Social Robots in Cognitive Interventions. Advances, Problems and Perspectives

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Abstract

Social Assistive Robots are being used in therapeutic interventions for elderly people affected by cognitive impairments. The present paper reports our research lines aiming at investigating the role of a social robot in aiding therapists during cognitive stimulation sessions for elders with Mild Cognitive Impairment and Mild Dementia. We review our studies whose results show that social robots have been positively accepted by the seniors in different experiments. Participants were very attentive and involved in the sessions' tasks and their experience was mainly positive. Our data suggest that this technology can be a valid tool to support psychotherapists in cognitive stimulation interventions emphasizing the need of multidisciplinary approaches combining assessment of behavior and robotics.

Keywords

Social Assistive Robots, Cognitive Stimulation Therapy, Elderly Care

1. Introduction

Robots serve various tasks and purposes in the health and social care sectors and are becoming one of the most important technological innovations of the 21st century. Robotics could partially fill in some of the identified gaps in current healthcare and home care/self-care provisions for their possibilities of engaging, stimulating and managing the users through social interactions and support them with a large range of functions and services in daily life including intelligent communication, safety, assistance, therapy, and cognitive stimulation. For these and other promising applications in support of elderly therapy and home assistance, we expect that robotics can play relevant roles in the future in the field of smart home technologies and social/companion robots.

The range of available robotic applications is extremely vast, different and continually growing, from robots used in minimally invasive robot-assisted surgery [1] and in rehabilitation [2], to robots designed to function in hospital/care homes and personal robots serving as motivational coaches or assisting older people [3, 4]. Socially engaging robots and interactive

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technologies aimed at provide people with long-term social and emotional support [5, 6, 7]. Recently, with the purpose to help people with special needs living healthier lives, connecting with others, the challenge of research is designing empathic robots able to assess and recognize the users' affective status. Currently, robots cover solutions at different stages of development, whether commercially ready and available on the market or still at the various stages of research experimentation and prototyping.

As far as elderly care is concerned, robots are being used as assistive technologies for people suffering from Mild Cognitive Impairment (MCI) to help them to remain in their familiar environment for as long as possible [6, 7, 8]. The increasing use of assistive technologies in this context is partially due to the fact that aging population is increasingly placing pressure on an already burdened healthcare system. Neuro-cognitive stimulation programs implemented in care settings are beneficial only when followed regularly and consistently. Due to financial and resource constraints, it is often difficult to arrange regular exercise sessions with a therapist or trainer. One way to potentially address this problem is to use a robot to fill these gaps.

The spectrum of required assistive functionalities of such a robot companion is broad and reaches from reminding functions (e.g., taking medication or drinking) and cognitive stimulation exercises, up to detection and evaluation of critical situations like falls. In particular, people suffering from dementia and cognitive impairments show deficits in memory, thinking and behavior, and symptoms usually develop slowly and get worse over time [9, 10] with devastating effects on the psychological well-being and quality of life.

Social humanoid robots seem promising since they can support more engaging interactions with users. Moreover, recent work exploring the use of robots for aiding cognitive treatments [11] has shown their potential in this field. They are being effectively used in dementia care, and several commercially available robots have been employed with satisfactory results in cognitive stimulation and memory training [9, 12, 13].

The integration of robotics into both formal and informal MCI care opens up new opportunities for improving the patient's quality of life relieving the caregivers and healthcare services burden. Early studies have shown that Social Assistive Robotics (SAR) has the advantage of enhancing mood, social relationships among patients, and emotional expression of individual dementia sufferers [14, 15]. As part of a training program aimed to improve the cognitive status of people with dementia, researchers investigated how patients relate to humanoid robots and perceive serious games accessed through it [13]. In this study, it was observed that, along with sessions, elders became more engaged with the Pepper robot showing a positive perception about the interaction with it. In [16] it has been argued that Pepper is a suitable robot to employ by patients with dementia, relatives, and caregivers and that its presence brings patients with dementia in a more positive emotional state. In particular, music sessions stimulate patients to recall memories and talking about their past. In [9, 17] researchers aimed at the design of assistive functions for humanoid robots and the NAO has been proposed as support to the training program. In particular, NAO has been employed in individual and group therapy sessions to assist the trainer through speech, music, and movement.

Following these findings, we started a research project aiming at investigating the effectiveness and acceptance of SAR in providing support to interventions addressed to people suffering from cognitive impairments related to aging and dementia. Our research aimed at providing evidence that large mutual influences between cognitive neuroscience and robotics enable a better understanding which leads to an increased acceptance of future robotics in society and health care services.

To this aim, we performed a few studies with the elderly affected by MCI and Mild Dementia (MD), with the social robot NAO or with Pepper. In every investigation, we implemented some cognitive stimulation tasks to be performed in a group with the robot and we measured, besides the performance in the task itself, the patients' engagement and attention and emotional response during the training program. In both cases, results showed that using a social robot as a cognitive coach is more effective to motivate and engage people, compared to what can be offered by interactions supported by traditional computers [13, 18].

In the present paper, we report and discuss the main results of these studies by emphasizing the effectiveness of social robots as a tool for cognitive stimulation therapy.

2. Experiences with Social Robots in Cognitive Rehabilitation

The ultimate goal of our research program is to create a user-friendly interface, for neuro-cognitive treatment in the health care environment. This paragraph is giving a summarizing overview of our progress in developing such an assistive robot and still ongoing functionality testing and pending usability studies with the end-user target groups.

2.1. NAO H25

The humanoid NAO is a fully programmable and valuable robot for Human-Robot Interaction (HRI) research. Our first experience with SARs for cognitive stimulation therapy in elderly care employed the NAO as a social platform ideally fitted to monitor and promote cognitive rehabilitation among the elderly population with neurocognitive disorders such as MCI and Mild Dementia (MD). NAO was included as an experimental platform in an ecological setting from a center of the Italian health service. Cognitive stimulation is a therapeutic activity that plays a crucial role in the recovery of memory functions, or in enabling persons to adapt to their problems by teaching them the use of different strategies to pay attention, and alternative ways of encoding, storing and retrieving information. This may offer protection from cognitive decline and mitigate dementia risk. For group-based interventions, the therapeutic effects of being with others with similar problems may also help.

The participants were selected from the population of outpatients attending the Center for Cognitive Disorders and Dementia of Parma (Italy). Twenty-one participants were enrolled in the experiment (10 females and 11 males) with a mean age of 73.45 years (SD = 7.71). All the participants were previously evaluated by memory-disorders specialists. Participants were diagnosed with MCI according to Petersen guidelines and full marks in the two tests measuring daily living activities (ADL and IADL). The study included data on objective measures of cognitive functions for baseline and immediately after treatment which was supervised by psychologists or neuropsychologists. The trial included a comparison between an experimental condition in which individuals received the training assisted by NAO, and a control condition in which subjects received the intervention without the robot. We introduced NAO in the manualized, group-based memory training consisting of 8 sessions lasting eight weeks of the standard program. Each session lasted about 70 minutes. The contents of the group treatment programs included education and teaching of compensatory strategies (both internal/mental strategies and external memory aids), education regarding memory function and deficit. Training involved written and verbal practice of memory strategies such as visual imagery, association or categorization and spaced retrieval, time orientation, spatial orientation, visual attention, logical reasoning. It also included metacognitive strategies to improve awareness and self-regulation, 15 minutes to discuss problems, how to transfer strategies to everyday situations to encourage practice and generalization of strategy use between sessions. The robot was programmed to implement five tasks. In different training conditions, seniors participated in sessions with the support of NAO or only from the psychologist while the interaction was recorded for subsequent exploration by two cameras.

The five tasks administered by NAO were: i) reading stories; ii) questions about the story; iii) paired words learning; iv) paired words recall; v) song-singer matching. Equivalent exercises were also performed by the psychologist in different conditions to obtain comparative data. For example, the song-singer matching is a task in which the seniors have to recall the song's title as a response to the name of the singer. In the experimental condition, NAO sings the song with the original singers' voice, and wait for a spoken response from each group member before to deliver a feedback about it. Conversely, the procedure with the psychologist is performed matching the title with a written response. In both situations, sessions were held in a room where the patients sat around a table. In order to evaluate the robot-elderly interaction, metrics were automatically extracted through the analysis of the video-recorded sessions. The analysis was made by a customized software that aimed to measure participants' smiles and visual attention (Figure 1). The automatically extracted metrics were:

- occurrence of visual attention (defined as the number of times each participant looks at NAO or the psychologist);
- length of visual attention (defined as the time, expressed in seconds, in which each subject turns to NAO or the trainer);
- frequency of positive expressiveness (described by the number of times each individual smile towards NAO or the psychologist);
- length of positive expressiveness (defined by time, expressed in seconds, in which a user smiles towards NAO or the clinician).

Results suggested a beneficial effect of training on objective reports across a number of domain-specific, global cognitive, and mood measures immediately after treatment. This indicates larger effects and clinical benefits following tasks assisted by NAO compared to the pen-and-paper condition. Furthermore, it appears that tasks assisted by NAO had a positive effect on reports of people who have had MCI. Significant comparisons emerged between the occurrence of smiles addressed to NAO and those focused on the psychologist, between the amount of the visual interaction towards NAO and that allocated to the trainer and, finally, that concerning the length of the visual attention towards NAO contrasted to that towards the psychologist. So far none of the studies reported the application of a humanoid robot in the health care setting for individuals with MCI. Our approach determined that training assisted by a robot allows that the elderly experienced more attention and less depressive symptoms during a memory-training protocol.

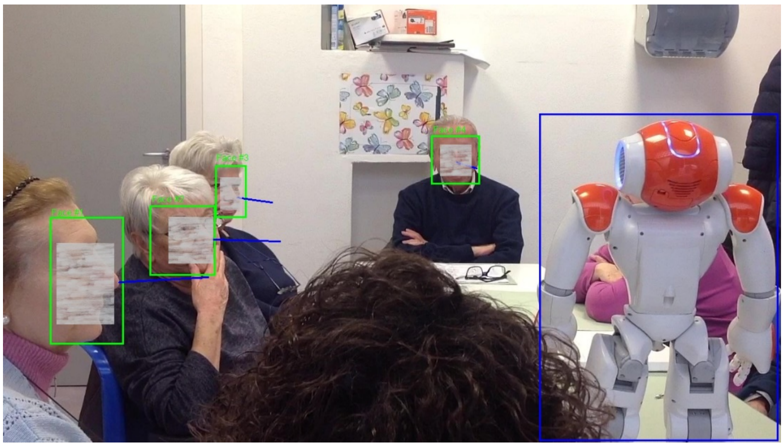


Figure 1: An example of a frame captured during the memory training program and processed by the automatic system.

In the previous study, we considered cognitive measures as the primary outcome of interest and clinical measures as secondary outcomes. We also believe that the quality of the interaction is perhaps another valuable concern because it can result in improvements in clinical gains. In this respect, in a second study [19] we addressed the effectiveness of a system in automatically decode facial expression from video-recorded sessions of a robot-assisted memory training. Empirical evidence determined that humans interacting with a robot engaged the same social conventions for eye-gaze and social distance as in human interaction. The study explored the NAO potential to engage participants in the intervention and its effect on their emotional state. Engagement in this field can be defined by the act of being involved with an external stimulus. The main aim of the second investigation was to explore, through a new tool based on computer vision, the engagement of participants in a cognitive stimulation program assisted by NAO robot who administered specific tasks from the protocol giving instructions, suggestions and consequences. The tool recognized six basic emotions detecting multiple faces in each video frame. During each session, participants were seated around a table where was seated NAO while the experimenter who operated the robot was in the same therapy room with the computer visible to the participants.

Data from this study concerned both the automatic recognition capabilities from the system and the participants' emotional expressiveness collapsed by tasks and gender. Findings revealed that the system is able to recognize facial expressions from robot-assisted group therapy sessions handling partially occluded faces. Statistical analysis revealed that emotional expressiveness differed for tasks and gender with a different pattern across tasks that entangle different abilities and personal preferences or interests, and females showing a larger number of emotions with respect to males suggesting that detecting affective states is particularly relevant in HRI. The more remarkable results were gender and task differences, with women showing mostly positive emotions probably, which is fully understandable if we take into account the variety of the nature of human emotions and the ways of expressing them.

Both studies [12, 19] indicated a reliable memory training program based on the NAO robot

Figure 2: Pepper and the group of elderly people during the cognitive stimulation program.

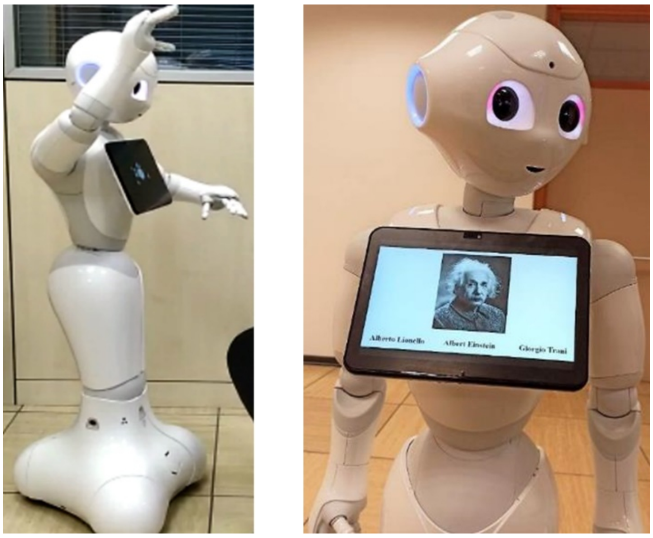
that adding new evidence base to factors involved in Human-Robot Interaction (HRI) for elderly people. The use of a humanoid robot as a mediating tool appeared to promote the engagement of participants in memory training programs. State anxiety level measured following a session with the NAO exhibited an average value below the mild anxiety threshold [12]. The humanoid robot provides engaging situations and, in some circumstances, enthusiastic behaviors were detected in patients as a reaction to some reinforcement phrases after a task, rather than during the task itself, as long as the reinforcement expressions were not repetitive, but casually chosen from a list of general reinforcements. Participants thought the interaction with NAO stimulating and many of them appreciated the reminders and prompts as the fact that the humanoid robot called them by name and started the training sessions with an orientation to time and place.

An important insight of these studies is that a robot could become the right support for therapist, in future work, particular attention has to be devoted to obtaining a robot able to respond autonomously adapting in the context of interaction its behavior to users' needs and emotional states evaluating its effectiveness on health and well-being of care recipients.

2.2. Pepper

In a further study, we included the social robot Pepper in a cognitive stimulation program in cooperation with the Alzheimer Bari ONLUS Association. Differently from the NAO used in the previous study, Pepper is 1.20 mt. tall semi-humanoid robot that can move around using wheels. He has got a tablet on its torso that can be used to show useful information (i.e., selection among multiple options).

The experiment was conducted with a group of eight participants for 3 weeks, with weekly meetings of about 35 minutes (Figure 2 illustrates the setting of the therapy with Pepper). The participants were selected according to their MMSE score (Mini-Mental State Examination [20]) and their willingness to take part in the study. The MMSE is a 30-point test used to measure cognitive functions (or "cognitive impairment"). It allows measuring a person's level or stage of dementia.



(a) (b)

Figure 3: Pepper showing (a) a physical exercise – (b) a visual-verbal associative memory task.

In order to form a group that could take advantage of the cognitive stimulation therapy, a week before the experiment, the therapists carried out neuropsychological assessments with the MMSE on potential participants in the experiments. We selected patients with an MMSE score between 13 and 26.2, i.e., patients with the beginning of MCI to a mild stage of dementia, since patients with these scores can make progress with the therapy. Mixed diagnoses studies are beneficial in determining the potential for the generalizability of training across diagnostic groups and reflect typical clinical practice in many centers.

The tasks to be performed during the training program with Pepper were selected by the staff of specialized therapists of the center from the volumes of "A gym for the mind" [21], and were adapted to Pepper communicative capabilities. Examples of exercises are:

- motor imitation, in which Pepper shows some physical exercises to the elderly (Figure 3a, 3b);
- word completion, in which the respondent is given the first few letters of a word (such as VIK) and tries to complete the word as quickly as possible;
- visual-verbal associative memory, as shown in Figure 3b where Pepper shows on the tablet the image of a famous person and asks for his/her name.

The interaction between the robot and the patients is vocal. More details about the experiment can be found in [22]. Before running the CST with Pepper, participants and their relatives received detailed information about the study and subsequently signed their consent to be video-recorded during the experiments. These informed consents were also signed by their legal representatives.

Each session was video-recorded. Besides the Pepper's internal video camera located inside its mouth (which allowed to better capture the faces of the patients), another video camera was positioned in the room in order to have a front view of patients' faces and to be able to analyze the entire group behavior. We collected the video-recording of the 3 sessions. Recordings were segmented to have one video for each task. Differently from the previous investigations with NAO, in this experiment, the same measures (the number of correct answers, eye contact, and emotions experienced by each participant during each session) were assessed by three expert observers (two women and one man, of average age 37.67 years old). They showed an almost perfect agreement index (0.83), calculated through the Fleiss' kappa [23].

We decided to adopt this approach because, in our future work, we want to compare the performance of our software for the automatic analysis of elderly behavior with human annotation. The three observers calculated the number of correct answers and the number and total time each senior looked at Pepper during each exercise of the session. In order to observe all basic emotions (angry, disgust, fear, happy, sad, surprise, and neutral) on each elderly face, the assessors were first trained on the Facial Action Coding System (FACS) [24].

From the analyses of the collected video, we can report that:

- Based on the number of correct answers, we can conclude that the patients participated actively in the experiment.
- The engagement was measured, according to [25], by recording the eye gaze of each participant towards Pepper. On average, seniors were engaged in the 70% of the time by Pepper and, in particular, they showed more engagement in the task about motor imitations, in which they paid attention to Pepper for the 76.53% of the duration of the exercise. The tasks on visual-verbal associative memory were also especially successful (74% on average).
- During the experiment, seniors experienced, besides the "neutral" state (on average 79.44% per session), more positive emotions (on average 19.33%) than negative ones (1.25% for Session 1, 2.02% for Session 2 and 1.08% for Session 3, respectively). Considering the videos, it has been noticed that these emotions emerged when subjects disagreed with the statements made by the other participants and not towards Pepper.
- There were some interesting correlations, calculated using the Pearson coefficient, between behavioral observations and the neuropsychological evaluations' scores. In detail, seniors with a higher MCI tended to experience mostly neutral emotions (r=0.70) and were less happy (r=-0.80) than the most seriously compromised seniors; positive correlations emerged between the eye gaze engagement estimation and the MMSE scores (r=0.42).

Despite the experiment design anticipated in the study protocol a comparison with a control group, because of the COVID-19 emergency, it was not possible to achieve this study arm.

3. Discussion and Outcomes

The reported studies aimed at investigating how social assistive robots can be used to support therapists in training programs for improving the cognitive function of elderly people suffering from MCI and MD. Results obtained so far are encouraging since they show that this technology is engaging and allows seniors to perform cognitive stimulation tasks, but we must recognize

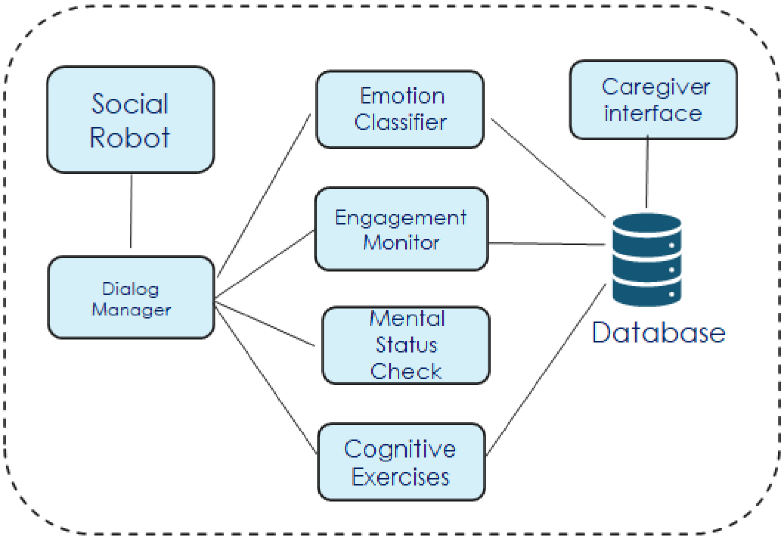


Figure 4: Robot-senior interaction architecture.

some methodological limitations that should be taken into consideration when interpreting the above-reported findings.

The first limitation concerns the sample size of groups in the experiments, even if the number of involved subjects is in line with the typical number of group members during cognitive stimulation sessions, these kinds of investigations should involve a larger sample also considering a greater number of trials extended over more sessions. Moreover, while in the experiments with NAO the presence of the control groups or conditions allowed to compare results in different situations, in the experiences with Pepper this was not possible because of the COVID emergency. Therefore, we cannot make quantitative but only qualitative comparisons between the results of the two experimental situations. Pepper appears more effective and engaging thanks to the tablet placed on the torso that can be used to play tasks including visual stimulation; it can also move towards the group and also towards specific group members. The sample groups in the studies with Pepper were heterogeneous concerning their clinical profiles, an aspect that limited the possibility of identifying a specific target. This issue would be a newsworthy dimension to scrutinize in future work.

In every investigation, evaluation and feedback from participants showed that the technology is easy to use and suggested future research challenges the community should address. The older adults approached the humanoid robot as a human, and a stimulus to go to the care-center to do the rehabilitation program. For example, participants talked to the robot as an entity having its own personality, they asked the robot to sing a song with them or to play with them. Robots applied to real-world applications should perform their activities in a reactive but flexible manner. Thus, a cognitive robot architecture capable to adapt to human interaction is very suitable.

Although the current paper concerns specific tasks, other abilities can be surely included for rehabilitation purposes. Given the great importance of the emotions and their expression, the investigation of new features and less restrictive forms of choosing robot behaviors may lead to relevant contributions. The analysis of expressiveness must be performed in real-time to consent the robot the ability to adapt its behavior to the sensed user reaction.

With this aim and taking into account what we learned from the findings of our studies, we are developing the architecture illustrated in Figure 4 that includes several modules that require artificial intelligence.

First of all, there is a clear need to include a module for automatic emotion and engagement recognition in our system for giving the robot the capability to understand in real-time seniors' affective reactions, motives on them, and activate the most suitable behavior for the situation. Then, in order to establish and enhancing social relations, tasks like the mental status check and the cognitive tasks will be proposed through multimodal dialog. The Dialog Manager module will understand the meaning of the user sentence by appropriately recognizing its intent and the involved entities generating the appropriate answer message (i.e., reminds, quiz exercises, jokes, object recognition, questions, etc.). The user's dialog move will be analyzed and the results will be forwarded to other components, if necessary. Thereby, the robot could personalize the interaction by detecting emotions and engagement. The Cognitive Exercises module provides cognitive stimulation or training. The user performance in the practice will be stored in a database for evaluation by careers. The database will keep data for all the modules. The caregivers need to be actively involved in this process using a web interface that will allow them to create a program of a therapeutic session and personalize the activities according to the cognitive evaluation of the members of the group. Caregivers will also able to monitor the progress of the therapeutic intervention.

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