Living With Seal Robots—Its Sociopsychological and Physiological Influences on the Elderly at a Care House

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***Abstract*—Robot therapy for elderly residents in a care house has been conducted since June 2005. Two therapeutic robots were introduced into a care facility, and activated for over 9 h each day to interact with the residents. This paper presents the results of the first month of this experiment. To investigate the psychological and social effects of the robots, each subject was interviewed, and their social network was analyzed. In addition, the activities of the residents in public areas were recorded by video cameras during daytime hours (8:30–18:00). For physiological analysis, residents' urine was obtained and analyzed for hormones 17-ketosteroid sulfate and 17-hydroxycorticosteroids. The experimental protocol was reviewed and approved by the ethical committee of the National Institute of Advanced Industrial Science and Technology. The results indicate that interaction with the seal robots increased their social interaction. Furthermore, the urinary tests showed that the reactions of the subjects' vital organs to stress improved after the introduction of the robots.**

***Index Terms*—Elderly care, human–robot interaction, mental commit robot, psychotherapy, robot therapy.**

I. Introduction

A LACK of social and community ties leads to loss of health. Over the last several decades, social psychologists have investigated the relationship between social ties and the health of elderly people. For example, Berkman and Syme assessed the relationship between social and community ties and mortality [1], and found that people who lacked social and community ties were more likely to die in the follow-up period than those with more extensive contacts. Zunzunegui *et al.* found that poor social connections, infrequent participation in social activities, and social disengagement predict increased risk of cognitive decline in elderly individuals [2].

Interaction with animals has long been known to be emotionally beneficial to people. The effects of animals on humans have been applied to medical treatment. In the United States, in particular, animal-assisted therapy (AAT) and animal-assisted activities (AAA) are now widely used in hospitals and nursing homes [3], [4]. AAT has clear goals, defined by therapy programs designed by doctors, nurses, or social workers, in cooperation with volunteers. AAA, however, refers to patients interacting with animals without any particular therapeutic goals, and depends on volunteers.

Animal therapy is expected to have three effects:

1) psychological effects (e.g., relaxation, motivation);
2) physiological effects (e.g., improvement of vital signs);
3) social effects (e.g., stimulation of communication among inpatients and caregivers).

However, although the positive effects of animal therapy are known, most hospitals and nursing homes, particularly in Japan, do not accept animals. The medical staffs fear the negative effects of animals on humans, such as allergies, infections, bites, and scratches. In addition, animal handlers are needed to prevent accidents, and these programs depend on many volunteers.

Meanwhile, the rapid development of high technology has produced robots not only for factories, but also for homes, hospitals, and museums. Human-interactive robots for psychological enrichment are expected to be a new area for robot application, attracting both researchers and companies [5]. Robots are being developed for entertainment, communication (social activity), as guides, edutainment, welfare, and mental therapy. Robots have been developed with various appearances, ranging from humanoid, to animal and those with a unique appearance. Examples include Sony's dog robot AIBO [6], Omron's cat robot NeCoRo [7], and Tiger Electric's new character robot Furby [8]. Like pets, these robots entertain and communicate with people. Replicas of King Kong and the robotic dinosaurs developed by SARCOS [9], animal type robots in many movies, and robotic fishes in an aquarium in Japan [10] are good examples of entertainment applications. Recent humanoid robots, such as Honda's ASIMO [11] and Sony's QRIO [12], can also entertain people. A new character robot Kismet [13] and the anthropologic robot Robovie [14] have been developed to study human–robot communication. In museums, the mobile robot RHINO [15] and anthropologic robot HERMES [16] guide visitors. Kokoro's ACTROID [17] mimics a real woman, and acts as the visitor information receptionist at the entrance of Aichi EXPO. Contests between robots, such as Micro-mouse, RoboCup [18], and RoboOne [19] (remote controlled humanoid robots that wrestle) are popular examples of edutainment. LEGO Mindstorms and I-Blocks are other examples [20].

For welfare and mental therapy, we studied and developed a mental commit robot, which aims to engender mental effects,

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such as pleasure and relaxation, in their role as personal robots. We also propose a robot therapy, which uses robots as substitutes for animals in AAT and AAA [5], [21]–[39]. The major goals of this research were:

1) investigation of psychophysiological influences on human–robot interaction, including long-term interaction;
2) development of a design theory for therapeutic robots;
3) development of a methodology for robot therapy.

Robot therapy consists of robot-assisted therapy programs designed by doctors, nurses, and social workers, and robot-assisted activity that allows patients to interact with robots without any particular therapeutic goals. These activities do not depend on volunteers, but are conducted by facility staff.

We developed a mental commit robot, named Paro, especially for robot therapy, and used it at pediatric hospitals and several facilities for the elderly, such as day service centers and health service facilities for the aged [27]–[31]. The results showed that interaction with Paro improved people's moods, making them more active and more communicative, both with each other and their caregivers. Results of urinary tests revealed that interaction with Paro reduced stress among the elderly [31]. In addition, we investigated the long-term interaction between Paro and the elderly, and found that the effects of interaction with Paro lasted for more a year [32]. Furthermore, the neuropsychological effects of Paro on patients with dementia were assessed by analyzing their EEGs [33]. The results showed that interaction with Paro improved the activity of the patients' cortical neurons, especially for those who liked Paro. Meanwhile, studies have been conducted using questionnaires given out at exhibitions held in six countries (Japan, U.K., Sweden, Italy, Korea, and Brunei), to investigate how people evaluate the robot. The results showed that the robot was widely accepted, regardless of cultural differences [5], [34], [35].

With regard to other research groups, Werry and Dautenhahn used mobile robots and robotic dolls for treating autistic children [40], and robot therapy, using commercially available animal type robots, such as AIBO [6] and NeCoRo [7], has been attempted [41]–[45]. For example, Yokoyama used AIBO in a pediatrics ward, and observed the interaction between children and the robot [41]. He pointed out that when people met AIBO for the first time, they were interested in it for a brief period. However, AIBO never produced relaxation effects, such as those obtained from petting a real dog. In other examples, Libin introduced NeCoRo to a nursing home, and observed their interaction [42]. Ohokubo *et al.* used AIBO, NeCoRo, etc. at pediatric wards, depending on volunteers, and then, investigated its influences by observation and with questionnaires [43]. Kanamori *et al.* examined the effects of AIBO on the elderly in a nursing home [44]. By measuring hormones in saliva, they found that stress decreased after a 1-h interaction with AIBO and loneliness improved after 20 sessions over a seven-week period. Tamura *et al.* compared exposing patients to AIBO with the effect of a toy dog [45]. They found that AIBO encouraged interaction less, and required more intervention from occupational therapist.

Because they are not designed for therapy, these commercially produced robots are easily broken by interaction with people. Therefore, it is difficult to use them in long-term situations.

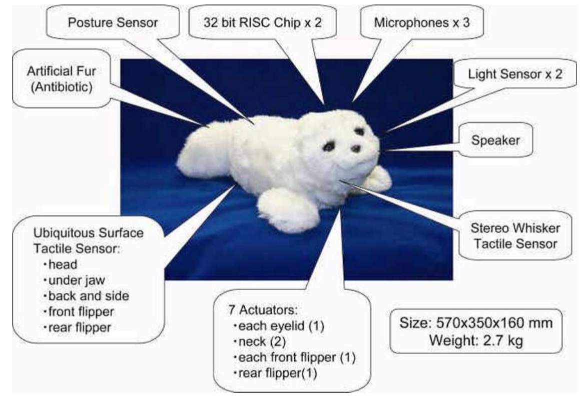

Fig. 1. Seal robot: Paro.

In this research, we introduced Paro to a care house, where relatively self-supporting elderly people reside. These people are provided with basic daily support, such as assistance with meals and bathing [36]–[38]. Two Paro robots were activated for over 9 h each day in a public area to investigate how people interact with Paro, and to determine its sociopsychological and physiological effects on the residents.

To investigate changes in the residents' social interactions, with each other and with Paro, we interviewed each subject using the free-pile sort method [46], which used deck of cards representing the residents' name, and we recorded the activities of the residents in the public areas with video cameras during daytime hours (8:30–18:00). Moreover, the levels of hormones 17-ketosteroid sulfate (17-KS-S) and 17-hydroxycorticosteroids (17-OHCS) in the residents' urine, which indicate the level of stress, were obtained and analyzed to investigate the physiological effects of the interaction with Paro. In this paper, we present the detailed results of this experiment over the first month.

Section II describes the robot used for robot therapy; Section III describes the experimental methods; Section IV describes the results; Section V discusses the current results of robot therapy and future work; and Section VI provides the conclusion.

II. Paro, The Seal Robot

Paro, the seal robot, is shown in Fig. 1. It is designed using a baby harp seal as a model for its appearance, and is covered with pure white fur. Ubiquitous surface tactile sensors are inserted between the hard inner skeleton and the fur to create a soft, natural feel, and to permit the measurement of human contact with Paro [39]. Paro is equipped with four primary senses—visual (light sensor), audio (determination of sound source direction and speech recognition), balance, and tactile senses. Its moving parts include vertical and horizontal neck movements, front and rear paddle movements, and independent movement of each eyelid, which is important for creating facial expressions. Paro weighs approximately 2.8 kg. Its operating time with the installed battery is approximately 1 h. However, Paro can continue operation using a battery charger, which resembles a pacifier.

Paro has a behavior generation system (Fig. 2) consisting of two hierarchical process layers: proactive and reactive. These

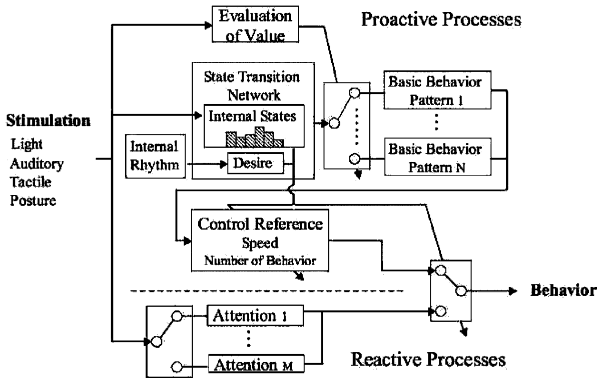

Fig. 2. Behavioral generation system of Paro.

two layers generate three types of behavior: proactive, reactive, and physiological.

A. Proactive Behavior

Paro has two layers that generate proactive behavior: a behavior-planning layer and a behavior-generation layer. By addressing its internal stimulation states, desires, and rhythm, Paro generates proactive behavior.

1) Behavior-Planning Layer: This consists of a state transition network, based on Paro's internal states and desires, produced by its internal rhythm. Paro has internal states that can be described with words that indicate emotions. Each state has a numerical level, which changes according to the stimulation. Moreover, each state decays with time. Interaction changes its internal states, and creates Paro's character. The behavior-planning layer sends basic behavioral patterns to the behavior-generation layer. The basic behavioral patterns include several poses and movements. Here, although the term "proactive" is used, the proactive behavior is very primitive compared to that of human beings. We programmed Paro such that its behavior is similar to that of a real seal.

2) Behavior-Generation Layer: This layer generates control references that allow each actuator to perform the determined behavior. The control reference depends on the magnitude of the internal states and their variations. For example, various parameters can change the speed of movement and the number of instances of the same behavior. Therefore, although the number of basic patterns is finite, the number of emerging behaviors is infinite because of the varying number of parameters. This creates a lifelike behavior. In addition, to gain attention, the behavior-generation layer adjusts the parameters according to the priority of reactive and proactive behaviors based on the magnitude of the internal states. This contributes to Paro's behavior, and makes it difficult for a subject to predict Paro's actions.

3) Long-Term Memory: Paro has reinforcement learning. It places positive value on preferred stimulation, such as stroking. It places negative value on undesired stimulation, such as beating. Paro assigns values to the relationships between stimulation and behavior. Users are prevented from changing its behavior program manually; however, Paro can be gradually tuned to the preferred behavior of its owner. In addition, Paro can memorize a frequently articulated word as its new name. Users can give Paro their preferred name during natural interaction.

TABLE I
BASIC ATTRIBUTES OF 12 SUBJECTS

Sex	Male	1
	Female	11
Age (avg. ± sd)		77.5 ± 7.3
MMSE (avg. ± sd)		25.3 ± 3.9

B. Reactive Behavior

Paro reacts to sudden stimulation. For example, when it hears a sudden, loud sound, Paro pays attention to it by looking in the direction of the sound. There are several patterns of combination of stimulation and reaction. These patterns are assumed to be behavior that is conditioned and unconscious.

C. Physiological Behavior

Paro has a diurnal rhythm. It has several spontaneous needs, such as sleep, based on this rhythm.

III. ROBOT THERAPY IN A CARE HOUSE

A. Care House

The experiment was conducted in the care house "Mori-no-Ie" in Tsukuba city, Ibaraki prefecture, Japan. A care house is a type of communal housing that provides basic daily care, such as assistance with meals and bathing to the residents. In general, the residents of care houses are over 60 years old. They have physical difficulties with regard to preparing their own meals and living alone. At the beginning of this experiment, 28 residents lived in the care house. We explained the purpose and procedure of the experiment to the residents, of which 12 residents gave their consent for participation in accordance with the ethical committee of the National Institute of Advanced Industrial Science and Technology (AIST). All of the residents agreed to the installation of video cameras in public areas of the house.

B. Subjects

Table I shows the basic attributes of the 12 subjects, aged 67–89 years, including one male. The subjects' mental cognitive states were assessed by the Mini Mental Status Examination (MMSE) [47]. Scores of less than 21 correspond to dementia, and their scores ranged from 15 to 29.

C. Methods of Interaction With Paro

The care house was situated on three floors. The first floor houses a dining room, a hall, and an office. Paro was introduced in the public areas of the second and third floors, which were residential floors. Caregivers activated Paro on the table in the public space of each floor at 8:30 and returned them to the office at 18:00. The residents could play with Paro whenever they wished during that time. Before introducing Paro, we explained that Paro is a robot and described its operation to the residents.

D. Interview

A free-pile sort method was used to investigate social ties among the residents [46]. This method uses a deck of cards, with one card representing each of the residents in the care house. The interviewee sorts them, and then, talks through the sort. Several blank cards are kept at hand. If the informant feels there are people missing, they are asked to fill in those people on the blank cards. They can sort these cards using their own classification system, and during that time, they build a network. The stack of cards is shuffled randomly and returned to a respondent with the following instructions: "Here are a set of cards representing the names of residents in this care house. I'd like you to freely sort them into piles. You can use as many or as few piles as you wish. Go!" An additional instruction: "For example, you can make the piles of your friends, those you eat meals together with, etc." was given to the people who couldn't understand how they should be sorted.

Regarding their relationship with Paro, people were interviewed using the following questions.

1) How is your daily life after introduction of the robots?
   a) Do you speak to and touch the robot?
   b) When do you play with the robot?
   c) How often do you play with the robot?
   d) What do you call the robot?
   e) Is the robot necessary/unnecessary in this house?
   f) What is the robot to you?
2) Are there any changes in your daily life?

At the beginning of the interview, a respondent was asked the first question, "How is your daily life since the introduction of the robots?" When the subject answered the question freely, the first author asked him/her the rest of items interactively.

The subjects were interviewed individually, using these methods, first at the beginning of the experiment, and then, one month later. Each interview lasted for approximately 30 min to 1 h.

E. Video Recording System

To objectively investigate changes in their social interaction with each other and with Paro, the activities of the residents in the public areas were recorded by video cameras during daytime hours (8:30–18:00) over three weeks before Paro was introduced. Since the video data obtained were too extensive to record on videotapes, each video camera was connected to an HDD video recorder (HDD: 250 GB, maximum recording time: approximately 460 h) to store the data automatically (Fig. 3).

Fig. 4 shows a map of the residential floor. Each video camera was located in a corner of the public areas on the second and third floors. The area that the video camera recorded is shown in gray. An example of a recorded image is shown in Fig. 5. We measured how long residents remained in the public area.

We classified the time spent in the public area into the following categories.

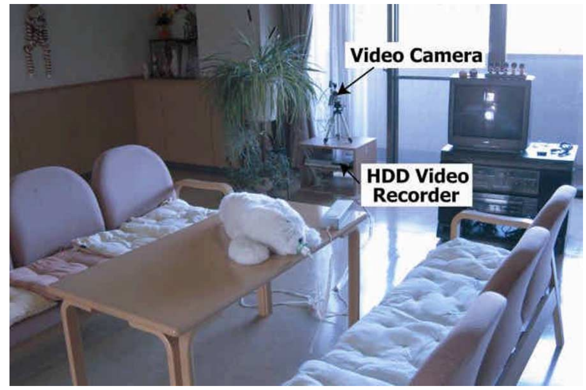

Fig. 3. Video recording system.

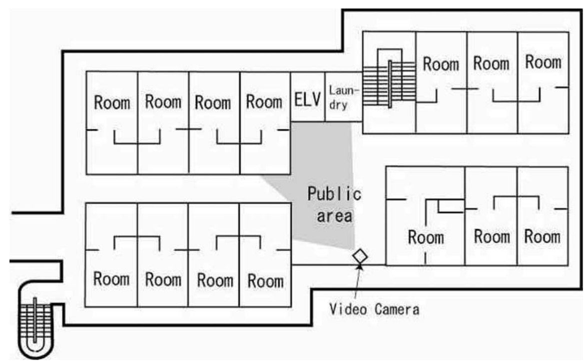

Fig. 4. Map of second floor (third floor is same as second floor).

Fig. 5. Scene recorded by the video camera on third floor.

1) Time spent, including interaction with Paro and other people: The resident had more than one interaction with Paro and other people during the time.
2) Time spent, including interaction with Paro: The resident had more than one interaction with Paro during the time, but no interaction with other people.
3) Time spent, including interaction with other people: The resident had more than one interaction with other people, but no interaction with Paro.
4) No interaction: The resident had no interaction with Paro or other people during the time.

We analyzed the video data from June 1 to July 24, for a total of 954 h of data. (We could not obtain data for July 5 and 6 on the second floor because of problems with the recorder.)

F. Urinary Test

To measure stress, it is possible to use urinary tests that are convenient and noninvasive. For this purpose, we measured the hormones 17-OHCS and 17-KS-S in the urine of the residents.

The 17-OHCS level rises during stress [48], whereas 17-KS-S has high levels in healthy individuals and decreases with failing health or the progress of disease [49]. In addition, the 17-KS-S value exhibits sensitivity to changes in psychological and social factors and relates greatly to a person's will, desire, and energy. The calculation of the 17-KS-S/17-OHCS ratio reveals dissonance in living organisms brought about by stress and/or gaining an inclusive understanding of the reactions of the living organisms. It is reported that the 17-KS-S/17-OHCS ratio clearly indicates a low value (0.15 or less) under social and psychological stress, and rises when the cause of the stress is eliminated. Both 17-KS-S and 17-OHCS values are shown in the ratio of creatinine (milligrams per gram creatinine). As a result, the influence of physique (such as racial differences and sex differences) was decreased.

Subjects' urine was collected and analyzed in the early morning. Each value was corrected with the creatinine.

Urinary tests were conducted on each subject three to five days before, and every two weeks after, the introduction of Paro. The median hormone values before the introduction of Paro served as the base condition for each subject. In the statistical analysis, Wilcoxon's sign rank sum test, together with Bonferroni's multiple comparison, was applied to the values for the week before, and two and four weeks after the introduction of Paro. These statistical analyses were carried out using SPSS 12.0 for Windows.

IV. Results of the Robot Therapy

A. Social Interactions Between the Subjects and Paro

We extracted social interaction (with residents and with Paro) information from the interviews. We classified them and defined the strength of social ties with other residents and with Paro as follows:

1) Interaction with other residents
   No tie:
   a) Do not know the resident.
   Weak tie:
   b) Knowing his/her name. But for greeting and small talk only.
   Moderate ties:
   c) Having meal at the same table.
   d) Going to the dining room together.
   e) Belonging to the same clubs.
   Strong ties:
   f) Playing cards together.
   g) Meeting voluntarily and talking in public areas.
   h) Visiting his/her room.
   i) Going for a walk, shopping together.
   j) Cooking a small dish and exchanging it.
2) Interaction with Paro
   No tie:
   a) Disregard
   Weak ties:
   b) Greeting when passing by.
   c) Joining the interaction only when somebody was playing with it.
   Moderate ties:
   d) Talking to it when passing by.
   e) Stroking and petting it.
   f) Naming it.
   Strong ties:
   g) Voluntarily leaving own room to play with it.
   h) Grumbling and sharing own feelings with it.
   i) Grooming it.
   j) Inviting somebody to play with it together.

For instance, a resident visited resident B's room and his/her only interaction with Paro was a greeting; in this case, the resident was defined as having a strong tie to resident B and a weak tie to Paro. Before the introduction, all the residents knew each other name.

B. Social Network Analysis

As the next step, we investigated changes in the social networks of the subjects. We excluded two subjects living on second floor from the analyses because the health of one deteriorated and that person could not come to the public area. The other had a problem (unrelated Paro) with other residents after the introduction of Paro, and changed her social interactions. In addition, we excluded subject D from this social network analysis because she grudgingly answered the pile sort. Fig. 6(a) and (b) shows sociograms for the tie strength of nine subjects before and after Paro's introduction. For instance, solid arrow A to B means subject A had strong ties with subject B. In Fig. 6(b), moderate and strong ties to Paro are depicted by broken and bold broken arrows. We calculated the density of the each social network of the subjects [50].

The density formula for these directed graphs is

$$\text{density} = \frac{l}{n(n-1)} \quad (1)$$

where l is the number of lines present and n is the number of points [e.g., $l = 14$, $n = 9$ in Fig. 6(a)]. The density before Paro's introduction [Fig. 6(a)] was 0.19 compared with 0.23 [Fig. 6(b)] after. Paro's introduction increased the density. This result applies particularly to the changes in subject G, who avoided other residents, and usually stayed her room before Paro's introduction. After the introduction, whenever she found someone playing with Paro, she voluntarily joined the interaction and talked with other people.

As for relationships with Paro, subjects A and E had no ties with Paro. Subject A, a male aged 89, said "I'm too old to be relaxed by (playing with) such a thing." Comments from subject E, female aged 71, were "I never interact with the robot,

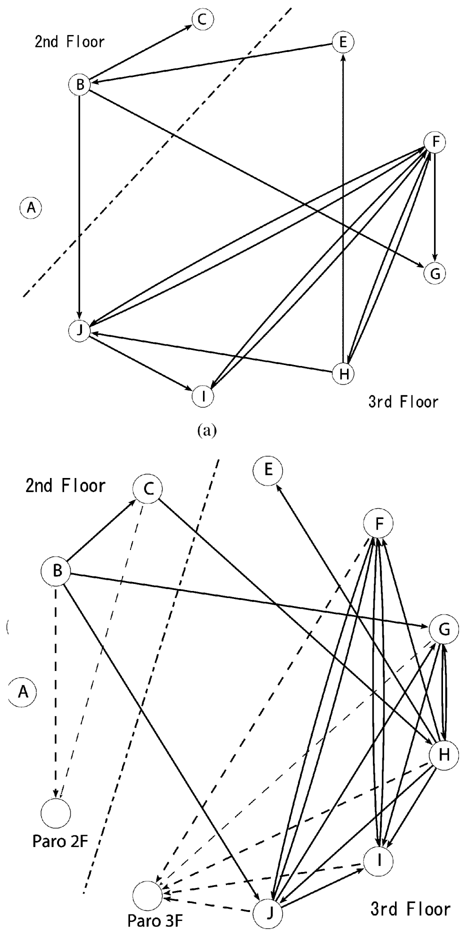

Fig. 6. Change of social network of nine subjects. (a) Before the introduction of Paro (June, 2005) density of the network = 0.19. (b) After the introduction of Paro (July, 2005) density of the network = 0.23.

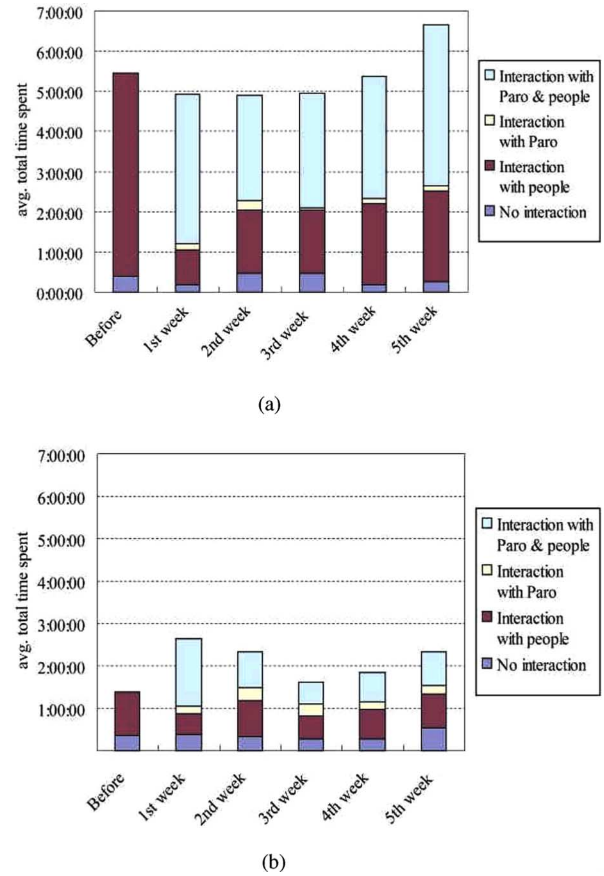

Fig. 7. Change of total time spent in the public area. (a) Second floor. (b) Third floor.

without a thought ... I might be heartless." However, most subject had moderate to strong ties with Paro. The subjects greeted Paro whenever they passed by, and addressed it by the names that they had given it: Paro, Shi-shi maru, Mori-kun, Mori-chan, Shiro, etc. For example, "See you, Shi-shi maru." "Watch the house please." "I'm back! Were you a good boy?" They stopped at Paro's place, especially after the meals, and stroked and soothed Paro like a baby. They talked about Paro's feelings and functions—it looks happy and hungry, Paro does not like whiskers, it awakens on hearing someone's footstep, etc. The subjects commented that the atmosphere was brighter, the people became more talkative and that abuse from others had decreased. One subject said, "Everyone greets Paro because the residents are starved for affection and conversation with children." "I feel a relaxed atmosphere when I see someone playing with Paro."

C. Results of Video Analysis

Fig. 7(a) and (b) shows changes of the average total time spent, per day, in public areas on the second and third floor. The maximum time spent at one time was 2:41:32, and the minimum time spent was 1 s.

Before Paro's introduction, subjects on the second floor stayed in the public area for longer periods than subjects on the third floor. These subjects were relatively communicative. They talked about the weather, disease, and gossiped about other residents. Moreover, four subjects played cards in the area. In contrast, most subjects on the third floor only passed the corridor. Typically, two or three spent few minutes in the area before meals, waiting for friends.

During the first week of Paro's introduction, the average total time spent on the third floor increased dramatically from about 1.4 h to over 2.5 h. In particular, the time spent that included interaction with Paro and people was about 1.5 h. There were many scenes in which a person happened to be passing the public area while another person was interacting with Paro, and they stopped and communicated. The time spent decreased after the second week; however, it was still longer than before Paro's introduction. This means that the subjects became accustomed to Paro's existence.

The time spent in the public area on the second floor, however, decreased from about 5.5 to 5 h. The reason was that subjects on the second floor stopped playing cards because those who were excluded from the analysis could not spend time in the public area. However, the time spent gradually increased after the fourth week. The time spent interacting with Paro and people increased to 4 h in the fifth week.

TABLE II
CHANGE OF HORMONES VALUES IN URINE OF NINE SUBJECTS

Hormones	Before	2 weeks after	4 weeks after
17-KS-S	1.00 ± 0.51	1.32 ± 0.78*	1.41 ± 1.09
17-OHCS	6.49 ± 3.74	6.53 ± 3.50	5.12 ± 2.73
17-KS-S /17-OHCS	0.18 ± 0.08	0.22 ± 0.10*	0.26 ± 0.09*

Comparison with Before: *$p < 0.05$

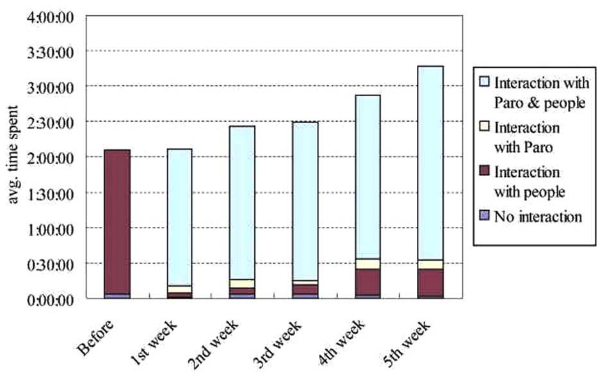

Fig. 8. Change in the total time subject D spent in the public area.

D. Results of the Urinary Test

We were able to obtain data from nine subjects. Table II shows the results. The hormone value of 17-KS-S and the 17-KS-S/17-OHCS ratio significantly improved after the introduction of Paro. In particular, significant improvements in the 17-KS-S/17-OHCS ratio were shown in the two weeks following Paro's introduction. We consider that the interaction with Paro and with other people (through Paro) physiologically improved the reactions of the residents' vital organs.

E. Case Studies

Subject D, a female aged 82, whose MMSE score was 15, resided on the second floor. She moved to the care house approximately five years before, when her husband died. Her only relative was a son, who usually visited her approximately once a month. She loved dogs and had owned five dogs. In the care house, she had a friend, who often asked her things; however, she was not eager to communicate with the other residents because she spoke in a dialect and was afraid of getting caught in an argument. She said, "It is safer to keep to oneself than talk to the others . . . because women suddenly make fish-fights."

Fig. 8 shows the average time that subject D spent in the public area on the second floor. Before Paro, she spent her time playing cards and talking with her friends. This seemed to be more out of politeness than desire. After Paro's introduction, she stopped playing cards because there were not enough people to play with. Nevertheless, the time she spent in the public area increased. She often came out from her room to see where Paro was and played with Paro for a while. She treated Paro as her pet and trained it to perform greetings. During her interaction with Paro, other residents communicated with her as they passed by the public area.

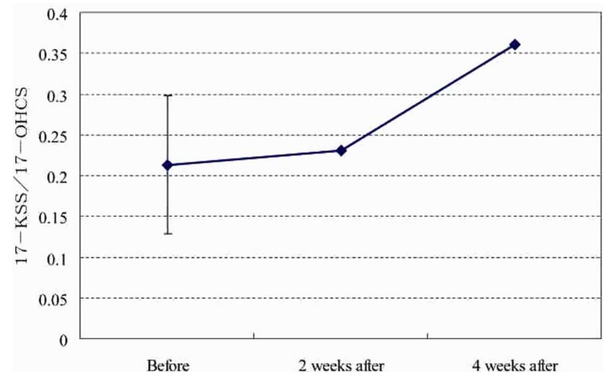

Fig. 9. Change in the 17-KS-S/17-OHCS ratio value of subject D.

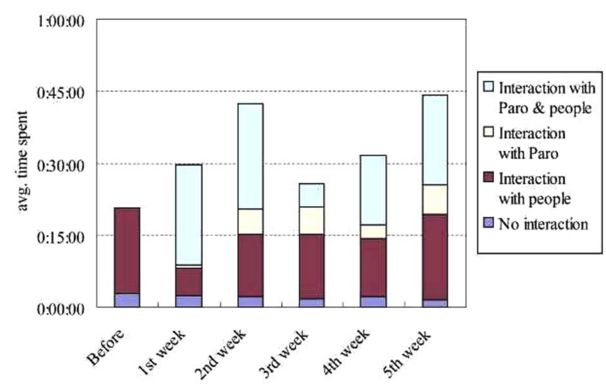

Fig. 10. Change in the total time subject I spent in the public area.

Fig. 9 shows the change in the 17-KS-S/17-OHCS ratio value of subject D. The value increased from 0.21 to 0.36. Therefore, it can be concluded that her vital organs improved after the introduction of Paro. In an interview one month after Paro's introduction, she commented, "I feel much better since Paro was brought here. Somehow, I feel like I have a new playmate. As you know, there is no play and no fun in the rooms . . . It is very interesting and a lot of fun. I feel lonely when Paro isn't here."

Subject I, a female aged 75 years, whose MMSE score was 27, resided on the third floor. She had been living in this care house for five years. She had lived in her hometown for 70 years and wished to die there. However, her husband became ill and was hospitalized. To have her daughter's help in looking after him, she had to leave her hometown and move close to her daughter. Unfortunately, her husband died last year (2004). At almost the same time, as a result of long-term nursing, she developed autonomic ataxia, for which she took some medication. In the care house, she had only one friend. Because she spoke in a dialect, and suffered from a complex because of it, the friend was the only one who understood her. She said, "I want to return to my hometown. But I can't . . . (my hometown) where I have lived for over 70 years . . . I have many friends, and brothers."

Fig. 10 shows the average time that subject I spent in the public area on the third floor. Before Paro, the only time she spent in the area was when she waited for her friend before meals. However, after the introduction of Paro, her time in the public

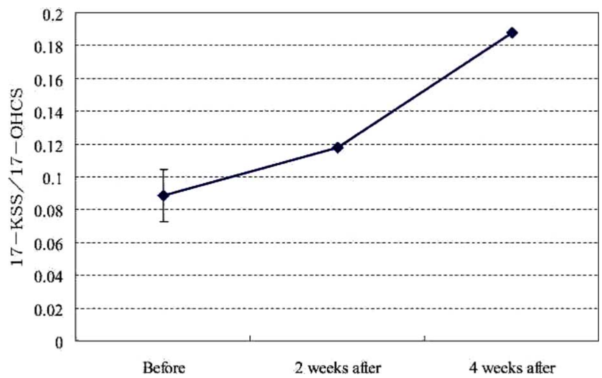

Fig. 11. Change in the 17-KS-S/17-OHCS ratio value of subject I.

area increased. She communicated with her friend and other residents through interaction with Paro. They discussed Paro's new name, different kinds of animals, reactions, feelings, etc. In addition, she taught Paro to answer her call and shake her hands, as if she wanted to learn what Paro could do. In the third week, she often said negative things about Paro when she was with other people, such as "It can't speak," "I got tired of Paro," and "It is not necessary to have Paro." And her time in the public areas decreased. However, she kept touching and whispering to Paro when she was alone with it. In addition, she greeted Paro whenever she passed by it. After the fourth week, she came to gradually understand Paro. She mimicked Paro's voice and groomed it, and the time she spent in the public area increased again.

Fig. 11 shows the changes in the 17-KS-S/17-OHCS ratio value of subject I. The value increased from 0.088 to 0.18. We conclude that the reactions of her vital organs improved after the introduction of Paro.

A month after Paro's introduction subject I commented that her health had improved. "I began to feel good. Last year, in early autumn, my health was really bad. I thought it would be better to die ... However, I don't think so. I don't know the exact reason (for my improvement); whether it is due to Paro coming, or the effect of the medicines, or some other factors." Her friend also commented that subject I cherished Paro. Furthermore, although she had been taciturn before, she now became more cheerful and more talkative. Everyone was surprised at the changes in subject I.

V. Discussion

Subjects D and I were both embarrassed by their dialect, and this affected their communication with the other residents. In our opinion, Paro broke through this barrier, making them talkative, and had positive effects on them. Before Paro, the third floor residents communicated very little with each other. The residents on the second floor were relatively more communicative; however, they engaged in extensive backbiting about others. The concern was that exposure to such an environment would increase the risks of contracting sicknesses and cognitive decline [1], [2]. The current results show that Paro has great potential for decreasing these risks.

This research is the first trial in investigating the interaction of people with robots like Paro, in situations where they can interact freely with the robot. It also investigated the sociopsychological and physiological effects of this interaction on the residents. The experiment was conducted at a care house, and 12 elderly subjects were investigated. The architectural constraints of the care house and the limited number of subjects precluded a control group; nevertheless, 9 out of 12 subjects commented on positive changes they observed in themselves and/or their relationship due to the introduction of Paro. (Two subjects commented that Paro changed nothing; the health of another prevented her from being interviewed.) In studies of this type, it is difficult to remove the influence of presence of researchers, however, Paro worked over 9 h every day for five weeks without researchers being present. Paro's presence was much longer than our presence. Therefore, we believe that the results obtained in this experiment reflect mainly the influence of the introduction of Paro. However, the results were obtained from limited number of subjects and there was no control group. We, therefore, plan clarifying Paro's influence more precisely with a case control study using a large number of subjects will be held in the future.

VI. Conclusion

We used seal robots with elderly residents in a care house from June 2005. The residents freely interacted with Paro for over 9 h daily. The current results show that Paro encouraged them to communicate with each other and brought about psychological improvements. Physiologically, urinary tests showed that the reactions of the residents' vital organs to stress also improved. In the future, we will report on the long-term influences on the residents of the care house.

References

[1] L. F. Berkman and S. L. Syme, "Social networks, host resistance, and mortality: A nine-year follow-up study of Alameda county residents," *Amer. J. Epidemiol.*, vol. 109, no. 2, pp. 186–204, 1979.
[2] M. Zunzunegui *et al.*, "Social networks, social integration, and social engagement determine cognitive decline in community-dwelling Spanish older adults," *J. Gerontol.: Social Sci.*, vol. 58B, no. 2, pp. 98–100, 2003.
[3] M. M. Baum, N. Bergstrom, N. F. Langston, and L. Thoma, "Physiological effects of human/companion animal bonding," *Nursing Res.*, vol. 33, no. 3, pp. 126–129, 1984.
[4] J. Gammonley and J. Yates, "Pet projects animal assisted therapy in nursing homes," *J. Gerontol. Nursing*, vol. 17, no. 1, pp. 12–15, 1991.
[5] T. Shibata, "An overview of human interactive robots for psychological enrichment," *Proc. IEEE*, vol. 92, no. 11, pp. 1749–1758, Nov. 2004.
[6] M. Fujita, "On activating human communications with pet-type robot AIBO," *Proc. IEEE*, vol. 92, no. 11, pp. 1804–1813, Nov. 2004.
[7] NeCoRo Web site [Online]. Available: http://www.necoro.com/home.html
[8] Furby Web site [Online]. Available: http://www.hasbro.com/furby/
[9] SARCOS Web site [Online]. Available: http://www.sarcos.com/
[10] Y. Terada and I. Yamamoto, "An animatronic system including lifelike robotic fish," *Proc. IEEE*, vol. 92, no. 11, pp. 1814–1820, Nov. 2004.
[11] K. Hirai, "Humamoid robot and its applications," in *Proc. IARP 1st Int. Conf. Humanoid, Human Friendly Robot.*, 1998, vol. 1, pp. 1–4.
[12] Y. Kuroki, T. Ishida, J. Yamaguchi, M. Fujita, and T. Doi, "A small biped entertainment robot," *J. Robot. Mechatron.*, vol. 14, no. 1, pp. 7–11, 2002.

[13] C. L. Breazeal, *Designing Sociable Robots*. Cambridge, MA: MIT Press, 2002.
[14] T. Kanda, H. Ishiguro, M. Imai, and T. Ono, "Development and evaluation of interactive humanoid robots," *Proc. IEEE*, vol. 92, no. 11, pp. 1839–1850, Nov. 2004.
[15] W. Burgard, D. Fox, G. Lakemeyer, D. Haehnel, D. Schulz, W. Steiner, S. Thrun, and A. Cremers, "Real robots for the real world—The RHINO museum tour-guide project," presented at the 1998 AAAI Spring Symp., Stanford, CA.
[16] R. Bischoff and V. Graefe, "HERMES—A versatile personal robotic assistant," *Proc. IEEE*, vol. 92, no. 11, pp. 1759–1779, Nov. 2004.
[17] ACTROID Web site [Online]. Available: http://www.kokoro-dreams.co.jp/ng/actroid/pdf/press_english.pdf
[18] H. Kitano *et al.*, "The Robocup'97 synthetic agents challenge," presented at the 1st Int. Workshop RoboCup, Nagoya, Japan, 1997.
[19] RoboOne Web site [Online]. Available: http://www.robo-one.com/
[20] H. H. Lund, "Modern artificial intelligence for human–robot interaction," *Proc. IEEE*, vol. 92, no. 11, pp. 1821–1838, Nov. 2004.
[21] T. Shibata *et al.*, "Emotional robot for intelligent system—Artificial emotional creature project," in *Proc. 5th IEEE Int. Workshop ROMAN*, 1996, pp. 466–471.
[22] T. Shibata and R. Irie, "Artificial emotional creature for human–robot interaction—A new direction for intelligent system," in *Proc. IEEE/ASME Int. Conf. AIM 1997*, Jun., p. 47 (CD-ROM).
[23] T. Shibata *et al.*, "Artificial emotional creature for human–machine interaction," in *Proc. IEEE Int. Conf. SMC*, 1997, pp. 2269–2274.
[24] T. Shibata, T. Tashima, and K. Tanie, "Emergence of emotional behavior through physical interaction between human and robot," in *Proc. 1999 IEEE ICRA*, pp. 2868–2873.
[25] T. Shibata, T. Tashima, and K. Tanie, "Subjective interpretation of emotional behavior through physical interaction between human and robot," in *Proc. Syst., Man, Cybern.*, 1999, pp. 1024–1029.
[26] T. Shibata and K. Tanie, "Influence of a-priori knowledge in subjective interpretation and evaluation by short-term interaction with mental commit robot," in *Proc. IEEE Int. Conf. IROS*, 2000, pp. 169–174.
[27] T. Shibata *et al.*, "Mental commit robot and its application to therapy of children," in *Proc. IEEE/ASME Int. Conf. AIM 2001*, Jul., Paper 182, pp. 1053–1058, (CD-ROM).
[28] T. Shibata, K. Wada, T. Saito, and K. Tanie, "Robot assisted activity for senior people at day service center," in *Proc. Int. Conf. ITM*, 2001, pp. 71–76.
[29] K. Wada, T. Shibata, T. Saito, and K. Tanie, "Effects of robot assisted activity for elderly people and nurses at a day service center," *Proc. IEEE*, vol. 92, no. 11, pp. 1780–1788, Nov. 2004.
[30] K. Wada, T. Shibata, T. Saito, and K. Tanie, "Analysis of factors that bring mental effects to elderly people in robot assisted activity," in *Proc. IEEE Int. Conf. Intell. Robot, Syst.*, 2002, pp. 1152–1157.
[31] T. Saito, T. Shibata, K. Wada, and K. Tanie, "Examination of change of stress reaction by urinary tests of elderly before and after introduction of mental commit robot to an elderly institution," in *Proc. 7th Int. Symp. AROB*, 2002, vol. 1, pp. 316–319.
[32] K. Wada, T. Shibata, T. Saito, K. Sakamoto, and K. Tanie, "Psychological and social effects of one year robot assisted activity on elderly people at a health service facility for the aged," in *Proc. IEEE ICRA*, 2005, pp. 2796–2801.
[33] K. Wada, T. Shibata, T. Musha, and S. Kimura, "Effects of robot therapy for demented patients evaluated by EEG," in *Proc. IEEE/RSJ Int. Conf. IROS*, 2005, pp. 2205–2210.
[34] T. Shibata, T. Mitsui, K. Wada, and K. Tanie, "Subjective evaluation of seal robot: Paro-tabulation and analysis of questionnaire results," *J. Robot. Mechatron.*, vol. 14, no. 1, pp. 13–19, 2002.
[35] T. Shibata, K. Wada, and K. Tanie, "Tabulation and analysis of questionnaire results of subjective evaluation of seal robot in Japan, U.K., Sweden and Italy," in *Proc. IEEE ICRA*, 2004, pp. 1387–1392.
[36] K. Wada and T. Shibata, "Robot therapy in a care house—Its sociopsychological and physiological effects on the residents," in *Proc. IEEE ICRA*, 2006, pp. 3966–3971.
[37] K. Wada and T. Shibata, "Robot therapy in a care house—Results of case studies," in *Proc. IEEE Int. Workshop ROMAN*, 2006, pp. 581–586.
[38] K. Wada and T. Shibata, "Living with seal robots in a care house—Evaluations of social and physiological influences," in *Proc. IEEE/RSJ Int. Conf. IROS 2006*, pp. 4940–4945.
[39] T. Shibata, "Ubiquitous surface tactile sensor," in *Proc. 2004 1st IEEE TExCRA*, pp. 5–6.
[40] I. Werry and K. Dautenhahn, "Applying mobile robot technology to the rehabilitation of autistic children," in *Proc. 7th Int. Symp. Intell. Robot. Syst.*, 1999, pp. 265–272.
[41] A. Yokoyama, "The possibility of the psychiatric treatment with a robot as an intervention—From the viewpoint of animal therapy," presented at the Joint 1st Int. Conf. SCIS ISIS, Tsukuba, Japan, 2002, Paper 23Q1-1 (CD-ROM).
[42] E. Libin and A. Libin, "Robotherapy: Definition, assessment, and case study," in *Proc. 8th Int. Conf. Virtual Syst. Multimedia*, 2002, pp. 906–915.
[43] E. Ohkubo *et al.*, "Studies on necessary condition of companion robot in the RAA application," in *Proc. 2003 IEEE Int. Symp. CIRA*, pp. 101–106.
[44] M. Kanamori *et al.*, "Maintenance and improvement of quality of life among elderly patients using a pet-type robot," (in Japanese), *Nippon Ronen Igakkai Zasshi*, vol. 39, no. 2, pp. 214–218, 2002.
[45] T. Tamura *et al.*, "Is an entertainment robot useful in the care of elderly people with severe dementia?," *J. Gerontol.: Med. Sci.*, vol. 59A, no. 1, pp. 83–85, 2004.
[46] S. Weller and A. Romney, *Systematic Data Collection*. (Qualitative Research Methods Series 10), Newbury Park, CA: Sage, 1988.
[47] M. F. Folstein *et al.*, "Mini-mental state: A practical method for grading the cognitive state of patients for the clinician," *J. Psychiatr. Res.*, vol. 12, pp. 189–98, 1975.
[48] H. Selye, "Stress and aging," *J. Amer. Geriatr. Soc.*, vol. 18, pp. 669–676, 1970.
[49] O. Nishikaze *et al.*, "Distortion of adaptation (wear & tear and repair & recovery)—Urine 17-KS-sulfates and psychosocial stress in humans," *Job Stress Res.*, vol. 3, pp. 55–64, 1995.
[50] J. Scott, *Social Network Analysis: A Handbook*. Newbury Park, CA: Sage, 1991.

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