improvement. Twenty-two members of the nursery staff and thirty-two parents completed questionnaires. Given that their response to all items was not obligatory, some of the questions remained unanswered.

4.3 Blood Tests

Blood was drawn from the antecubital veins of the teleoperator participants into blood collection tubes by a nurse, before and after the teleoperation of the robot. The blood samples were centrifuged according to the manufacturer's instructions. Serum and plasma samples were aliquoted into 1.5-mL centrifuge tubes and stored at −80°C until assayed. Corti-

Table 2 Reasons for the failure to completing the health-screening task

Rate [%]	Reason	Cumulative Total[%]
Reasons why the pupil did not stop by the robot		
30	The pupil was held by the parent	30
22	The parent was in a hurry	52
16	The pupil did not notice the robot	68
12	The pupil was distracted by other things	80
7	Other pupils were standing in front of the robot	87
5	The pupil was not interested in the robot	92
Reasons why the task did not complete while the pupil stopped by the robot		
17	The pupil is not old enough to talk	17
13	The pupil was held by the parent	30
11	Other pupils were standing in front of the robot	41
10	The parent was in a hurry	51
8	The pupil was distracted by other things	59
8	The teleoperator did not talk to the pupil	67
8	The pupil could not hear the teleoperator	75
7	The teleoperator did not notice the pupil	82
6	The pupil was shy to interact with the robot	88

Items lined up with a rate of 5% or more

sol, growth hormone (GH), dehydroepiandrosterone sulfate (DHEA-S), and oxytocin levels were measured. We also evaluated the d-ROMs/BAP score, which is an indicator of aging. Owing to their engagements related to COVID-19, five participants were unable to give their blood samples for the initial few days. Therefore, blood samples were collected only from 15 participants.

Enzyme-Linked Immunoassay (ELISA): Serum levels of cortisol, GH, DHEA-S, and plasma levels of oxytocin were determined using commercially available ELISA kits. (cortisol: Detect X Cortisol Enzyme Immunoassay Kit, Arbor Assays, Michigan, USA; GH: Quantikine ELISA Human Growth Hormone Immunoassay, R&D Systems, Inc., Minnesota, USA; oxytocin: Oxytocin ELISA kit, Enzo Life Sciences, Inc. New York, USA; DHEA-S: DHEA-S ELISA RUO, DRG International, Inc., USA) The limits of detection were 45.5 pg/mL (0.00455 ug/dL) for cortisol, 2.10 pg/mL for GH, 15.0 pg/mL for oxytocin, and 0.044 ug/mL for DHEA-S; the intra- and interassay coefficients of variation were below 10% for all assays, except oxytocin (below 17%).

Cortisol: Cortisol is a primary stress hormone produced and secreted by adrenal cortex in response to stress [37]. This experiment aimed to confirm whether the cortisol level reduces after their teleoperation of the robot.

Dehydroepiandrosterone-Sulfate (DHEA-S): DHEA-A is a precursor molecule to male sex hormone androgen and female sex hormone estrogen. Low DHEA-S levels may be associated with aging. Recent research has suggested that low DHEA-S scores affect cognitive function, resulting in dementia [38]. The production of DHEA-S starts to increase from 6 to 7 years of age, peaks around puberty, remains high until 35 years of age, and then gradually decreases over time. Therefore, it is difficult for older adults to increase the levels of this hormone even though it plays an important role in anti-aging.

Growth Hormone (GH): GH is a peptide hormone secreted from the anterior pituitary gland and regulates somatic growth (in children) and metabolism [39]. Its secretion peaks around puberty and decreases with age. GH levels increase during sleep and exercise. It is vital to maintain a healthy body composition (tissues and organs), regulate blood sugar levels, build proteins, and break down fat. Maintaining proper bone density and heart muscle function is also important. Therefore, we used the GH level as an indicator of the health status of the participants.

Oxytocin: Oxytocin is a neuropeptide hormone produced by hypothalamus, stored and secreted from the posterior pituitary gland [40]. Oxytocin secretion includes (1) positive physical contact, such as cuddling, kissing, hugging, and massage; and (2) social bonding, such as talking, making eye contact, and laughter. Therefore, we used this as an indicator of social bonding between older adults and children.

Assay of oxidative stress and antioxidant potential (d-ROMs & BAP Test): Serum oxidative stress levels and antioxidative potential were determined using commercially available kits, d-ROMs (oxidative stress) and BAP (biological antioxidant potential) tests (Wismerll Co. Ltd., Tokyo, Japan) using a photometer, REDOXLIBRA (Wismerll Co., Ltd., Tokyo, Japan), which can measure oxygen species/free radical levels and antioxidant levels. The oxidative stress and antioxidant potential of the serum samples were measured in accordance with the manufacturer instructions.

Oxidative stress (reactive oxygen species) occurs during normal cellular metabolism and can damage DNA, lipids, and proteins. However, the body also produces antioxidants that counteract the damage caused by reactive oxygen species. Antioxidants include endogenous enzymes such as superoxide dismutase, catalase, glutathione peroxidase, thioredoxin, and low-molecular-weight compounds such as vitamins (C and E), β-carotene and uric acid. When the generation of reactive oxygen species and antioxidants in one's body are in balance, the damage is eliminated [41]. However, when this balance tips toward reactive oxygen generation, it leads to premature aging, allergies, diseases, and/or cancer. Factors known to increase reactive oxygen species/free radicals in the body include (1) an unhealthy lifestyle, (2) an unbalanced diet, (3) psychological stress, (4) excessive fatigue, and (5) toxic metals and chemicals. Factors known to increase the antioxidant potential in the body are (1) balanced diet, (2) antioxidant foods, (3) adequate rest, (4) proper exercise, and (5) sound sleep. Antioxidants help eliminate reactive oxygen species/free radicals from the body.

d-ROMs test (diacron reactive oxygen metabolites): This test does not measure reactive oxygen and free radicals directly, rather quantifies the hydroperoxide generated by reactive oxygen and free radicals, which when combined with chromogen causes color reaction. The detection limit was 11 U. CARR and the reproducibility CV% was less than 3%.

BAP test (biological antioxidant potential test): This test evaluates antioxidant potential by quantifying the body's iron-reducing power by the addition of serum samples (Fe^{3+} to Fe^{2+}). The detection limit was 150μmol/L and reproducibility CV% was less than 3%.

5 Result and Discussion

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

5.1 For Children

Task completion: The number of times the pupils passed by the robot at the time of arrival at school was 580. Of these, the pupils stopped by the robot 398 times (approximately 69%). Of these, temperature measurements were performed 270 times (approximately 68%).

These rates for stopping by the robot and task completion were lower than the values (approximately 76% and 82%, respectively) reported in a previous pilot study [5]. The main difference between the previous and current experiments was the content of the task. Compared to the previous task, which was solely a greeting task, the health-screening task required more time to complete. This implies that while one pupil is undergoing health screening, other pupils are not engaged. In fact, "Other pupils were standing in front of the robot." and "The pupil was distracted by other things." were cited as reasons for the lower rate for task completion (Table 2). Thus, the increase in task content may have been a factor that reduced the task-completion rate. To mitigate this issue, multiple robots must be installed to reduce the waiting time and enable the handling of more pupils.

Looking at the other top reasons for the failure to completing the task, factors beyond the control of the communication form existed: (i.e., "The pupil was held by the parent.", "The parent was in a hurry.", and "The pupil was not old enough to talk."). Failure of the interaction for these reasons is inevitable in this experimental setting and is not addressed in this study. Next, there are factors related to communication failure (i.e., "The pupil could not hear the teleoperator.", "The teleoperator did not talk to the pupil.", and "The teleoperator did not notice the pupil."). These problems often occurred when the teleoperator dealt with multiple pupils simultaneously. This problem could be alleviated by installing multiple robots. For some pupils, the robot failed to attract their attention (i.e., "The pupil did not notice the robot." and "The pupil was not interested in the robot."). In this experiment, the task was not mandatory for the pupils, hence, to some extent, it was unavoidable. The task-completion rate could have been higher if the task was mandatory for every pupil. Finally, the reluctance of some pupils to interact with the robot was also a factor (i.e., "The pupil was shy to interact the robot."). However, this factor was relatively insignificant.

Enjoyment: In terms of enjoyment, of the 522 times the pupils who stopped by the robot (regardless of the interaction being at time of arrival or any other time), 439 were positive, 58 were neutral, and 25 were negative. The rate of negative results (approximately 5%) was low. Therefore, it is unlikely that most children would resist interacting with robots.

Continuity: Fig. 4 depicts the stop-by, task-completion, and positive rates for each day. The stop-by rate is the percentage of pupils who stopped by the robot at the time of arrival; the task-completion rate is the percentage of pupils who completed the health-screening task at the time of arrival; and the positive rate is the percentage of pupils exhibiting positive facial expressions among those who stopped by the robot. The regression analysis showed significance for the positive

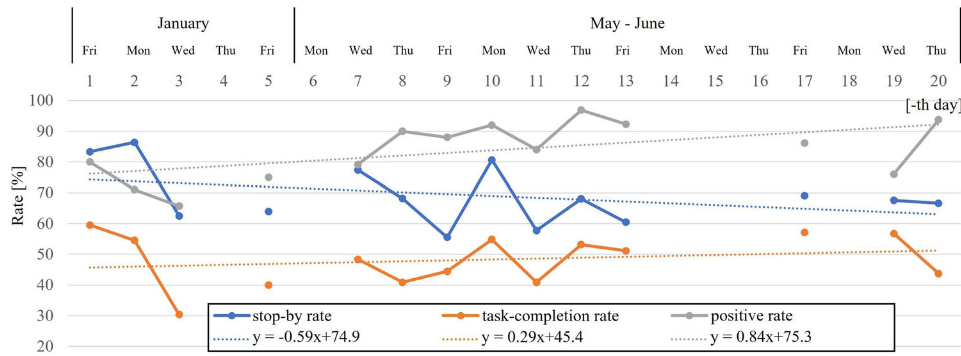


Fig. 4 Rates of the pupils' reactions on each day. The dotted line represents the regression line for rates

Table 3 Summary of feedback from nursery staff and parents

Number	Category & examples of feedback
Nursery staff	
8	*Voice interaction*: "Some of the 0-1 year olds were startled by the loud male voice.", "It would be nice if the voices were the same.", "Sometimes, the experimenter's voice was heard over that of robot.",..
3	*Other negatives*: "The way the robot speaks to them is not appropriate for children.", "Younger children may get scared when they suddenly hear robot's voices when they pass in front of it.", "I think some children are not compatible with robots."
7	*Positives*: "I would like the pupils to experience more robot-related activities in the future.", "It was heartwarming to see the pupils greeting each other.", "I was very happy that the robot greeted me as well.",..
Parents	
11	*Voice interaction*: "Sometimes it was hard to hear the robot's voice.", "Cannot you make it so that Sota's voice is the same no matter who teleoperates?", "It was hard to tell how far the microphone was picking up the children's voices.",..
5	*Time management*: "It took additional time to send the children off in the morning, which was difficult.", "I think it would be helpful for parents that multiple robots deal with children at the same time.", "Just after 8:00 a.m., they were often not up and running, so we could not take temperatures or greet them very well.",..
5	*Appearance and behavior*: "Small animal-shaped robots such as rabbits and squirrels may be better than human-shaped robots for interactions with small children.", "I think the child would be pleased if the facial expressions could change a little more.", "I thought it would be easier for younger children to get used to a robot that sings and dances.",..
7	*Other negatives*: "Even when I was in the designated position, I often could not take temperature of the child owing to her short stature.", "My child cried the first time he did it, and he started avoiding it after that. So, he did not do it.", "It would be nice if the robot could manage the children's arrival and departure from preschool by facial recognition ", "It might be fun when the child is a little older.", "As a child, he would like to touch the robot's body more and play with it. ",..
5	*Positives*: "My son seemed to look forward to seeing Sota-kun every day. ", "I was very happy not only to see my child enjoying but also to hear the robot say "see you later" every day after I dropped him off. ", "I was a little surprised at how well he responded when I talked to him about various things.",..

rate (coefficient of determination $R^2 = 0.30$, $p = 0.043$), and no significance for the stop-by rate ($R^2 = 0.14$, $p = 0.18$), and task-completion rate ($R^2 = 0.043$, $p = 0.48$).

The positive rate appeared to have increased over time. This suggests that the pupils become more familiar with the robot, even with a different teleoperator each day. One can imagine that this is difficult to achieve through face-to-face interactions. This study suggests that one of the advantages of robot-mediated interactions is that when a teleoperator is replaced, the relationship established by the previous teleoperator can be continued. The stop-by and task-completion rates appeared to have been high during the first two days and then have remained at a certain level. As in a previous study on robot-child interactions, the novelty factor of the robot attracted the interest of many pupils in the initial days [42, 43]. Importantly, these rates did not appear to have decreased in the period after the first two days or after the first two days in May. This implies that such a robotic system can continue to support childcare over a prolonged period.

Table 4 Averages and statistics of Profile of Mood States (2nd edition)

Item (min-max)	Pre	Post	W	p-value
Anger-Hostility (0–44)	6.60	5.00	32.50	0.22
Confusion-Bewilderment (0–40)	12.20	11.80	70.50	0.52
Depression-Dejection (0–52)	9.65	8.70	79.00	0.34
Fatigue-Inertia (0–24)	4.05	6.00	78.50	0.11
Tension-Anxiety (0–40)	12.45	13.60	128.00	0.40
Vigor-Activity (0–36)	20.35	21.10	76.50	0.68
Friendliness (0–24)	14.50	15.15	110.00	0.11

Feedback from nursery staff and parents: The average satisfaction scores for the nursery staff and parents were 3.5 ($SE = 0.14$) and 3.38 ($SE = 0.15$), respectively. It can be said that many of them expressed satisfaction with this robotic system.

Table 3 lists the results of categorizing the feedback and improvements suggested by the nursery staff and parents. The most common comment from both groups was regarding voice of the robot. First, the teleoperator was difficult to adjust the voice of the robot (his/her own voice) such that the children feel more comfortable listening to it. The speakerphone equipped on the robot has an echo canceling function that prevents the teleoperator from hearing the robot's voice. Thus, the teleoperator did not understand how his/her voices were being heard by the children. One possible solution is for the teleoperator to listen to the local robot's voice with another mic. However, in this system, the voice is delayed about 1 s after the teleoperator speaks, which interferes with the teleoperator's speech [44]. Second, the sounds coming from the microphone contain a lot of noise, making it more difficult to hear the other partner's voice than in face-to-face conversations. The children were sometimes puzzled, because they could not communicate with the robot even when they spoke at their usual volume. Finally, it is preferable that the voice of the robot remains the same even when the teleoperator changes. It is disconcerting for a user to hear a robot that looks the same but acts as if its personality changes every day. As stated above, teleoperated robot systems have communication problems that must be addressed. Other problems that have been raised include the installation time and the appearance and behavior of the robot, which should be considered in future studies.

5.2 For Older Adult Teleoperators

Mood state: Table 4 lists the results for POMS2. No significant differences in mood were observed before or after the intervention. Previous studies have found a decrease in mood related to depression and stress [18, 31, 32]. In these studies, intergenerational interactions were performed more than a dozen times by a single participant; therefore, it might be possible to improve the mood with a similar number of repetitions in this study.

Table 5 Averages and statistics of Age Group Evaluation and Description Inventory

Item (min-max)	Pre	Post	W	p-value
Goodness (1–49)	26.58	28.68	88.50	**0.025**
Positiveness (1–49)	31.42	32.21	102.50	0.47
Vitality (1–49)	28.16	29.31	115.50	0.20
Maturity (1–49)	26.42	27.37	115.50	0.26

Bold text means 5% significance

Attitude toward children: Table 5 lists the AGED Inventory results. Significant improvements in attitudes toward children were found in terms of goodness. This implies that intergenerational interaction, even when robot-mediated, potentially contributes to positive changes in older adults' attitudes. A previous study demonstrated improvements in Goodness, positivity, and maturity, which differed from these results [20]. In that study, the children were 4th grade elementary school students, and the task was 10 sessions of music therapy. The age group of the children and the number of tasks differences may have contributed to the differences in the results.

Willingness to work: Table 6 lists a summary of the responses to the work willingness questionnaire. The teleoperators rated Q1, Q2, and Q3 highly. The high scores for Q1 suggest that teleoperators felt that their job had a positive impact on the community, potentially indicating a sense of job satisfaction derived from the societal value of their work.

Table 6 Averages and standard errors of continuous willingness to work

Questions (min:1-max:5)	Ave	SE
Q1: Do you think this job contributed to the community?	4.65	0.11
Q2: Did you enjoy this job?	4.75	0.12
Q3: Would you like to do this job again?	4.50	0.15
Q4: Was this job difficult?	3.00	0.26

Table 7 Reasons for answers to work willingness questionnaire

Number	Category & examples of reason
Q2: Did you enjoy this job?	
6	*Interaction with children*: "The expressions on the children's faces take me back to the past.", "I enjoy interacting with children.", "Responding to children's reactions stimulates my own communication skills.",..
6	*Experience*: "It is something I do not get to experience every day.", "I felt nostalgic because it reminded me of the old days.", "I think the robot's involvement with people seems to ease my anxiety.",..
5	*Contribution to society*: "I would be happy to be of service to the local community.", "It could be effective in terms of welfare.", "I think it is good because older adults can do the job.",..
2	*Negatives*: "The pupils had gotten used to the robot, so I wanted to try it on a little earlier experimental day.", "Long hours and a little tired."
Q3: Would you like to do this job again?	
8	*Enjoyable*: "It was interesting.", "It was fun.",..
5	*Self-improvement*: "For my brain activity.", "I think I could be a better conversationalist.", "New experience.",..
2	*Contribution to society*: "Because I could help in some small way.", "I can spend my time to contribute to society."
1	*Interaction with children*: "I love children."
4	*Others*: "I would like to meet the upgraded robot.", "I like working at university.", "If there is a request", "This job refreshes the mind."
Q4: Was this job difficult?	
10	*Conversation*: "I am worried about whether the timing and content of what I say were appropriate.", "It was difficult to interact with children", "I could not become a robot.",..
3	*Teleoperation*: "There were some problems because I was not familiar with teleoperation.", "Sometimes the robot did not work.",..
7	*No particular difficulty*: "It was easy because of the procedure.", "I do not think it was difficult.", "It was fun with children.",..

The high scores for Q2 indicate that teleoperators found their jobs enjoyable, which is important because job satisfaction can lead to higher productivity, lower attrition, and overall improved workplace outcomes. The teleoperators cited their interaction with the pupils, overall experience, and social contribution as reasons for their enjoyment (Table 7). Two teleoperators indicated areas of dissatisfaction, but no teleoperator said they did not enjoy it (no one answered Q2 with 1 or 2). The high scores for Q3 imply that teleoperators are willing to take on the job again. This willingness to reengage in the same job role in the future is indicative of a positive overall job experience. Teleoperators cited enjoyment and self-improvement as their main reasons (Table 7). None of the teleoperators indicated that they would not want to do this job again (no one answered Q3 with 1 or 2). The scores against Q4 indicated that it was neither difficult nor easy. The teleoperators cited uncertainty about the appropriateness of their speaking with children and the content of the dialogue as reasons for the difficulty (Table 7). The teleoperators also mentioned that they could not communicate well with children when the communication conditions were unstable. Only a few participants responded that basic teleoperation was difficult, suggesting that robot-mediated interaction was possible for older adults. It would be simpler to accomplish this task if they were taught how to interact with the children in advance.

Blood test: Table 8 lists the results of the blood tests. A significant decrease in the levels of cortisol, which is a primary stress hormone, was observed. This implies that intergenerational interactions, even robot-mediated, potentially contribute to stress relief in older adults. However, it is possible that the higher levels of cortisol prior to the interaction were because of anxiety about participating in the experiment. This is because older adults have little or no experience interacting with children through teleoperated social robots.

Enjoyment: In terms of enjoyment, of the 491 times the pupils stopped by the robot (including both the time of arrival and not), 465 were positive, 5 were neutral, and 21 were negative. The percentage of negative results (approximately 4%) was small. This result is consistent with the results of Q2 on Willingness to Work questionnaire.

Table 8 Averages and statistics of the blood test

Item (unit)	Pre	Post	W	p-value
Cortisol (μg/dL)	9.42	6.69	106.00	**0.0098**
GH (pg/mL)	562.89	871.63	48.00	0.51
DHEA-S (μg/mL)	0.65	0.64	70.00	0.59
Oxytocin (pg/mL)	1703.47	1789.80	36.00	0.18
d-ROMs (U.CARR)	295.60	306.20	26.00	0.057
BAP((umol/L))/d-ROMs	6.96	6.71	91.00	0.083

Bold text means 5% significance

6 General Discussion

This study contributes significantly to the emerging field of robot-mediated intergenerational interactions, offering novel evidence on benefits of children and older adults. Our findings demonstrate that robot-mediated interactions can effectively circumvent the limitations of traditional face-to-face interactions, which are particularly pertinent in the context of pandemics and physical limitations of older adults.

For Children: This robotic system has shown sufficient potential to accomplish the health-screening task with the children. Although there was a certain rate of pupils who did not complete the task primarily due to the experimental setting, the presence of the robot was rarely a bottleneck, and multiple robots would work well for the health-screening task. In addition, with continued long-term use, the pupils and robot appeared to get along well, even with a different teleoperator each day. Moreover, the nursery staff and parents who closely observed their children expressed a high level of satisfaction with the robot.

In summary, the results of the study suggest that a teleoperated robot system can assist in childcare in nursery schools and other facilities. The children's positive response and adaptability to the robotic system, underline the potential of this technology in educational and childcare settings. Moreover, satisfaction reported by nursery staff and parents reinforce the feasibility and acceptability of this approach in a real-world environment. Unlike telepresence robots and video calls, the proposed system provides the possibility of maintaining a relationship between the robot and the children even when a teleoperator is replaced by another.

On the other hand, we must not forget that some children did not get along with the robot, although only a few. It is assumed that this is due to individual preferences or experiences. Some improvement may be possible by modifying the way the robot is introduced, its appearance, and its physical movements. However, there would be a limitation that no matter how far we go, the robot will not be appropriate for all children.

In addition, there are a number of technical issues that need to be addressed in order to adapt this robotic system to childcare other than the health-screening task. In discussions with the nursery school, the most important issue that was felt to be a challenge was physical safety. Childcare activities include playing, eating, napping, etc. Since children are still immature, they are often cared for through physical contact. For example, holding hands to move around, using a spoon to bring food to the child's mouth, rubbing the child's body to help him or her fall asleep, etc. When a robot is engaged in a task that involves such physical contact, a safety mechanism to prevent children from being injured is key to its introduction. This is especially true if the teleoperator is cognitively declined or unfamiliar with the robot's teleoperation.

For Older Adult Teleoperators: Rrobot-mediated intergenerational interactions could bring several benefits to older adult teleoperators, including an improved attitude toward children and stress reduction. Additionally, the teleoperation experience can be generally positive for teleoperators. High scores on the work willingness questionnaire indicate a sense of job satisfaction and willingness to reengage in the role in the future. Although there were challenges related to communication and task complexity, only a few teleoperators found basic teleoperation difficult, indicating that robot-mediated interaction is feasible for older adults.

However, this study was not without limitations. First, the impact on some of the attitudes toward children and the teleoperators' mood states was not significantly evident, possibly because of the limited number of interactions that each teleoperator had. The past studies of face-to-face intergenerational interactions have evaluated after multiple interactions [18, 20, 31–33]. Therefore, future studies with longer intervention periods may yield more pronounced results.

Second, it is important to note that the results for older adults in this experiment cannot be ruled out as simply attributable to intergenerational interactions. The achievement of similar results may be possible by simply performing teleoperation tasks, regardless of the involvement with children. Future research should focus on investigating this aspect by conducting a comparative study with a condition that includes teleoperation but does not involve children. This can help to isolate the variables and better understand the precise impact of robot-mediated intergenerational interactions on older adults.

7 Conclusion

This study explored the feasibility and potential benefits of robot-mediated intergenerational interaction between older adults and small children in a nursery school setting. The findings of the study suggest that the proposed system is promising.

Our results suggest that a teleoperated robot system can successfully assist older adults in childcare tasks and foster positive interactions between them and children. Despite a somewhat high rate of task noncompletion, mostly owing to situational factors, the presence of the robot itself was rarely a bottleneck. With continuous usage, children and robots seem to develop a better relationship, even when the teleoperators change daily. This suggests the potential of teleoperated robots to offer sustainable and flexible childcare solutions, wherein multiple remote workers can interact with children using the same robot.

The proposed system offered multiple benefits for older adult teleoperators. Teleoperating social robots to interact with children improved their attitude toward children, reduced their stress levels, and was perceived as a rewarding and enjoyable experience. Their willingness to engage in this role again in the future was high, demonstrating the potential of robot-mediated intergenerational interactions as a form of meaningful engagement for older adults.

In conclusion, robot-mediated intergenerational interactions offer a promising avenue for facilitating meaningful interactions between children and older adults, addressing several practical limitations of traditional face-to-face interactions. This approach holds considerable potential for societal benefits, including improved social and emotional growth for children and enhanced psychological well-being and engagement for older adults. Future studies should further explore these benefits, investigate optimal strategies for the deployment of the system, and consider its broader implications for childcare and geriatric care.

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