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ORIGINAL RESEARCH PAPER

The effects of assistive walking robots for health care support on older persons: a preliminary field experiment in an elder care facility

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Abstract
In the present research, we prepared a human-size humanoid that autonomously navigates alongside with a walking person. Its utterances were controlled by Wizard-of-Oz method. A field experiment in which older persons walked in an elder care facility together with the robot while it talked to them was conducted to investigate the effects of robot accompaniment on older people requiring health care support in terms of increasing their motivation to engage in physical exercise. The participants ($N = 23$) were residents in the facility or persons with health problems who had been receiving day care at the facility. The experimental results suggested that (1) the participants enjoyed walking with the robot more than walking alone, (2) the physical burden did not differ between walking styles, and (3) walking with the robot evoked the participants' perception of novelty or stimulated an existing interest in assistive robotics, both leading to positive feelings.

Keywords Communication robots · Elderly · Health care · Walking · Field experiment

1 Introduction

The recent development of artificial intelligence and robotics technologies is well known among the general public. Hence, people have developed higher expectations regarding the use of robots in daily life, for instance, to help manage the care of older people and assist them in living independently. Several studies have investigated assistive robots for older people. Wada et al. used Paro, a seal-like robot that provides robot-assisted therapy with the aim of helping to prevent dementia [1]. Another study reported that a human-like communication robot could improve cognitive function in older individuals [2]. Robots are considered to be useful in a health care context [3] and have successfully been used to carry out tasks such as giving instructions to older persons [4] and providing prescription medicine reminders [5].

On the other hand, in a health care context, it is important to help older people maintain their physical health and ability to live independently, for which daily exercise is known to be important [6]. In 2011, the World Health Organization (WHO) presented recommendations for physical activities for adults aged 65 years and older, including walking [7]. Some studies have already begun investigating ways to use robots for this purpose. For instance, Fasola et al. developed a robot system to encourage older people to engage in physical exercise [8]. As recommended by the WHO, walking is known to be important for older people to improve cardiorespiratory and muscular fitness, bone and functional health, and reduce the risk of non-communicable diseases (NCDs), depression, and cognitive decline [9]. Hence, researchers have developed some mechanical devices to

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assist older adults in walking alone [10, 11]. In addition, recent studies have described the use of a mobile robot to assist older people in rehabilitation for walking [12] and to walk together with older people for motivation [13].

Although the usefulness of robots for encouraging people to maintain their physical health has been reported [8], few studies have investigated whether robots can help motivate older adults who require exercise, such as those who must use a cane or walker, to carry out physical activities. Therefore, it is important to investigate whether older adults would accept social robots if they were to be used in their health care program. Hence, we decided to conduct a study in a care facility for older adults who required physical activity.

As part of our investigation, we also decided to focus on perceived enjoyment. Exercise enjoyment is a psychological factor that encourages habitual exercise [14] and is considered important to influence the long-term effects of affective responses to exercise on mental health outcomes [15]. Thus, exercise enjoyment should be measured as an index of motivation to evaluate health care support systems for older persons. To our knowledge, no previous studies have sufficiently considered this factor when evaluating the effectiveness of assistive robotic systems. This subjective index could be used when health care support systems for older persons target those who have face challenges for which normal measurement methods such as questionnaires are ineffective.

Therefore, the present study aimed to investigate the effects of assistive walking robots on the motivation of older people in consideration of the following question: "Is walking with a robot more enjoyable for older persons who require urgent health care support compared with walking alone?" To investigate this question, we conducted a field experiment in which older persons walked in an elder care facility while being followed by a human-size humanoid robot. This paper reports the results of this experiment and discusses its implications in robotics applications for elder care.

2 Field experiment

2.1 Facility and participants

The field experiment was conducted at an elder care facility in the western part of Japan. The facility has several service sections and provides day care, a nursing home, and short-term stays. The present experiment was associated with the day care section.

A total of 23 older persons who were residents or had been practicing day care in the facility (men: $N=3$, women: $N=20$, mean age = 88.3 years, standard deviation [SD] = 5.7 years) participated in the experiment. The participants were selected by the facility staff, including a physical therapist, based on their physical and mental states. Among those selected, 20 required assistive equipment for walking, such as a cane or a walker. All of the participants were affected by internal or circulatory organ diseases, and about half had been diagnosed with dementia.

This study was approved by the ethical review board of ATR Intelligent Robotics and Communication Laboratories, with the number RIN-17-502-7. Informed consent for participation in the study was obtained from the participants and their families.

2.2 Robot used in the study

A wheeled humanoid robot, the Robovie-R3 developed by ATR Intelligent Robotics and Communication Laboratories (Fig. 1) [16], was used in the field experiment. The robot's maximum speed is 1.0 m/s and maximum acceleration is 0.8 m/s^2. This robot can interact with people through utterances and gestures. A 3D laser range finder (HDL-32E from Velodyne) was placed 1.40 m above ground level to enable it to gain sufficient visibility of its environment for localization and people tracking. In addition, a 2D laser range finder (UTM-30LX from Hokuyo) was placed near the ground surface (0.07 m above ground level) to observe obstacles and make emergency stops. This robot is equipped with wheel encoders and an inertial measurement unit (VG400 from Crossbow).

In the field experiment, the robot was programmed to move alongside each participant while maintaining a certain distance based on sensor data. During the walking session, the robot made utterances to the participant regarding light topics such as food, sports, and the weather (e.g., "What did you eat for lunch?", "It is fine weather today."). These utterances were manually controlled by one of the experimenters using a speech generation system embedded in the robot system.

2.3 Procedure

To compare older people's enjoyment between walking with robots and walking alone and answer the research question, the field experiment used a within-participant design consisting of a without-robot condition in which each participant walked alone and a with-robot condition in which he/she walked with the robot. In each condition, the participants walked back and forth once in a 47-m corridor of the facility (see Fig. 2).

In consideration of the burden on the participants and several constraints on the usage of time and space in the facility, the experiment was conducted for 3 days. On the first day (mid-December 2017), the experiment sessions for the without-robot condition were conducted for 18 participants. On

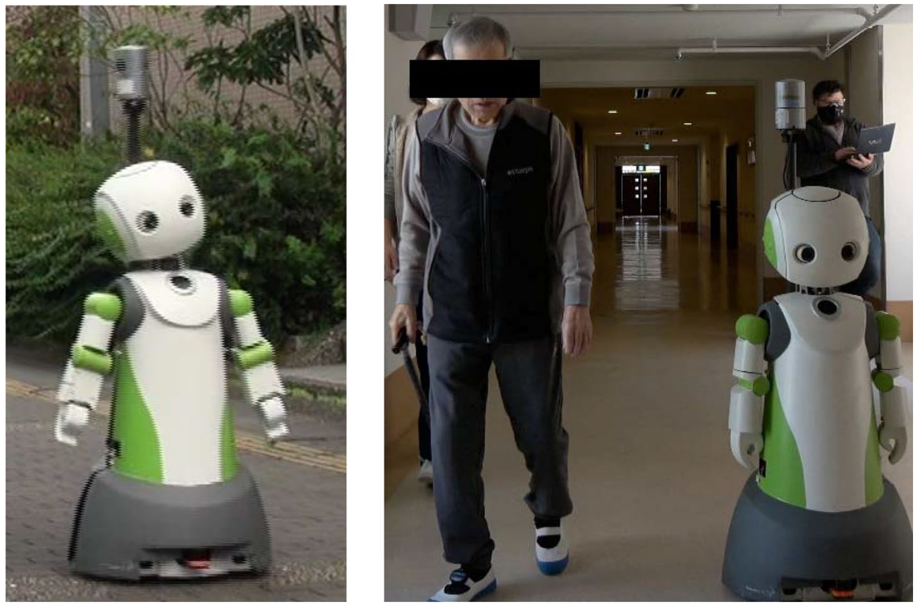

Fig. 1 The Robovie robot used in the field experiment

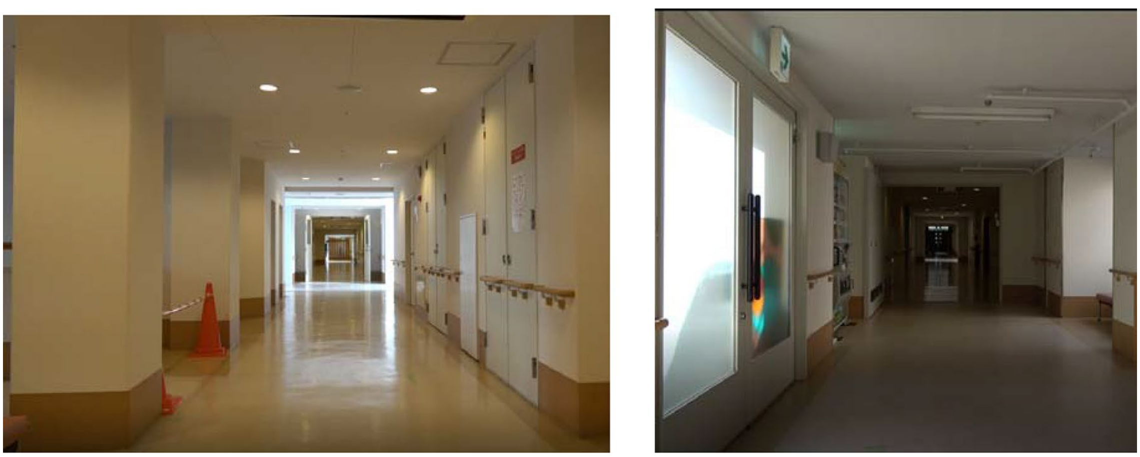

Fig. 2 The corridor in which the participants walked during the field experiment. (Left: view from the starting point, Right: view from the turning point)

the second day (5 weeks after the first day), the experiment sessions using the without-robot condition were conducted for the remaining five participants, and the sessions using the with-robot condition were conducted for nine participants who experienced the without-robot condition on the first day. On the third day (7 weeks after the first day), the remaining 14 participants experienced the with-robot condition.

Participants' task in the experiment was a round-trip walk in the corridor, that is, they were asked to walk toward the turning point and come back to the starting point. Each session was conducted as follows:

1. Before starting to walk, each participant was told to walk at his/her own pace because the experiment was not a competition about walking speed. Then, a pedometer was attached to his/her shoes to measure the number of steps taken during the round-trip walk in the corridor.
2. Under the without-robot condition, one facility staff walked with the participant while standing behind her/him to prevent accidents. Under the with-robot condition, in addition to the facility staff, two experimenters walked behind the participant while staying out of his/her view so that they could make detailed adjustments to the robot's movement and control the robot's utterances.
3. Under the without-robot condition, the participant walked alone in the corridor without interacting with anyone, except for receiving some instructions about the experiment from the facility staff and experimenters when necessary. Under the with-robot condition, the

robot made utterances to the participant regarding light topics such as food, sports, and the weather.

4. Immediately after walking, the pedometer was removed and the number of steps was recorded. Then, one of the experimenters interviewed the participant to obtain his/her subjective evaluation about walking with/without the robot.

2.4 Measurements

We measured the enjoyment of the participants in two ways: objectively and subjectively. For the objective measurement, we video-recorded the scenes of the experiment using two cameras, each placed at an opposite side of the corridor, i.e., the starting and turning points. Based on the recorded video, we conducted a standard method in psychology as follows: Two independent human coders (one of the authors and another person) manually decided whether each participant smiled or laughed at the end of the walking. Then, κ-coefficient was calculated to evaluate how well their codings matched. When this value is higher than 0.6, the results can be considered well matched and the codings valid.

As subjective indices, we measured the enjoyment and anxiety experienced by each participant during walking under each condition. Although the use of questionnaires is standard for evaluations of healthy young participants, many of the participants in the present field experiment had difficulty answering a complicated sentence-based questionnaire because of their health issues. Therefore, we assessed each participant's enjoyment and anxiety during walking via an interview after each session using face scales [17]. That is, enjoyment and anxiety during walking were measured using five-face facial scales, as shown in Fig. 3a and b, respectively. Finally, each participant was asked which of the without- and with-robot conditions was more enjoyable based on a three-face facial scale, as shown in Fig. 3c.

As a final physical measure, we calculated the time spent and steps taken by each participant to complete a round-trip walk in the corridor.

3 Results

3.1 Observations

All participants successfully completed a round-trip walk in the corridor under both the without- and with-robot conditions. As shown in Fig. 4, each participant walked at his/her own pace under the without-robot condition and sometimes adapted to the robot's pace under the with-robot condition. No participants showed excessive fatigue, and all provided complete answers in the interviews.

After the experiment, the facility staff asked some of the participants who could provide their opinions verbally regarding walking with the robot. Some of the positive responses were as follows:

- "This was my first experience walking with robots, and it was very valuable for me."
- "The robot was pretty."
- "I have heard some news on robots assisting humans, and I am very glad to have been involved in the development of these robots."
- "Although the robot uttered something, I could not catch what it said."

On the other hand, one participant had the following negative response:

- "Although the robot uttered something, I could not catch what it said."

In fact, during walking with the robot in the experiment, hardly any of the participants responded to the robot's utterances.

3.2 Behavioral indices

To investigate differences between the with- and without-robot conditions on the steps taken and time spent for a round-trip walk in the corridor, t tests were conducted for these variables. Figure 5 shows means and *SD*s of the indices and results of the *t* tests. No significant differences were found in these indices, although the participants spent more time under the with- than under the without-robot condition at a statistically significant trend level and a moderate effect size. Since tests of normality revealed that the assumption of normality was rejected in these variables, except for the steps in the without-robot condition ($p = 0.075$ in the steps of the with-robot, $p = 0.200$ in the steps of the without-robot, $p = 0.001$ in the time of the with-robot, $p = 0.029$ in the time of the without-robot), Wilcoxon tests were additionally conducted. The results of the tests showed the same tendency ($p = 0.543$ in the steps, $p = 0.073$ in the time).

Regarding the enjoyment index based on participants' smiling or laughing at the end of the walking, the κ-coefficient was 0.603, indicating sufficient validity. The coders reached consensus on whether each participant smiled or laughed based on discussions.

Table 1 shows the numbers of participants who smiled or laughed and the results of a chi-square test. As a result, more participants showed their laugh in walking with the robot compared with walking alone at a statistically significant level and a moderate level of effect size.

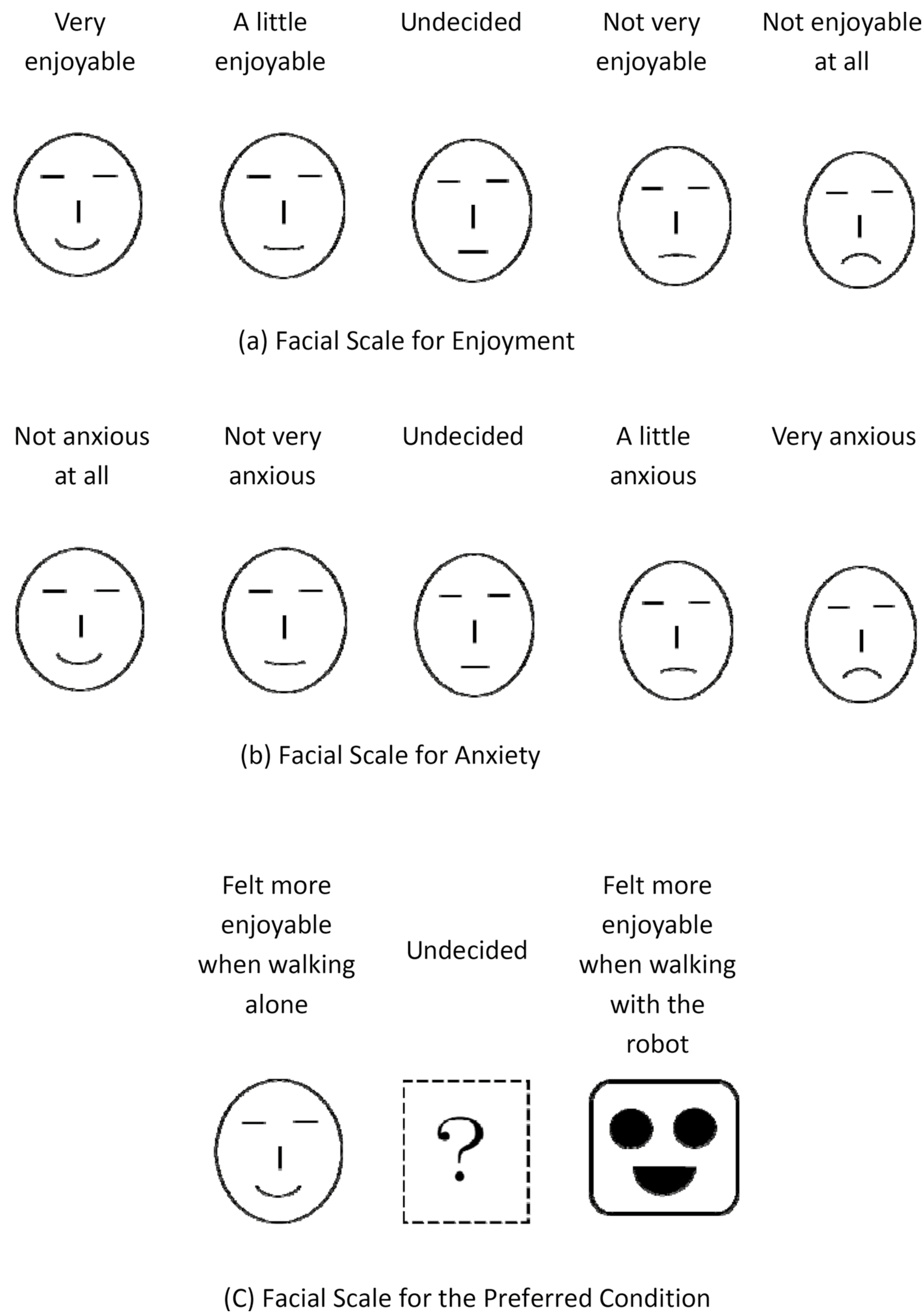

Fig. 3 Facial scales used for the subjective indices

3.3 Subjective indices

Enjoyment and anxiety during walking were coded from 1 to 5, with higher scores indicating more positive feelings. *T* tests were conducted for these subjective indices to investigate the differences between the with- and without-robot conditions. Figure 6 shows the means and *SD*s of the indices and the test results. Although no significant differences were found for anxiety, the participants reported experiencing significantly more enjoyment under the with- than under the without-robot condition with a large effect size. Since tests of normality revealed that the assumption of normality was rejected in these scores ($p < 0.001$ in the enjoyment of the with-robot, $p = 0.013$ in the enjoyment of the without-robot, $p < 0.001$ in the anxiety of the with-robot, $p < 0.001$ in the anxiety of the without-robot), Wilcoxon tests were additionally conducted for these variables. The results of the tests showed

Fig. 4 Scenes of participants walking in the field experiment. (Left: without-robot condition, Right: with-robot condition)

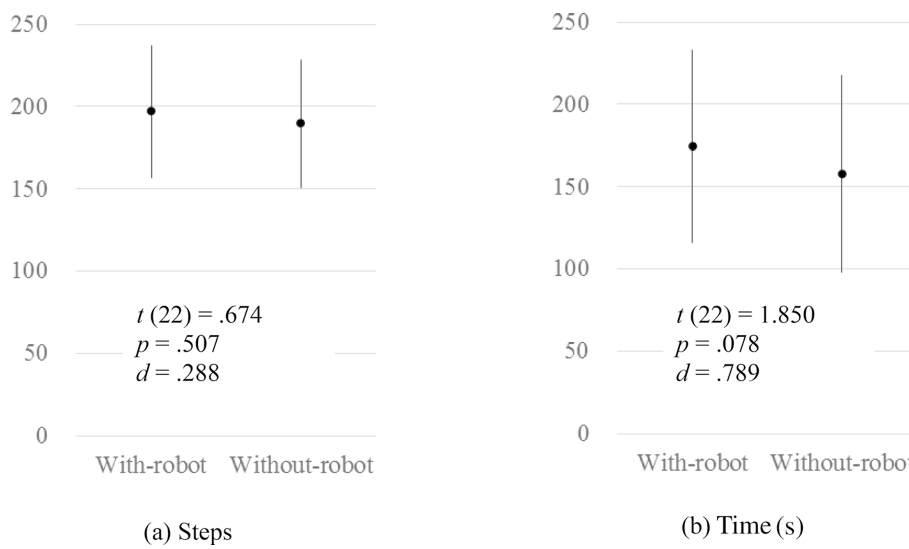

Fig. 5 Means and standard deviations of time spent and steps taken for round-trip walk in the field experiment, and the results of the *t* tests

Table 1 The numbers of participants who smiled or laughed after walking, and results of the chi-square test

Condition	With-robot	Without-robot
Laugh	$N=6$	$N=1$
No-laugh	$N=17$	$N=21$

$\chi^2(1)=3.972$, $p<0.05$, $\phi=0.297$

One participant data lacked under the without-robot condition

the same tendency ($p=0.009$ in the enjoyment, $p=0.163$ in the anxiety).

Table 2 shows the responses for enjoyment under both conditions and the results of a goodness-of-fit test for investigating the presence of a distribution bias in the responses using chi-square distribution. The results indicated that more participants preferred walking with the robot over walking alone.

4 Discussion

4.1 Findings

Regarding our research question "Is walking with a robot more enjoyable for older persons who require urgent health care support compared with walking alone?", the field experiment provided some affirmative answers. The results of the analysis of enjoyment (the facial scales and smiling/laughing) suggested that the participants in the experiment

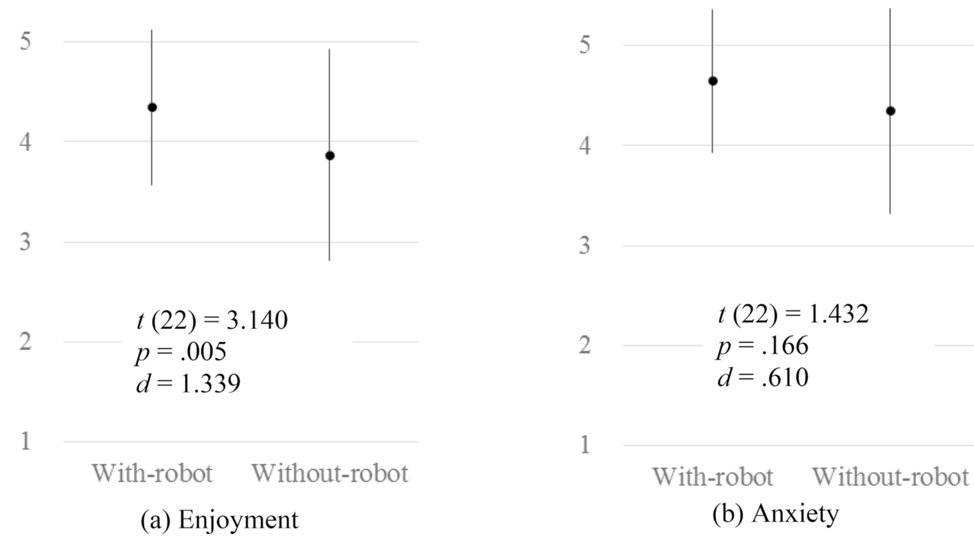

Fig. 6 Means and standard deviations of subjective evaluation scores for the round-trip walk in the field experiment, and results of the *t* tests

Table 2 Responses for enjoyment under both conditions and the results of a goodness-of-fit test

Answer	Robot	Undecided	Alone
N	18	4	1

χ^2 (2) = 21.48, $p < 0.01$

experienced more enjoyment from walking with the robot than from walking alone. Moreover, the results of the time and steps analysis revealed no differences in physical burden between walking styles in the experiment, although the effect size suggested the possibility of an influence based on the time. The comments from some participants suggested that walking with the robot evoked a perception of novelty or stimulated an existing interest in assistive robotics, resulting in positive effects.

On the other hand, utterances from the robot did not encourage communication with the participants during walking. Talking while walking is considered a dual task that places a cognitive burden on older persons [18, 19], and these burdens may have inhibited communication between the participants and the robot.

4.2 Implications

This field experiment was conducted as a part of day care services in an elder care facility. The results suggested the novelty of and interest in walking with a robot may have had positive effects on the participants and the staff. In other words, robots used in care facility activities, even those at the current technological level, can help promote physical exercise in older people.

Utterances from robots may not motivate older people to participate in walking exercises. By contrast, it may be possible that robots utterances inviting older people to participate in walking exercises may cause some positive effects into those who feel as though physical exercise is bothersome.

4.3 Limitations

Although the results of the present field experiment showed that robots may help encourage older people to participate in walking exercises, it is difficult to generalize the results because of the use of a single type of robot, the physical and mental states of the participants, the fact that only Japanese participants were analyzed, and the fact that the study was conducted in a single facility. Moreover, it remains unclear whether the robot alone influenced the participants' feelings, or whether these were the results of group dynamics involving mutual interaction effects between the robot, staff, participants, and experimenters. In addition, the experiment lacked a part of strict procedures to be conducted such as randomization of the conditions, more objective measures, and gender balance due to several schedules other than our experiment in the facility and avoidance of the participants' burden. In this sense, this study remains preliminary. These problems should be investigated in future studies. In particular, the effects of walking with robots on older persons who feel as though physical exercise is bothersome should be examined.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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