

Assistive Robotic Technology to Combat Social Isolation in Acute Hospital Settings

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Abstract Social isolation in hospitals is a well established risk factor for complications such as cognitive decline and depression. Assistive robotic technology has the potential to combat this problem, but first it is critical to investigate how hospital patients react to this technology. In order to address this question, we introduced a remotely operated NAO humanoid robot which conversed, made jokes, played music, danced and exercised with patients in a London hospital. In total, 49 patients aged between 18–100 took part in the study, 7 of whom had dementia. Our results show that a majority of patients enjoyed their interaction with NAO. We also found that age and dementia significantly affect the interaction, whereas gender does not. These results indicate that hospital patients enjoy socialising with robots, opening new avenues for future research into the potential health benefits of a social robotic companion.

Keywords assistive robotic technology, social robot, human-robot interaction, hospital patients, ageing, dementia

1 Introduction

Depression, malnutrition and cognitive decline are common sequelae of social isolation and disengagement of patients in

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Fig. 1 A patient socially interacting with NAO. Patient consent was obtained to take and publish this picture.

hospitals [13]. As the population grows older, the problem of social isolation in hospitals becomes even more of a priority.

Previous studies illustrate the magnitude of these problems. Depression is common in hospitals: Shah et al. revealed that up to 46% of older patients are depressed using the Geriatric Depression Scale; yet, as many as 90% of these cases are not identified [28]. Further, studies show that direct patient contact time makes up only 12% of the junior doctors time [3]. Similarly, only 50% of nurses time is spent in direct contact with patients [30]. These findings suggest patients may spend the day with little or no social interaction. Moreover, with an expected shortage of healthcare workers due to ageing [5], social isolation will only increase.

We believe robots have the potential to counter these problems derived from social isolation. Indeed, research has already shown robots can help improve the well-being of users [15, 22]. However, before studying any potential health benefits of a social robotic companion, we need to verify whether adult patients are actually happy to interact socially with a robot whilst they are hospitalised.

The primary aim of this article is to explore that question. To this end, we carried out an exploratory trial during one week at a busy hospital in London where 49 patients interacted with a small humanoid robot, NAO. Our purpose was for NAO to interact with a wide variety of patients: participants in our study were aged from 18 to 100 and had been admitted for a variety of reasons, such as surgery, infections or dementia.

Throughout this article we focus on analysing how patients engaged with NAO, rather than on the development of a social companion. In fact, NAO was remotely controlled during our study. Nonetheless, this article presents a brief overview of the software and hardware of our set-up.

To our knowledge, this article describes the first study to place a social robot with a large variety of adult patients in an non-controlled hospital setting. Still, there have been similar studies with children [23] and elder adults in care-home and clinics [36] which are reviewed in the next section.

The rest of this article is organised as follows: section 2 reports on the relevant research literature, section 3 describes the hardware and software set-up of NAO, section 4 sets out the setting, procedure, hypotheses and analysis tools for the trials, sections 5 presents the results while section 6 analyses them, discusses the limitations of this work and outlines future avenues of research. Finally, section 7 contains our conclusions.

2 Related Research in Assistive Robotic Technology

Our robot, NAO, conforms to the description of a *socially assistive robot* [7]; that is, a robot which assists users through social interaction rather than physical contact—in NAO's case through talking, exercising, playing music and dancing. One of the earliest examples of a socially assistive robot is reported by Kanda et al. where a robot spent two weeks at a Japanese school teaching English to pupils [11].

Why use a robot over an avatar? Fasola et. al found that a humanoid robot was more persuasive at convincing older patients to perform exercises than a virtual agent, also setting a precedent for robots to help older people exercise [6].

Robots have been trialled with the aim of making children feel at ease in hospitals [14, 23, 1, 24, 19]. For instance, Pulido et al. reports on the use of a robot as physical therapist trialled with 50 school-children and 3 hospitalised children [19]. Their robot is autonomous and asks its users to imitate the pose it is making.

The work of Ros et al. is noteworthy as the authors explore the use of a semi-autonomous robotic dancing tutor in a hospital in Italy [23]. 12 children took part in the trials, though most of them were not hospitalised. Results showed that children mostly perceived the robot as a *friend* or a *sibling*. Subsequently, the authors applied *creative dance* tech-

niques to encourage 41 children to eat healthily and be physically active [24].

In another relevant study, a robot was used to promote the psychological well-being children with cancer [1]. In this article, NAO is deployed in a therapy group of 6 children to help them deal with distress arising from their ongoing treatment. The authors report an improvement in anxiety, depression and anger with respect to a control group.

The previous articles [19, 23, 24, 1] have in common the use of NAO as their robot. This provides mounting evidence that, at least for children, robots can be socially acceptable in health-related scenarios. They also evidence a dichotomy between having the robot act autonomously and the need for a controlled environment. This led us to chose a remotely-controlled architecture due to the unpredictability of the environment where we deployed our robot.

Furthermore, many of the above articles use dance as one of the activities that NAO executes. As it has been previously noted, dance is salient and easy to perceive [16]. This makes it appropriate for both children and adults and gave us a strong reason for incorporating it into NAO's set of activities.

To our knowledge, this is the first study of social companions with actual inpatients in an actual hospital. Further, this study presents several novel characteristics not found in the literature: the hospital setting, its population—comprising adults of all ages—as well as the fact that is not focused on a single condition. Still, there have been many studies on the effects of social companions for older people, yet all of the ones we reviewed happened outside the hospital: in specialised clinics or care-homes (eg. [36]).

One such study is described by Tapus et al. where a humanoid-like robot played musical games with 4 people with dementia over a period 6 months [34]. Encouragingly, the authors found improvements in error rates and game reaction times among the participants as the study progressed.

Schroeter et al. describes trials with another robot which was deployed in a smart house fitted with people-tracking sensors. 6 patients with cognitive impairments lived at the smart house with the robot for 2 days. The aim of the robot was to remind users of their daily tasks as well as to cognitively stimulate them with interactive games [27]. The authors confirmed the viability of this type of companion with evidence of 120 hours of user contact and positive user feedback.

McColl et al. used a robot to keep 8 individuals, aged 82-93, company as they ate their meals in a care-home [15]. The authors noted an 87% compliance rate when the robot encouraged patients to eat.

PARO is a robotic soft toy in the shape of a baby sea lion that reacts to the user's presence and touch. PARO was developed with the aim of reducing social isolation in an older population. Robinson et al. demonstrated that PARO signifi-

cantly reduced the patients' loneliness by an average of 5.38 points as measured by the UCLA Loneliness Scale [21]. The trials were performed in a care home in New Zealand over 12 weeks with 40 residents. In a follow-up article, Robinson et al. showed that even if some participants were emotionally attached to PARO, they were fully aware it was a machine [22]. Moreover, Takayanagi et al. established PARO was preferred by patients with mild/moderate dementia and severe dementia over a lion soft toy in a care home in Japan with patients talking and laughing more with PARO than with the soft toy [33].

It is important to highlight that NAO is a very different kind of robot than PARO. NAO can talk, walk and has more degrees-of-freedom, which will impact user expectations [8]. Another difference between PARO and NAO is that our trials were conducted in an acute hospital setting, an unpredictable environment where issues such as infection control arise.

3 Hardware and Software Overview

An overview of the software and hardware components described in this section is shown in figure 2.

The trials were carried out with NAO, a 58cm tall humanoid robot with 25 degrees-of-freedom manufactured by Aldebaran. NAO is equipped with two cameras, an array of microphones as well as several proximity sensors. It is able to stand and walk on its own. NAO has a non-threatening appearance due to its small size and cartoon-like features. Furthermore it has successfully been deployed in many social robotics trials [2, 25]. Aldebaran provides a library called NAOqi for developers to control NAO's behaviour.

We used two NAOs during trials, though only one at a time. Having two robots allowed us to run trials continuously without the risk of empty batteries or overheating robot joints.

NAO stood on top of a rolling table with its feet anchored to the table by velcro, this way the 58cm tall robot was able to interact with patients face to face. This set-up also had the advantage of allowing us to move the robot from bed to bed quickly. The flexibility lost by anchoring the robot feet was balanced with the extra safety of stopping the robot from falling on the patient in the event the motors failed.

We used Wi-Fi to communicate between the robot and the tablet-PC which ran our custom remote operator interface (figure 2e). The robot (figure 2a) received motor and speech commands from the remote operator interface and transmitted video from its top camera as well as audio from its front microphone. However, the relatively low-bandwidth and variable latency of Wi-Fi communication meant that the sound was noisy with occasional fragments of sound missing and that the camera resolution was limited to 160x120 pixels.

To develop the remote operator interface, we chose the Robot Operating System library (ROS) [20] as the base robotic middleware since it is flexible and widely used in the community which allowed for rapid development. At its core, ROS is an interprocess communication library which passes information from program to program (denoted as *nodes* by ROS) through a network channel (*topics* in ROS terminology). ROS is generally intended to be used in a distributed manner, with many simple, independent nodes communicating through ROS's topics. This is the approach we followed.

As we already mentioned, NAO is controlled through NAOqi. This meant we had to create control nodes which convert ROS topics into the appropriate NAOqi function calls (figure 2d). We wrote all the control nodes in Python, again for rapid development. The split in node competencies paralleled NAOqi's split of its developer modules, thus reducing inter-dependencies. The exception is the microphone node which directly sent the information it received from NAOqi to the sound system through the *pyalsaaudio* library (figure 2c). This was done in an attempt to counter the problematic audio latency we encountered. All the control nodes ran on the remote operator's tablet-PC.

The remote operator interface allowed the operator to trigger robot behaviours as well as to type text for NAO to say (figure 2e). The interface was designed as to minimise the operator's reaction time. The interface was written in ROS, and makes use of PyQt to render the user interface on the tablet-PC. The final user interface is the result of several iterations of trial and testing. Originally, the interface only had an input box for NAO's speech, but we found that easily accessible fillers gave extra time to the operator to type a complete answer. Similarly, the pre-written sentences in small talk gave the operator some structure for the interaction.

Controls for rapidly adjusting NAO's speaking volume in the remote operator interface were found to be important very early on, as was the ability to trigger stored behaviours on the robot. Finally, we programmed the interface so that if the remote operator clicked anywhere on the view of NAO's camera, NAO would move the head toward that point. This allowed the operator to ensure NAO was looking at the patients even if they shifted positions. Our remote operator interface also was executed on the tablet-PC which helped make the interaction more responsive as the operator could simply touch the desired behaviour, speech filler or gaze position. This remote operator interface is an instantiation of what in the literature is known as *Wizard of Oz* [18].

ROS has the ability to save all the information that it transmits to a log file (figure 2b). During trials we recorded interaction aspects such as robot's camera view and the robot activities into the log files. These were later used for analysis purposes.

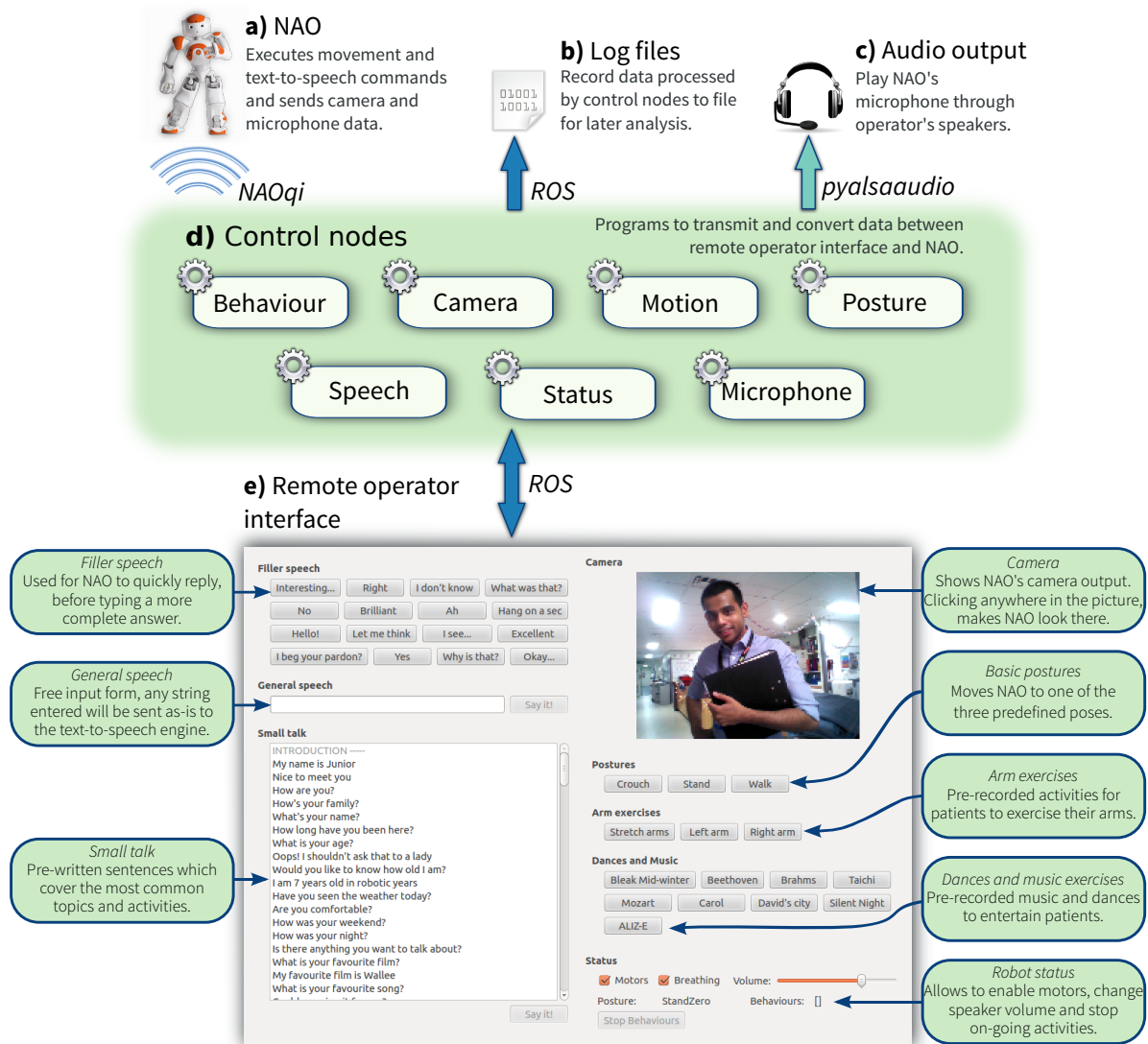


Fig. 2 Overview of the hardware and software components of the trials. Elements in *italics* are computer libraries. ROS stands for the Robotic Operating System. See *Hardware and Software Overview* for a detailed explanation of each component.

Putting all these components together allowed us to program NAO so it was able to perform the following actions to socialise with patients:

- Tell jokes.
- Read a verse of poetry.
- Read the news (pre-fetched on the morning).
- Play classical music pieces.
- Demonstrate arm flexing and stretching exercises and then request that the patient repeats them.
- Perform two dances: one was Tai chi inspired and relaxing; the other was more energetic and based upon the work of Ros et al. [23]

Furthermore, NAO would ask some of the following questions to patients as a means to start a conversation:

- *What is your name?*

- *How are you? Or, alternatively, are you comfortable?*
- *How is your family?*
- *How old are you?* Note that, after asking this, NAO would immediately apologise for its etiquette error.
- *How was your weekend? Or, how was your night?*
- *What is your favourite film/song?*
- *Have you seen the weather today?*

The fact that NAO was remotely operated meant that the robot was less responsive than it could have otherwise been. The limiting factor lies at the speed the operator can type which usually meant the robot replied with a delay of 2-3 seconds.

4 Trials Set-up

4.1 Setting

Trials took place in the Chelsea and Westminster Hospital in London from the 15th to the 19th of December 2014. Sessions were carried out from 9.30am until 5.30pm every day. Patients were chosen from the following wards: the stroke and neurology rehabilitation unit; the orthopaedic, urological, general and plastic surgery unit; the intensive care unit; the gastroenterology, general surgery and bariatric surgery unit; the gynaecology unit; and the gastroenterology, endocrinology and haematology unit. Most patients were located in a bay with 6 beds, though a few had their own individual room. A total of 69 patients were offered the option to take part in the trials.

The introduction of robots at Chelsea and Westminster Hospital was approved by the Medical Devices Committee, Safety and Effectiveness Group, Clinical Engineer (Reference 266, v01.38) and the Research and Development Department at Chelsea and Westminster NHS Foundation Trust. This project was granted Clinical Governance and Caldicott approval in September 2014 (CAPP 1087) and it was conducted in accordance with the Patient Protection Act 1998.

4.2 Trial procedure

A flowchart of the trial procedure we describe in this section is shown in figure 3. Note that the robot was introduced to patients as *Junior* rather than NAO in order for the robot to appear more approachable. Moreover, patients were not required to leave their bed, which meant that often other patients would witness the interaction.

For each session, a Clinical Research Fellow (CRF) carried NAO near the bed of a patient and obtained their consent for participation in the trials. If the patient refused, the CRF thanked them and moved on to another bed. If they accepted the CRF proceeded to introduce NAO. At this point, the remote operator would start controlling NAO and the CRF would leave the patient's bed. Thus the patient was left to interact with the robot alone; the CRF remained in the ward—a few steps away—in case his intervention was necessary.

Subsequently, NAO tried to engage the patients with conversation, jokes, dance, music and exercises. The robot started by asking the patient how she was feeling, about the weather and her family. It would also offer to tell jokes or read the news. If all this failed to catch the attention of the patient then the robot would start playing music or dancing. In general the approach was to try a range of topics or activities until the user became engaged.

When all interaction possibilities had been exhausted the robot operator indicated the CRF to take the robot away and escort it to the next patient's bed.

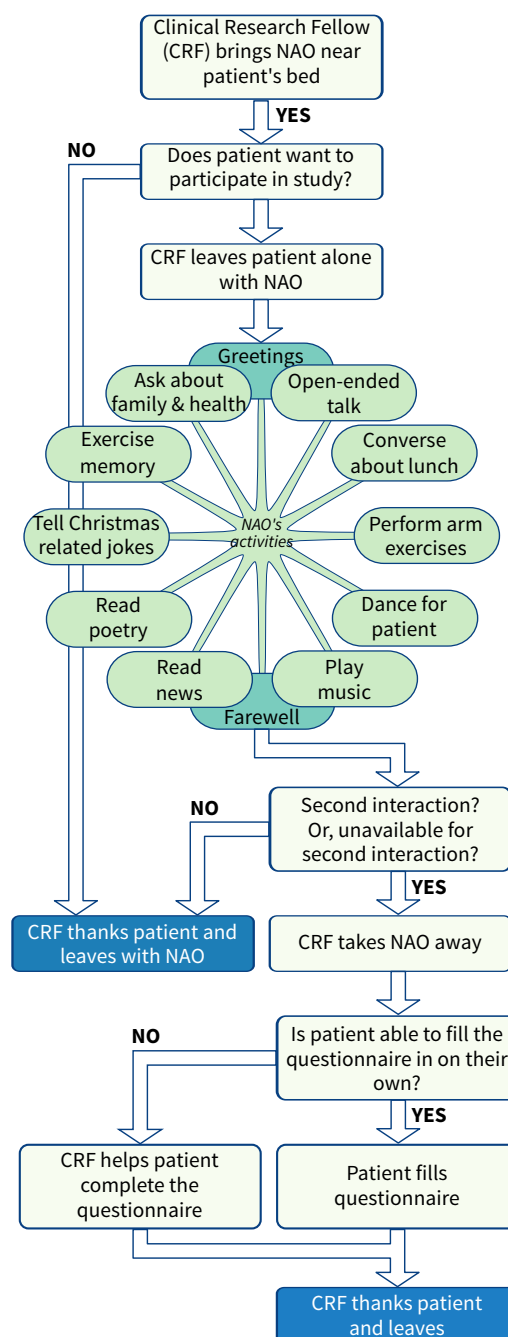


Fig. 3 Flow diagram for patient interactions with NAO. Boxes in light background represent steps performed by the clinical research fellow. Boxes with green background represent NAO actions triggered by the remote operator interface. Finally, boxes in dark blue background indicate final steps of the interaction.

Once the robot had been taken away, if the CRF—a trained medical doctor—had identified a patient as having dementia, this was noted down on the interactions log. The age and gender of the patients as well as whether they had made eye contact and talked to the robot were also annotated on the interaction logs. Neither the medical conditions of the patients nor the length of their stay were recorded.

After a second interaction with NAO, or if it became clear the patient would not be able to have a second interaction due to time constraints, the CRF would give the patient a questionnaire to fill in. In several occasions, patients that had interacted with the robot did not fill in a questionnaire, leading to the disparity between the number of questionnaires and interactions recorded. This situation mostly arose when we expected to have a second interaction with a patient who was later not present. The questionnaires asked for age, gender, comments as well the following questions:

- Have you enjoyed interaction with the robot during your time in the hospital? (*Enjoyed interaction*)
- Would you want to use the robot again? (*Would like to use the robot again*)
- Do you think the robot will be a useful tool in patient care in the future? (*Robot will be useful in the future*)

The questionnaires were anonymous, which meant cross-correlating them with the recorded interactions was not always possible afterwards.

Most patients filled in the questionnaire by themselves once the robot had left. However, if the patient was not able to do so the CRF would then read the questions out loud and would write down the answers.

4.3 Research questions

Our analysis was aimed at answering the following research questions:

- Will patients enjoy their social interactions with NAO?
- How long can an social interaction with a robot be sustained?
- Will the age or gender of patients have any effect on enjoyment, interaction duration or their preference over NAO's activities?
- How well will the above results translate to patients with dementia?

The goal of these questions was to understand how to create successful social human-robot interactions for future hospital studies.

4.4 Statistical analysis methodology

For analysis purposes, we set the statistical significance threshold at $p < 0.05$, and employed non-parametric tests (χ^2 , Spearman correlation, Mann-Whitney U and point-biserial correlation) to obtain the p-values. Much of our statistical analysis focussed on ages, consequently we used correlation (Spearman and point-biserial) between continuously-valued ages of patients and the different quantities we were testing in order to increase the robustness of the tests.

However, since correlation is difficult to visualise, we split the participants into three age groups: *group* <60 is composed of patients whose age is 59 years or less, *group* $60-79$ contains all participants aged 60–79, finally *group* ≥ 80 gathers everyone 80 years old or more. We chose these groups so as to evenly split the study population. These groups were not used in the statistical tests and are simply an aid to present the results in the next section.

The interaction duration metric was extracted automatically from the recorded logs and was defined as the time elapsed between the first and last time the robot spoke to the patient.

5 Results

5.1 Patients

In total, 49 patients interacted with the robot, 32 of them were female and 17 male (see figure 4a). The ages of subjects varied from 18 to 100 with 16 in each of the age groups. One of the participants' age is unknown and was excluded from the age analysis. 7 women aged 79–99 had dementia. Moreover, 15 patients (4 male, 11 female) had a second interaction with NAO.

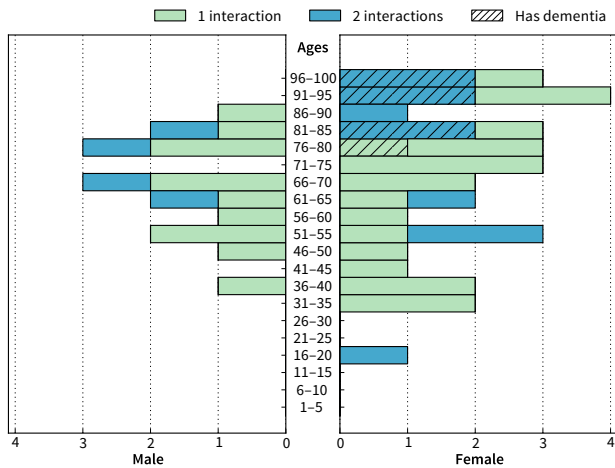
This adds up to a total of 64 interactions spanning 9 hours and 38 minutes, with the median interaction being 8min 39s, and the interquartile range (IQR): 4min 58s.

Additionally, 32 people filled in the questionnaire (12 male, 17 female, 3 undeclared), 15 in *group* <60 , 6 in *group* $60-79$ and 7 in *group* ≥ 80 (figure 4b). Four respondents did not declare their ages and were consequently excluded from the age analysis. As mentioned earlier, not all people who interacted with the robot filled in a questionnaire. Consequently, correlating the questionnaires to the interactions was challenging. Still, we were able to uniquely match 13 questionnaires and interactions by using both the age and gender.

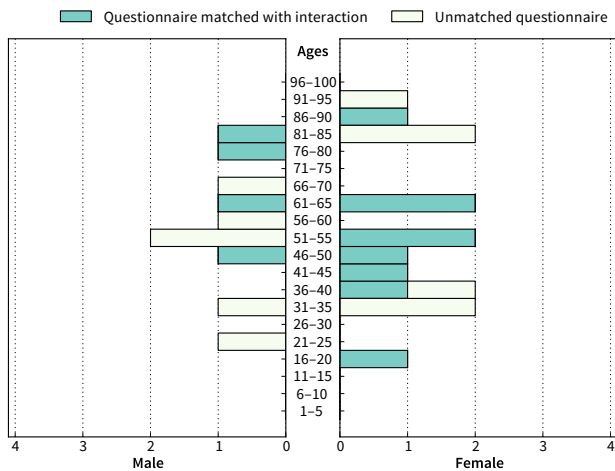
Finally, 20 patients (6 male, 14 female) refused to take part in the trials. Of these, 5 belonged to *group* <60 , 10 to *group* $60-79$ and 4 in *group* ≥ 80 (we were not able to establish the age of one of these patients). Eight patients mentioned being too tired as the reason for their refusal.

5.2 Quantitative Analysis

We found that 84% of the respondents agreed with *enjoyed interaction*, 50% agreed with *would like to use the robot again* and 72% were in agreement with *robot will be useful in the future*. Figure 5 shows these results broken down by age groups. We checked the Spearman rank correlation between the age and answers of the participants for each question and found none of the correlations to be statistically significant ($p > 0.10$). Likewise, a χ^2 test revealed no



(a) Interaction participants by age and gender. Figure also shows whether participants had dementia and their number of interactions with NAO. Note, 1 male participant did not declare his age and has been excluded from the graph.



(b) Questionnaire respondents by age and gender. The figure also indicates whether a respondent's questionnaire was matched to their interaction. Note, 7 respondents did not declare their age or gender and have been excluded from the graph.

Fig. 4 Study population. Discrepancies between graphs are due to incomplete data and not all participants filling in a questionnaire.

statistically significant differences in answers to the questionnaires by gender ($p > 0.10$).

The pattern was different when analysing the actual interactions, as can be seen from Figure 6. Regarding patient reactions to the robot, we found that all subjects of group <60 made eye contact, whereas for both other groups 25% of patients did not look at the robot. 25% of those in 60–79 made eye contact but did not talk with the robot, this figure is 12.5% for group ≥ 80 . That leaves 50% of group 60–79 and 62.5% of group ≥ 80 which both made eye contact and talked with the robot. A point-biserial statistical test suggests a negative correlation ($r = -0.255$) between a patient making eye-contact and increasing age, but does

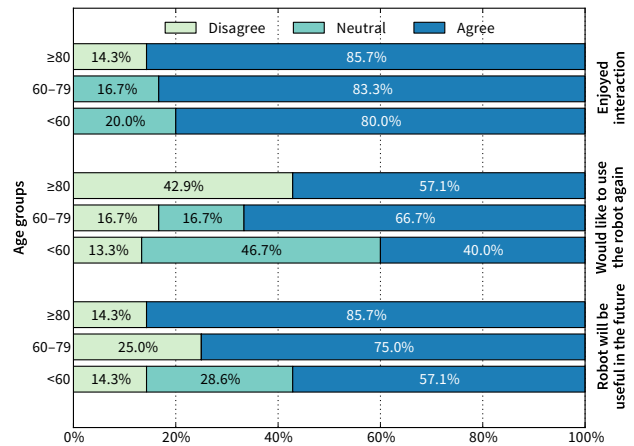


Fig. 5 Questionnaire responses by age group.

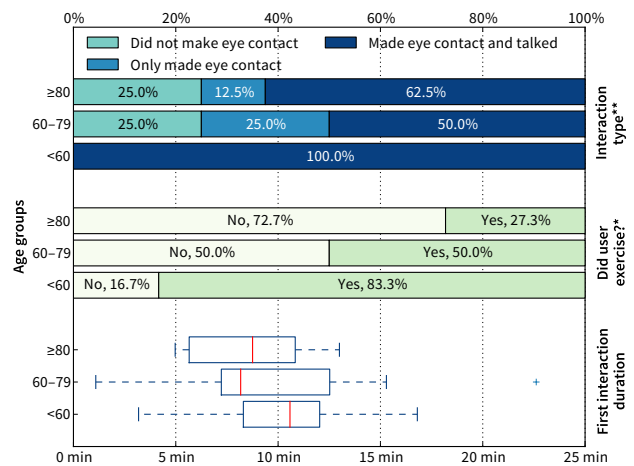


Fig. 6 Age differences in type of interaction, response to exercises and first interaction duration. * differences in exercise responses are statistically significant. ** differences between *made eye contact and talked* are statistically significant.

not reach statistical significance ($p = 0.080$). Similarly, the point-biserial correlation between verbal interaction and age is $r = -0.356$ and this was found to be statistically significant ($p = 0.013$).

24 patients were asked by the robot to perform some arm flexing and stretching exercises with it, 7 of them were in group <60 , 6 in group 60–79, and 11 in group ≥ 80 . The percentages of patients that exercised when the robot asked them to do so were: 86% for group <60 , 50% for group 60–79 and 27% in groups for group ≥ 80 and 50% overall. The point-biserial correlation between exercising and age is $r = -0.45$ and this was statistically significant ($p = 0.028$).

We also checked if age or dementia was a factor in whether patients made eye contact, talked and exercised, yet a χ^2 test revealed no statistical differences ($p > 0.10$).

For group <60 the median duration of the first interaction was 11min 8s (IQR: 3min 17s), for group 60–79 the

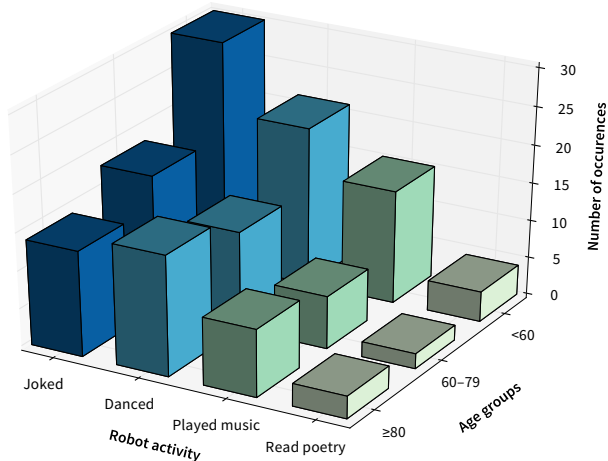


Fig. 7 Robot activities by age group. Differences in total number of activities by age are statistically significant.

median interaction duration was 8min 10s (IQR: 5min 18s), and for the last age group it was 8min 45s (IQR: 5min 11s). These results did not reach statistical significance ($p > 0.10$).

Looking only at those patients who had a second interaction ($N = 15$) yields similar results. The median interaction duration for group <60 was 12min 45s (IQR: 8min 58s, $N = 3$), for group 60–79 it was 6min 35s (IQR: 2min 48s, $N = 3$), and for group ≥ 80 the median interaction duration was 6min 43s (IQR: 3min 44s, $N = 9$). Again, the Spearman rank correlation was not statistically significant ($p > 0.10$).

Patients with dementia had significantly shorter interactions. The median first interaction duration for patients with dementia was 7min 10s (IQR: 3min 2s, $N = 7$) whereas for the rest of the patients was 9min 58s (IQR: 4min 57s, $N = 42$). Performing a Mann-Whitney U test shows these differences to be statistically significant ($u = 77.0$, $p = 0.047$). For the second interaction we found similar results: the median second interaction duration for patients with dementia was 3min 23s (IQR: 2min 16s, $N = 6$); for other patients it was 7min 48s (IQR: 1min 25s, $N = 9$). In this case, the results did not reach statistical significance ($u = 12.0$, $p = 0.087$).

Additionally, a Mann-Whitney U test revealed gender did not affect the interaction duration ($p > 0.10$).

Interestingly, there were statistical differences between the duration of the first interaction (median: 9min 55s, IQR: 5min 27s) and the second (median: 6min 51s, IQR: 4min 45s) for patients that interacted twice with the robot. Furthermore, a two-tailed Mann-Whitney U test showed these differences to be statistically significant ($u = 63.0$, $p = 0.042$).

Concerning NAO's activities during the trials, we found that the total number of activities performed by the robot for the patients correlates negatively with age ($\rho = -0.394$) and this correlation was statistically significant ($p = 0.012$). For a breakdown of the activities by age and type of activity refer to Figure 7.

In regards to the questionnaires which could be matched to interactions, we were not able to find any significant correlation between most of the activities the robot performed or the duration of the interaction. There was one exception in that the Spearman rank correlation was statistically significant between the number of times the robot danced and whether a patient answered affirmatively to *robot will be useful in the future*: $\rho = 0.629$, $p = 0.021$.

Our data did not show any effect of age or gender in whether patients agreed to participate in the trials ($p > 0.10$ in both cases). We checked the effect between age and participation with a point-biserial correlation, and the effect between gender and participation with a χ^2 test.

5.3 Interaction Analysis of Patients with Dementia

In order to capture specific elements of the interaction with patients with dementia, five interactions from four different patients were chosen at random and further analysed as shown in figure 8. Patient A only spoke to the doctor, and when NAO started dancing she closed her eyes, only to briefly reopen them when spoken to by the robot. Though Patient B did not speak very much nor did the arm exercises with NAO, she did try to touch it and smiled when the robot spoke to her. Patient C only spoke twice but she smiled many times and even laughed. The interaction became strained one minute into the song NAO was playing as she became disengaged, though she re-engaged with the robot once it started speaking again. Patient D, whose first and second interactions are shown in the figure, was very engaged with NAO: she laughed, smiled, gestured and talked to the robot. Curiously, towards the end of the interaction she started gesturing the robot to go away and frowned when the robot did not do so immediately. Yet this seemed to have no effect on her second interaction, during which she laughed and smiled and even attempted to give NAO a £10 note. Note that at the end of the second interaction patient D started frowning again and gesturing NAO to go away again.

6 Discussion

Subjective responses towards the quality of interaction with Assistive Robotic Technology were overwhelmingly positive. There were no statistical differences across age groups in questionnaire data. Notably, 84% of all respondents agreed that they enjoyed interacting with the robot. This finding answers the main question we asked of this study: whether hospitalised adult patients would enjoy socially interacting with a robot. This finding extends to a hospital setting the results which had previously shown that people generally find social interactions with NAO enjoyable: for example Ros et

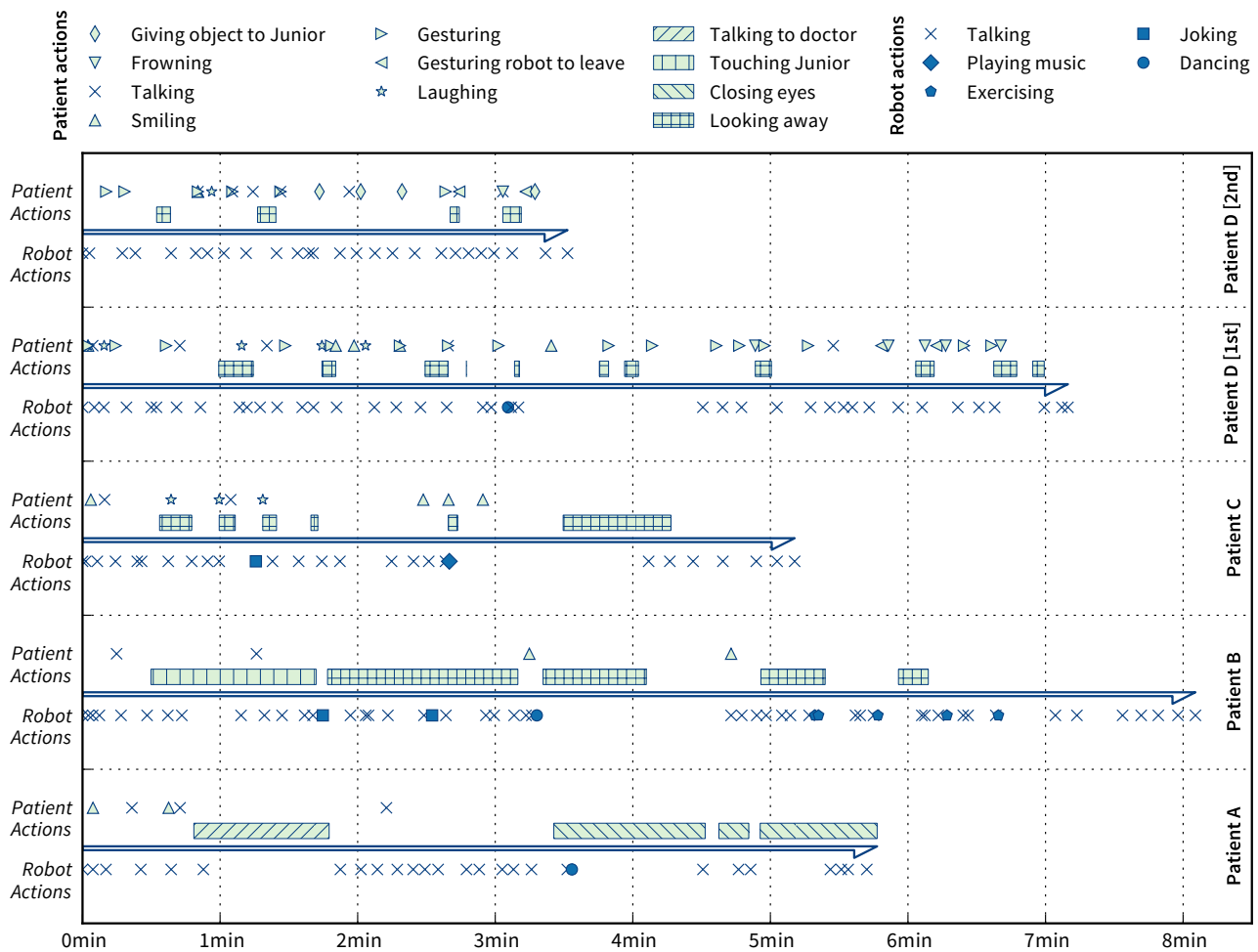


Fig. 8 Timelines of interactions with 4 patients with dementia aged 84–99. The graph shows the actions of the robot and the actions of the patient. Patient D had 2 interactions. *Junior* is the name we gave NAO for the patients.

al. who used NAO as a dancing tutor [23], or Sarabia et al. where NAO was a guide for wheelchair users [25].

The median interaction duration, 8 minutes 39 seconds, was slightly shorter than that of other relevant research. The median interaction duration for the dance tutor [23], the meal companion [15] and the physiotherapy robot [19] was approximately 13 minutes. Similarly, the interaction duration of patients with dementia with PARO was 10 minutes in the experiments conducted by Robinson et al. [22]. This difference was probably due to the long delays in conversation which made it difficult to extend the interaction further.

Nonetheless, it remains to be seen whether patients are still happy to interact with the robot in the longer term. The statistically significant differences in duration between the first and second interactions as well as the fact that only 50% of questionnaire respondents agreed that they would like to use the robot again could be explained by the novelty factor. It is hypothesised that the first interaction with a robot is unusually positive due to novelty. Therefore, as interactions repeat and novelty wears off, users may be less positive to-

wards the robot [31]. Further research is required to clarify if this is indeed the case.

Regarding the research question of how age affects the interaction, we found that verbal interaction, engagement with exercise and the total number of activities NAO performed negatively correlate with increasing age in a statistically significant manner. The data suggests the same could be true of interaction duration and eye contact but these measures did not reach statistical significance.

In consequence, one of the challenges that our study outlines is how to determine the specific activities that can best engage older patients. For example, from figure 7 we can see how joking was not something that patients in the *age group* ≥ 80 appreciated. In contrast, for the other two age groups joking was the most common activity, but for older people dancing proved more effective. This leads to the hypothesis that more tailored interactions with a focus on music and movement –such as music therapy [37]– may be more beneficial for older people. Likewise, speech and humour was used more often with younger patients, suggesting

WHOLLY POSITIVE (16 comments in this category)	☞ “Improvement in my mood.” ☞ “I loved Junior.” ☞ “This is a fun way to encourage a return to health.” ☞ “[Interaction was] a bit too short, I prefer a longer time” [93 year old woman].	☞ “[Junior is] lively and amusing.” ☞ “Funny robot.” ☞ “Thank you for being chosen to meet Junior.” ☞ “He is so good and amazing. Well done Junior.”
POSITIVE, BUT SCEPTIC (10 comments in this category)	☞ “It was a bit of a novelty for the day—the idea of it made me laugh, but I wouldn’t really need any more time with it.” ☞ “[Conversation was] slightly stilted but a great diversion.” ☞ “I can’t say exactly if I have enjoyed it, but it was exciting.” ☞ “I enjoyed but found it a bit intimidating.”	
NEGATIVE (3 comments in this category)	☞ “Tried to ignore it but it didn’t go away. Its limited vocabulary and intellect made it difficult to converse.” ☞ “We have enough machines.” ☞ “People want to speak to people.”	

Table 1 Example of patients’ comments classified by *wholly positive*, *positive but sceptic* and *negative*. In total, 29 patients provided comments. *Junior* is the name we gave NAO for the patients.

with that for the *age group* ≥ 80 speech is a more important factor in the interaction. Finally, from figure 7 we observe that reading poetry –which entailed NAO monologuing for a relatively long period of time– was not attractive to any age group.

Our results, in contrast, do not show any relevant effects of gender on the interaction. This suggests that future studies of robotic social interaction in hospitals should pay more attention to both the effects of age, interaction duration and repeated interactions rather than gender. This is somewhat surprising since previous research established that gender does affect interaction in some circumstances. For instance, Siegel et al. found that the sex of users played a role in whether they perceived the robot as persuasive [29]. Similarly, Heerink et al. states that age and gender have a moderate effect on users acceptance of robots [10].

Results show that interactions with dementia patients were the shortest. Though most dementia patients were in *age group* ≥ 80 , the effect of age was not found to be significant in interaction duration. This was in contrast with dementia, which did have a significant effect in interaction duration. Despite engagement difficulties, we observed that many patients with dementia smiled even if they did not speak as much as other patients.

It is clear then, that dementia strongly affects the interaction with the robot (thus answering our last research question). Yet, at least for some patients, the interaction with the robot may still be beneficial. This finding corresponds with existing research: we have already described the positive role of PARO on patients with dementia [33, 22] and recently it was found that NAO could help patients with dementia stop cognitive decline according to certain metrics [35].

Additionally, we were curious about the strong and statistically significant correlation that we found between the number of times the robot danced and participants agreeing

with the *robot will be useful in the future* question. This correlation may be explained by the fact that the dance was the most sophisticated of NAO’s activities, where it had to move its arms, torso, head and play music in synchrony. This differs from conversational interaction which was slower due to delays related to the operator having to type NAO’s speech and the noisy audio capture which meant the operator sometimes did not understand what had been said. Indeed, as Hebesberger et al. note “a robot’s task, its functionality and usability are a crucial factor influencing its acceptance” [9]. Thus, patients who saw the robot performing a complex task may have been more agreeable to the future possibilities of using the robot in healthcare.

6.1 Analysis of Patients’ Comments

Studying the patients’ comments on the questionnaires reinforces our finding that patients were largely positive about their time with NAO. Examples of these comments are shown in table 1. Out of the 29 questionnaires, 16 were classified as *wholly positive*, 10 were *positive, but sceptic* and just 3 were *negative*.

The comments in the *positive, but sceptic* category also highlight the difficulties we had already identified in the discussion, namely the risks of the novelty effect and the reaction delay caused by controlling NAO remotely. We were surprised to find only 3 patients were overly negative towards NAO, particularly given the sensitivity of their situation as well as possible cultural preconceptions [12].

Finally, eight respondents commented they thought NAO would be useful with children, which we expected from the literature [19, 23, 24, 1].

6.2 Limitations and Future Work

There are several limitations to this study, which at the same time open new research avenues.

The chief limitation of this study was that the participants' contact with the robot was limited to one or two interactions. This limitation did not allow us to observe what –if any– health effects does interacting with a social companion have on a patient. Based on our medical experience, we hypothesise that robots can help keeping patients engaged mentally, giving them something to look forward to during their days and encourage them to eat, which should lead to improved health, fewer accidents and a lower hospital mortality rate. Notwithstanding the short-term nature of the trials with patients, our study does however prove that a more in-depth study looking at the previous medical effects may be carried out with reasonable confidence that patients will not flatly reject to interact with a robot.

The second limitation of this study is the use of a remote operator interface since it requires a full-time operator controller robot, who could well keep the patient company directly. Nonetheless, we conjecture that interacting with a robot may have advantages over directly interacting with the robot operator (eg. NAO may be perceived as more friendly and less threatening). Still, taking advantage of recent advances in conversational agents, a system could be developed whereby an operator would control several robots remotely and simultaneously. Importantly, we do not consider a fully autonomous solution to be ideal for this scenario, since a mis-recognition if a patient asks for help or is in pain could have potentially fatal consequences.

Though the population of this study covered a wide range of ages and occupations, we hypothesise the interactions may be improved by the use of user-modelling techniques [4, 17, 26], particularly for a semi-autonomous robot in a long term study. This would allow the robot to perform the most successful activities for a particular patient according to their preferences.

There were also limitations of a more technical nature. In particular, audio transmission was both lagged –due to the inherent latency limitations of a wireless network in a public hospital– and noisy – due to the proximity of NAO's microphones to its motors. This made the task of NAO's remote operator harder as sometimes it was difficult to understand what the patient was saying. Going forward we will look into the use of a higher quality directional microphone to better capture patients' utterances as well as the use of new, less congested, network technologies for transmission of the audio signal.

The challenging and uncontrolled hospital environment also raised challenges that may have impacted our results. In particular, strict infection control measures made it impossible for patients to interact physically with NAO. It is possible that

patients, particularly the more senior, would have engaged better if they could touch the robot. Further, the open-plan layout of the hospital wards meant that some patients could see the robot interacting with another patient and, as a result, chose not to participate in the study.

Finally, we can observe from the patients comments in table 1 that some patients found the robot not to be responsive enough. This led to patients and the robot speaking at the same time. As a remedy, we propose that NAO should convey to the patient that the operator is typing in the remote operator interface via blinking lights or a custom animation. This technique has already been used in the robotics literature [32] as well as in instant messaging services.

7 Conclusion

We have presented the outcomes of a week-long trial with NAO in several wards within a busy London hospital. The results revealed that, whilst engagement varied in many ways with age, 84% of patients rated their interaction with the robot positively. This was further corroborated by comments written by patients in the study questionnaires as well as a median interaction duration of 8 minutes and 39 seconds. In addition, the interactions of four patients with dementia were qualitatively analysed, showing that many of these patients smiled, laughed and remained engaged with NAO.

This study confirms our hypothesis that hospitalised patients are happy to interact socially with a robot, in spite of the difficulties of their personal situations. Having confirmed that social robotic interactions may be successfully carried out in a hospital, three new questions are now open for research: how can we develop a semi-autonomous social robotic companion? Is it possible to sustain a long-term social robotic interaction? Can social robot provide health benefits to patients? We believe this to be the case; and, as the world population grows older and demands on health services increase, so does the potential impact of assistive robotic technology in hospitals.

Acknowledgements We would like to thank all the staff at the Chelsea and Westminster Hospital for their support in conducting the trials. In particular, we thank Vino Loganathan and Naz Nordin for introducing Junior to the patients as well as Paulo Guiran Pestana and Rachel-Hannah Strong for their great effort documenting the interactions.

Last but certainly not least, we would like to acknowledge all the patients who took part in the trials.

This research was supported by: a Doctoral Training Award from the Engineering and Physical Sciences Research Council to MS; a research fellowship from the Chelsea and Westminster Hospital to NY; Fund 556, Education & Research Fund from the CW Health Charity to Rachel Hannah-Strong and Paulo Guiran Pestana; and EU projects ALIZ-E (FP7-248116) and PAL (H2020-643783) to YD.

References

1. Alemi M, Ghanbarzadeh A, Meghdari A, Moghadam LJ (2016) Clinical application of a humanoid robot in pediatric cancer interventions. *International Journal of Social Robotics* 8(5):743–759, DOI 10.1007/s12369-015-0294-y
2. Belpaeme T, Baxter PE, Read R, Wood R, Cuayáhuil H, Kiefer B, Racioppa S, Kruijff-Korabayová I, Athanasopoulos G, Enescu V, Looije R, Neerincx M, Demiris Y, Ros R, Beck A, Cañamero L, Hiolle A, Lewis M, Baroni I, Nalin M, Cosi P, Paci G, Tesser F, Somnavilla G, Humbert R (2012) Multimodal Child-Robot Interaction: Building Social Bonds. *Journal of Human-Robot Interaction* 1(2):33–53, DOI 10.5898/JHRI.1.2.Belpaeme
3. Block L, Habicht R, Wu AW, Desai SV, Wang K, Silva KN, Niessen T, Oliver N, Feldman L (2013) In the wake of the 2003 and 2011 duty hours regulations, how do internal medicine interns spend their time? *Journal of General Internal Medicine* 28(8):1042–1047, DOI 10.1007/s11606-013-2376-6
4. Demiris Y (2009) Knowing when to assist: Developmental issues in lifelong assistive robotics. In: *Proceedings of the Annual Conference of the IEEE Engineering in Medicine and Biology Society*, pp 3357–3360, DOI 10.1109/IEMBS.2009.5333182
5. European Commission (2012) Action Plan for the EU Health Workforce. <http://ec.europa.eu/health/workforce/policy>
6. Fasola J, Mataric MJ (2013) A Socially Assistive Robot Exercise Coach for the Elderly. *Journal of Human-Robot Interaction* 2(2):3–32, DOI 10.5898/JHRI.2.2.Fasola
7. Feil-Seifer D, Mataric MJ (2005) Defining socially assistive robotics. In: *Proceedings of the International Conference on Rehabilitation Robotics*, pp 465–468, DOI 10.1109/ICORR.2005.1501143
8. Goetz J, Kiesler S, Powers A (2003) Matching robot appearance and behavior to tasks to improve human-robot cooperation. In: *Proceedings of the IEEE International Workshop on Robot and Human Interactive Communication*, pp 55–60, DOI 10.1109/ROMAN.2003.1251796
9. Hebesberger D, Koertner T, Gisinger C, Pripfl J (2017) A long-term autonomous robot at a care hospital: A mixed methods study on social acceptance and experiences of staff and older adults. *International Journal of Social Robotics* 9(3):417–429, DOI 10.1007/s12369-016-0391-6
10. Heerink M, Kröse B, Evers V, Wielinga B (2010) Assessing Acceptance of Assistive Social Agent Technology by Older Adults : the Almere Model. *International Journal of Social Robotics* 2(4):361–375, DOI 10.1007/s12369-010-0068-5
11. Kanda T, Hirano T, Eaton D, Ishiguro H (2004) Interactive Robots as Social Partners and Peer Tutors for Children: A Field Trial. *Human-Computer Interaction* 19(1):61–84
12. Kaplan F (2004) Who is afraid of the humanoid? Investigating cultural differences in the acceptance of robots. *International Journal of Humanoid Robotics* 1(3):465–480, DOI 10.1142/S0219843604000289
13. Lowenthal MF (1964) Social Isolation and Mental Illness in Old Age. *American Sociological Review* 29(1):54–70, DOI 10.2307/2094641
14. Lu SC, Blackwell N, Do EYL (2011) mediRobbi: An interactive companion for pediatric patients during hospital visit. In: *Human-Computer Interaction. Interaction Techniques and Environments*, Springer, Lecture Notes in Computer Science, vol 6762, pp 547–556, DOI 10.1007/978-3-642-21605-3_60
15. McColl D, Nejat G (2013) Meal-Time with a Socially Assistive Robot and Older Adults at a Long-term Care Facility. *Journal of Human-Robot Interaction* 2(1):152–171, DOI 10.5898/JHRI.2.1.McColl
16. Michalowski MP, Sabanovic S, Kozima H (2007) A dancing robot for rhythmic social interaction. In: *Proceedings of the ACM/IEEE International Conference on Human-Robot Interaction*, pp 89–96, DOI 10.1145/1228716.1228729
17. Nikolaidis S, Ramakrishnan R, Gu K, Shah J (2015) Efficient Model Learning for Human-Robot Collaborative Tasks. In: *Proceedings of the ACM/IEEE International Conference on Human-Robot Interaction*, pp 189–196, DOI 10.1145/2696454.2696455
18. Ping L (1993) Wizard of Oz Studies: Why and How. In: *Proceedings of the ACM International Conference on Intelligent User Interfaces*, pp 193–200, DOI 10.1145/169891.169968
19. Pulido JC, González JC, Suárez-Mejías C, Bandera A, Bustos P, Fernández F (2017) Evaluating the child-robot interaction of the naotherapist platform in pediatric rehabilitation. *International Journal of Social Robotics* 9(3):343–358, DOI 10.1007/s12369-017-0402-2
20. Quigley M, Gerkey BP, Conley K, Faust J, Foote T, Leibs J, Berger E, Wheeler R, Ng A (2009) ROS : an open-source Robot Operating System. In: *Proceedings of the Open Source Software Workshop at the International Conference of Robotics and Automation*
21. Robinson H, MacDonald B, Kerse N, Broadbent E (2013) The Psychosocial Effects of a Companion Robot: A Randomized Controlled Trial. *Journal of the American Medical Directors Association* 14(9):661–667, DOI 10.1016/j.jamda.2013.02.007

22. Robinson H, Broadbent E, MacDonald B (2015) Group sessions with Paro in a nursing home: Structure, observations and interviews. *Australasian Journal on Ageing* DOI 10.1111/ajag.12199
23. Ros R, Baroni I, Demiris Y (2014) Adaptive human-robot interaction in sensorimotor task instruction: From human to robot dance tutors. *Robotics and Autonomous Systems* 62(6):707–720, DOI 10.1016/j.robot.2014.03.005
24. Ros R, Oleari E, Pozzi C, Sacchitelli F, Baranzini D, Bagherzadhalimi A, Sanna A, Demiris Y (2016) A Motivational Approach to Support Healthy Habits in Long-term Child–Robot Interaction. *International Journal of Social Robotics* 8(5):599–617, DOI 10.1007/s12369-016-0356-9
25. Sarabia M, Demiris Y (2013) A Humanoid Robot Companion for Wheelchair Users. In: *Social Robotics*, Springer, Lecture Notes in Computer Science, vol 8239, pp 432–441, DOI 10.1007/978-3-319-02675-6_43
26. Sarabia M, Lee K, Demiris Y (2015) Towards a Synchronised Grammars Framework for Adaptive Musical Human-Robot Collaboration. In: *Proceedings of the IEEE International Symposium on Robot and Human Interactive Communication*, pp 715–721, DOI 10.1109/ROMAN.2015.7333649
27. Schroeter C, Mueller S, Volkhardt M, Einhorn E, Huijnen C, Van Den Heuvel H, Van Berlo A, Bley A, Gross HM (2013) Realization and user evaluation of a companion robot for people with mild cognitive impairments. In: *Proceedings of the IEEE International Conference on Robotics and Automation*, pp 1153–1159, DOI 10.1109/ICRA.2013.6630717
28. Shah A, Herbert R, Lewis S, Mahendran R, Platt J, Bhattacharyya B (1997) Screening for depression among acutely ill geriatric inpatients with a short geriatric depression scale. *Age and Ageing* 26(3):217–221, DOI 10.1093/ageing/26.3.217
29. Siegel M, Breazeal C, Norton MI (2009) Persuasive Robotics: The influence of robot gender on human behavior. In: *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp 2563–2568, DOI 10.1109/IROS.2009.5354116
30. Storfjell JL, Omoike O, Ohlson S (2008) The balancing act: patient care time versus cost. *The Journal of Nursing Administration* 38(5):244–249, DOI 10.1097/01.NNA.0000312771.96610.df
31. Sung JY, Christensen HI, Grinter RE (2009) Robots in the Wild: Understanding Long-term Use. In: *Proceedings of the ACM/IEEE International Conference on Human-Robot Interaction*, pp 45–52, DOI 10.1145/1514095.1514106
32. Takayama L, Dooley D, Ju W (2011) Expressing thought: improving robot readability with animation principles. In: *Proceedings of the ACM/IEEE International Conference on Human-Robot Interaction*, pp 69–76, DOI 10.1145/1957656.1957674
33. Takayanagi K, Kirita T, Shibata T (2014) Comparison of verbal and emotional responses of elderly people with mild/moderate dementia and those with severe dementia in responses to seal robot, PARO. *Frontiers in Aging Neuroscience* 6(257), DOI 10.3389/fnagi.2014.00257
34. Tapus A, Tapus C, Mataric MJ (2009) The use of socially assistive robots in the design of intelligent cognitive therapies for people with dementia. In: *Proceedings of the IEEE International Conference on Rehabilitation Robotics*, pp 23–26, DOI 10.1109/ICORR.2009.5209501
35. Valentí Soler M, Agüera-Ortiz L, Olazarán Rodríguez J, Mendoza Rebolledo C, Pérez Muñoz A, Rodríguez Pérez I, Osa Ruiz E, Barrios Sánchez A, Herrero Cano V, Carrasco Chillón L, Felipe Ruiz S, López Alvarez J, León Salas B, Cañas Plaza JM, Martín Rico F, Abella Dago G, Martínez Martín P (2015) Social robots in advanced dementia. *Frontiers in Aging Neuroscience* 7, DOI 10.3389/fnagi.2015.00133
36. Wada K, Shibata T, Musha T, Kimura S (2005) Effects of Robot Therapy for Demented Patients Evaluated by EEG. In: *Proceedings of the IEEE International Conference on Intelligent Robots and Systems*, pp 1552–1557, DOI 10.1109/IROS.2005.1545304
37. Wall M, Duffy A (2010) The effects of music therapy for older people with dementia. *The British Journal of Nursing* 19(2):108–113, DOI 10.12968/bjon.2010.19.2.46295

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