Music Therapist Robot: A Solution for Helping People with Cognitive Impairments *

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Abstract

The world population is growing older. Global aging is occurring at a rate never seen before, it is expected that in 2040 there will be three times more people over the age 85 than there are today. Population aging is a fundamental transformation of human society and many implications for health and long-term care policy are occuring. Even if nursing homes and other care facilities can provide assistance, space and staff shortages are already becoming an issue. In this paper, a new research work that depicts a music therapist robot that helps people suffering from cognitive changes related to aging and/or Alzheimer's disease, is presented. The social therapist robot tries to provide customized cognitive stimulation by playing a music game with the participants. This research work presents a 12 months longitudinal study.

1 Introduction

The world's population is growing older, thereby introducing a wide array of challenges. It is estimated that in 2040 there will be three times more people over age 85 than they are today. Many are expected to need physical and cognitive assistance, due to physical and/or cognitive changes related to aging, e.g., Traumatic Brain Injury (TBI), Parkinsons Disease (PD), stroke (e.g., each year over 730,000 American people and one million of people from 22 European countries suffer a stroke, and nearly 400,000 survive with some form of neurologic disability placing a tremendous burden on both the private and public health resources of the nation) and Alzheimer's disease (the latest estimate is that 26.6 million people were suffering from Alzheimer's disease worldwide in 2006, and it will rise to 100 million by 2050 1 in 85 of the total population).

The research work that is proposed here defines a new niche of human-robot interaction for assistive applications, one that involves an autonomous robot providing monitoring, assistance, and encouragement, while also being capable of providing detailed reports of user progress to physicians, therapists, and caregivers. The main advantages of the proposed approach are in providing time-extended personalized exercise/activity supervision and encouragement while saving therapist/caregiver time. In contrast, tele-video systems require therapist time and oversight while home logs and related independent methods fail to provide personalized and adaptive care and interaction with the patient. The only comparable technology is computer-based rehabilitation, which could provide personalized care but without the physical embodiment of a robot. In our previous work [Tapus and Matarić, 2007], [Tapus *et al.*, 2008], [Tapus and Matarić, 2008], it was shown that an in-home socially assistive agent can improve the ability of the patient to function at home and within society. This is based on the socially assistive framework, which consists of the use of disencumbering physiological sensors and intelligent robotic agents for real-time activity tracking and determination of user state. The combination of these components forms a customized therapeutic tool that adapts to the users personality, preferences, profile, state, and cognitive/physical disability in order to continuously encourage them to remain engaged in an activity. Thus, the goal of this research work is to improve quality of life of the users; this is done through the use of a robotic agent that supervises, encourages, and engages the user's as they perform tasks such as cognitive therapy.

The robotic literature that looks into long-term studies in the area of therapeutic robots for individuals suffering from dementia and cognitive impairment is very little. Some of the representative work is described below. In their research work [Libin and Cohen-Mansfield, 2004], Libin and Cohen-Mansfield describe a preliminary study that compares the benefits of a robotic cat and a plush toy cat as interventions for elderly persons with dementia. Furthermore, Kidd, Taggart, and Turkle [Kidd *et al.*, 2006] use Paro, a seal robot, to explore the role of the robot in the improvement of conversation and interaction in a group. Marti, Giusti, and Bacigalupo [Marti *et al.*, 2008] justify a non-pharmacological therapeutic approach to the treatment of dementia that focuses on social context, motivation, and engagement by encouraging and facilitating non-verbal communication during the therapeutic intervention.

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The work presented in this paper focuses on the study of the social, interactive, and adaptive aspects of robot behavior in an assistive context designed for the elderly and/or individuals suffering from dementia. This study aims to address the following research questions:

- Can elderly individuals with dementia and/or cognitive impairments maintain attention to music with the help of a robot in an intervention specifically designed to promote active listening?
- How do their responses and performance compares to responses and performances of well-elderly and elderly that have not participated in the study?
- What are short-term effects of attention training with elderly who are suffering from dementia and/or other cognitive impairments?
- Will the music-based cognitive game with the robot help the elderly individuals with dementia and/or cognitive impairments increase their "positive behavior" (e.g., smiling, speaking, and participating in group activities)?

2 Hypotheses

This work tests the following two hypotheses:

Hypothesis 1: The social robot can help to improve and/or maintain the cognitive attention of individuals with dementia and/or cognitive impairments through its encouragements in a specific music-based cognitive game. Active listening provides a potential method for engaging cognitive skills of individuals with Alzheimer's and/or dementia.

Hypothesis 2: The robot can adapt its behavior (based on the user's disability level) to improve the user's task performance in the cognitive game.

3 Robotic Platform

The experimental testbed is a humanoid torso mounted on a mobile platform (Figure 1). The mobile platform is an ActivMedia Pioneer 2DX robot equipped with a speaker, a Sony Pan-Tilt-Zoom (PTZ) color camera, and a SICK LMS200 eye-safe laser range finder. The biomimetic anthropomorphic setup involves a humanoid Bandit II torso, consisting of 22 controllable degrees of freedom, which include: 6 DOF arms (x2), 1 DOF gripping hands (x2), 2 DOF pan/tilt neck, 2 DOF pan/tilt waist, 1 DOF expressive eyebrows, and a 3 DOF expressive mouth. All actuators are servos allowing for gradual control of the physical and facial expressions.

We are particularly interested in utilizing the humanoid's anthropomorphic but not highly realistic appearance as a means of establishing user engagement, and comparing its impact to our prior work with non-biomimetic robot test-beds [Tapus and Matarić, 2007], [Tapus *et al.*, 2008].

4 Experimental Design

The experiment consists of repeated sessions, during which the user and the robot interact in the context of a cognitive game. The first session is the orientation, in which the participant is 'introduced' to the robot. The robot is brought into the room with the participant, but is not powered on. During

Figure 1: Robot test-bed: Bandit II humanoid torso mounted on the Pioneer mobile base

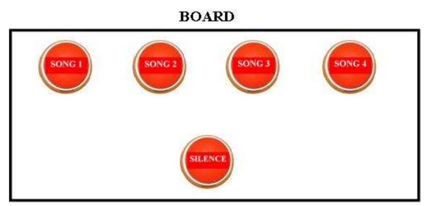
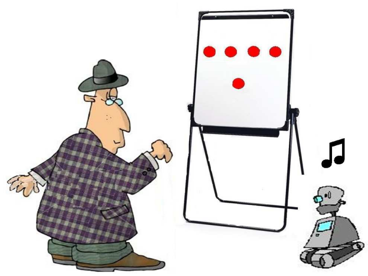


Figure 2: Cognitive Game: Name That Tune

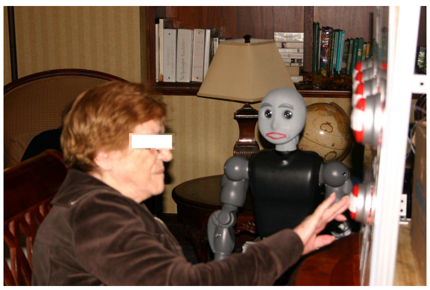
this introduction period, the experimenter or the participant's nurse/physical/music therapist explains the robot's behavior, the overall goals and plans of the study, and what to expect in future sessions. The participant is also asked about his/her favorite songs from a variety popular tunes from the appropriate time period; those songs are later used in the subsequent sessions. At the end of the session, the Standardized Mini-Mental State Examination (SMMSE) cognitive test is administered so as to determine the participant's level of cognitive impairment and the stage of dementia. This test provides information about the cognitive (e.g., memory recall) level of impairment of the participant for use in initializing the game challenge level. The data determine the participant's initial mental state and level of cognitive impairment, and serve as a pre-test for subsequent end-of-study comparison with a post-test.

This experiment is designed to improve the participant's level of attention and consists of a cognitive game called Song Discovery or Name That Tune. The participant is asked to find the right button for the song, press it, say the name of the song, and sing along. The criteria for participation in the experiment (in addition to the Alzheimer's or dementia diagnosis) include the ability to read large print and to press a button. The participant stands (see sketch Figure 3a) or sits (see Figure 3b) in front of a vertical experimental board with 5 large buttons (e.g., the Staples EASY buttons - see Figure 2). Four buttons correspond to the different song excerpts (chosen as a function of the user's preference) and the last button corresponds to the SILENCE or no song excerpt condition. Under each button, a label with the name of the song (or SILENCE) is printed.

The robot describes to each participant the goal of the game before each session, based on the following transcript: "We



(a)



(b)

Figure 3: Human-Robot Interaction Cognitive Game Setup: (a) standing position; or (b) sitting position

will play a new music game. In it, we will play a music collection of 4 songs. The songs are separated by silence. You will have to listen to the music and push the button corresponding to the name of the song being played. Press the button marked "SILENCE" during the silence period between the songs. The robot will encourage you to find the correct song."

Each participant is first asked by the music therapist or the robot to read aloud the titles of the songs and to press a button. Some additional directions are given. The participant is also directed to press the SILENCE button when there is no music playing. After a review of the directions, the participant is asked by the robot to begin the music game. The music compilation is composed of a random set of song excerpts out of the four different songs that form the selection and the silence condition. The entire music compilation lasts between 10 and 20 minutes, and is based on the user's level of cognitive impairment: the larger the impairment, the shorter the session. A song excerpt can be vocal, instrumental, or both. The order of song excerpts is random.

The experiment was repeated once per week for a period of 12 months in order to capture longer-term effects of the robot therapist. A within-subject comparison was performed to track any improvement over multiple sessions. No between-subject analysis was done due to the small sample size and large differences in cognitive ability levels.

5 Robot Learning and Behavior Adaptation

The learning and robot behaviour adaptation methodology was designed for the interaction between the robot and people suffering of dementia and/or Alzheimer's disease, with the main goal of helping these individuals to improve or maintain their cognitive attention through encouragements in a specific music based cognitive stimulation game.

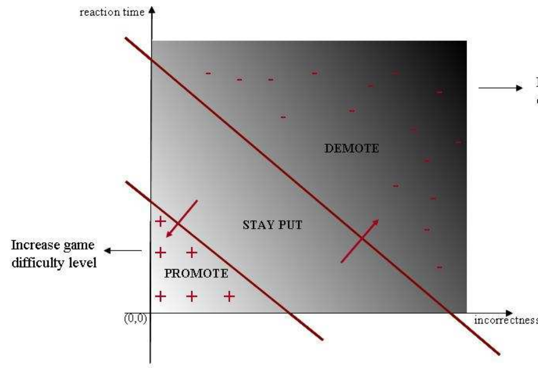


Figure 4: Adaptation System

This approach consists of two parts: supervised learning and adaptation. The robot models the following interaction parameters:

- Level of game challenge presented by the robot/computer:
  - No hint (difficult level);
  - When the song excerpt starts say "push the button" but do not indicate which button to push (medium level);
  - When the song excerpt starts say which button to push (easy level).

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The supervised learning system learns for each game level and for each disability bucket (mild, moderate, and severe) an Accepted Variation Band (AVB) as a function of users' task performance to the cognitive game and the correctness of their answers. The learning phase is followed by an adaptation phase where the robot adapts its behavior so as to minimize reaction time and maximize user correct answers.

If the user's task performance is below the Accepted Variation Band, this indicates that the user is performing better than during the learning phase and results in promoting the user to the higher the game difficulty level. In contrast, if the user's task performance is above the Accepted Variation Band, this indicates that the user is not performing well enough and the game difficulty level is decreased, as shown in Figure 4.

6 Experimental Results

The initial pilot experimental group consisted of 9 participants (4 male, 5 female), from our partner Silverado Senior Living care facility. All the participants were seniors over 70 years old suffering of cognitive impairment and/or Alzheimer's disease. The cognitive scores assessed by the SMMSE test were as follows: 1 mild, 1 moderate, and 7 severe. Due to the total unresponsiveness of 6 of the severe participants, only 1 severely cognitively disabled participant was retained for the rest of the study, resulting in a final group composed of 3 participants (3 female).

Figure 5: Human-User interacting with the robot during the actual music game: the robot is giving hints related to the music game, the user answers, and the robot congratulates and applauses the correct answer of the user

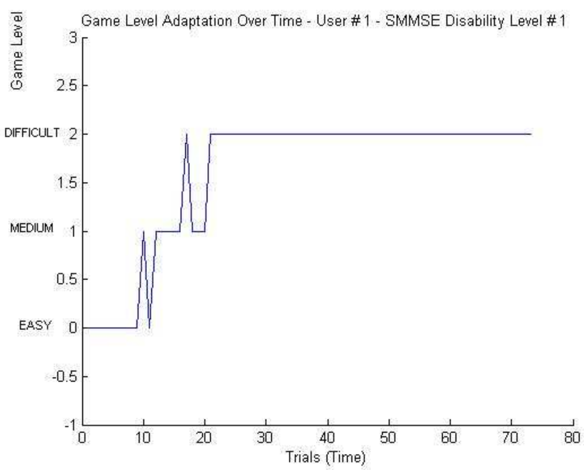

Figure 6: Game Level Adaptation and Evolution Over Time (6 months) for User Id 1

We constructed the training data and built a model for each cognitive disability level and for each game level. The participants played each game level 10 times (stages) in order to construct a robust training corpus.

The results obtained over 6 months of robot interaction (excluding the 2 months of learning) suggest that the elderly people suffering of dementia and/or Alzheimer's can sustain attention to music across a long period of time (i.e., on average 20 minutes for mildly impaired participants, 14 minutes for moderately impaired participants, and 10 minutes for severely impaired participants) of listening activity designed for the dementia and/or Alzheimer's population. Figures 6, 7, and 8 illustrate the evolution of the game difficulty over time, as well as response incorrectness and reaction time for user_id 1.

Outcomes are quantified by evaluating task performance and time on task. Based on the results to date, it can be con-

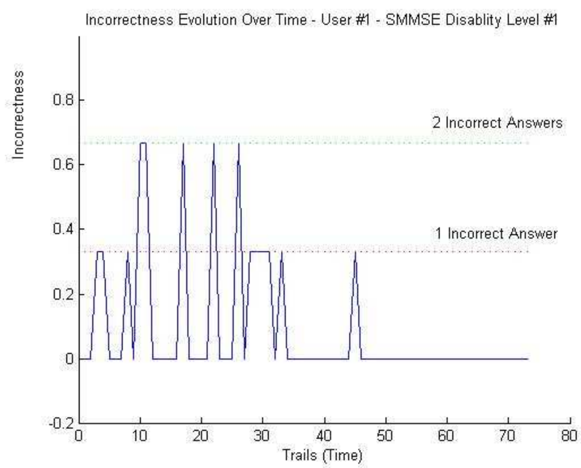

Figure 7: Incorrectness Evolution Over Time (6 months) for User Id 1

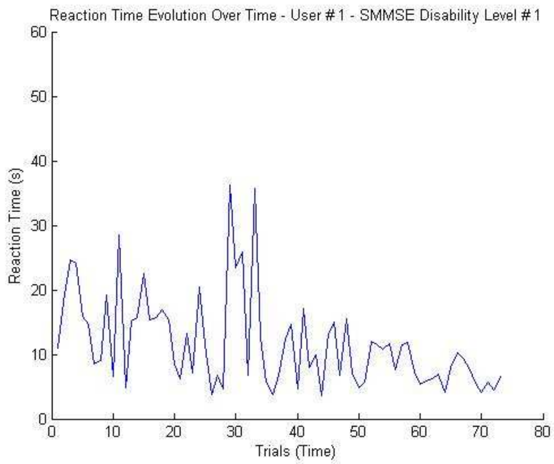

Figure 8: Reaction Time Evolution Over Time (6 months) for User Id 1

cluded that the SAR system was able to adapt the challenge level of the game it was presenting to the user in order to encourage task improvement and attention training. Figure 6 shows the evolution in time of the game level for user_id 1. The participant started at the easy game level and remained there for several sessions. The participant then started to perform better and diminished the reaction time and reduced the number of incorrect answers, which, in turn, resulted in a game level evolution from the easy level to difficult. Starting from the 22nd trial, the participant consistently remained at the highest level of difficulty in the game (see Figure 5). Figures 7 and 8 depict the evolution of the reaction time and the number of incorrect answers. The decrease of those metrics indicates improvement on the task. Similar improvement was observed for all participants.

The participants recognized the songs and identified the silence periods with the same probability. Hence, the analysis of the "no answer" situation among our elderly participants provides us with additional information. From our experiments, we noticed that the average rate of absence of response to silence was higher than the average rate of absence of response to songs, and that this phenomenon increased with the severity of the cognitive impairment. Our conjecture is that music stimulates the interest and responsiveness of the patients.

Another interesting observation that deserves more study is the users' ability to participate simultaneously in different tasks (multitasking): the participants were able to sing and push the correct buttons at the same time. This is notable in particular for participants with cognitive disability, since multitasking requires dividing attention.

The results obtained to date support our theory. First, our social robot was able to improve or maintain the cognitive attention of the patients with dementia and/or cognitive impairments through its encouragements in a specific music-based cognitive game. Second, the robot's capability of adapting its behavior to the individuals' level of disability helped to improve the user's task performance in the cognitive game over time.

This study is ongoing; two more weeks of active experimentation with the current group of participants are needed to complete the results. Once the study is complete, we will perform an SMMSE post-test and look for any possible differences from the pre-test. We will also collect feedback from the facility's music therapist (via a Likert-type questionnaire) about the participants' attentional and cognitive responses in the music attention settings. Finally, caregivers will also be asked about the improvements and the possibility of transfer of knowledge (interactive format with the patients, family members, and the robot). More details will be available by the time of the workshop.

7 Conclusions

This research aims to develop a socially assistive therapist robot that can provide through long-term learning customized cognitive stimulation for individuals suffering from dementia and/or other cognitive impairment. The main goal of the robot is to improve through the social interaction their cognitive abilities and therefore their quality of life. This model involves user engagement through speech and gesture. The preliminary results already show promise for our approach.

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