A Robotic Companion for Dolphin Therapy among Persons with Cognitive Disability

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***Abstract*— Our research addresses persons with Cognitive Disability (CD) and aims at developing social robots to support new forms of interventions for this target group. The paper described a "smart" stuffed dolphin called Sam designed to engage subjects with CD in a variety of tasks inspired by the practice of Dolphin Therapy (a special form of Pet Therapy). Sam emits different stimuli (sound, vibration, and light) with its body in response to user manipulation. Its behaviour is integrated with lights and multimedia contents displayed in the ambient (animations, videos, and 3D virtual spaces) and can be customized by therapists to address the specific needs of each person with CD.**

I. INTRODUCTION AND BACKGROUND

Cognitive Disability (CD) is characterized by severe impairments in intellectual skills and adaptive functioning, and affects about 2-3% of the world population. CD has often an incurable nature, but early interventions and appropriate therapeutic approaches can help these persons to improve their intellectual and behavioural skills [16][17].

Pet Therapy (PT) is a treatment that has been proved to work well with CD persons (especially children), leading to improvements in various areas. According to current research [4], PT helps subjects with CD to release their state of anxiety and improves relaxation, as human-animal bond acts on "stress hormones" production, inducing a reduction of arterial pressure, cardiac and respiratory rates. Some studies have found that 5- and 6-year-olds who were more attached to their pets expressed more empathy toward peers [14], and that 7- to 10-year-olds who had more "intimate talks" with their pets also had more empathy toward their peers [5]. Many beneficial, even if indirect effects arise from the presence of an animal in the CD child's life. To care for pet "virtual" alimentation, for example, leads to care also for one's alimentation.

The use of interactive technology to provide alternative, "virtual" forms of Pet Therapy has been explored in research since late nineties [13]. The pioneer in this field is PARO [18], a stuffed robot shaped like a baby harp seal and equipped with five kinds of sensors - tactile, light, audition, temperature, and posture sensors - with which it can perceive people and its environment.

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By interaction with people, PARO responds as if it is alive, imitating the voice of a real baby harp seal and moving its head and legs [19][20]. PARO, now a commercial product, has been proved to have psychological, social, and physiological positive effects especially on elderly CD people and has advantages over real animals in PT: there are no infections to worry about, no one is afraid of a stuffed animal, and PARO can be used in environments such as hospitals and extended care facilities where live animals present treatment or logistical difficulties [23][22].

A large amount of research has explored social robots [2][6][8] in interventions for persons with CD (particularly autism). As part of our work in this field, we have extended Paro's approach and developed a "smart" stuffed dolphin called Sam [7] that is meant to be integrated in a special form of Pet Therapy – Dolphin Therapy. Sam's affordances and behaviour have been designed in cooperation with a team of therapists from SAM Foundation, a non-profit institution in The Netherlands that, per year, offers Dolphin Therapy at a local dolphinarium to over 800 subjects with CD (mainly Down Syndrome and Autisms Spectrum Disorder – ASD)

After an overview of Pet Therapy, focused on Dolphin Therapy, the paper describes Sam and two preliminary empirical studies that explored the behaviours of persons with CD while interacting with this robotic companion.

II. PET THERAPY

The results of several researches show that Pet Therapy is useful for the prevention and treatment of human diseases and it can be used both to psychological-educational aims (therapy of behaviour disorders) and psychiatric aims (therapy of Deprivation Syndrome Autism, in particular mild or moderate forms) [1].

Pet Therapy has different ways of action. The most important way of action is the *affective* one and it has a more or less strong emotional base. According to the most recent opinions [21], Pet Therapy, at least in part, works by the same biochemical ways of relaxing response. A reassuring, positive and relaxing human-animal bond acts on adrenal (epinephrine) and other corticosteroid hormones or "stress hormones" production, inducing a reduction of arterial pressure, cardiac and respiratory rates and other beneficial effects.

Another way of action is the *psychological stimulation*. Pet Therapy influences social behaviour and relational mechanisms, character features and cognitive aspects. For example, a study of 68 5-year-olds found that 42% of the children that have pet result less anxious and withdrawn when compared with age-matched children who did not have pets [15].

The third way of action is the *game mechanism*. When a child with intellectual disabilities plays with an animal or laughs for its behaviour, he is better and he is more joyful. Finally, Pet Therapy is a way to do physical activity. Typical examples are Hippo Therapy and the water games with dolphins.

The research reported in [12] evaluated the effects of therapeutic horseback riding on social functioning in persons with ASD and provided evidence of the reduction of sedentary behaviours, and improvements in body posture, balance, and mobility.

A particular form of Pet Therapy is Dolphin Therapy. The choice of dolphins is based on a number of factors [10][3]:

- Positive image of these animals in the general population (big, protective, friendly aquatic mammals, intelligent and communicative);
- Curious and capable of sustaining complex interaction with humans;
- General cooperative and playful attitude;
- Accepting physical contact, including hugs, caresses and kisses;
- Soft skin and delicate movements.

Therapeutic programs based on dolphins (Figure) have been proved effective to support relaxation, stimulate and help increase children's emotional, cognitive, social and physical development.

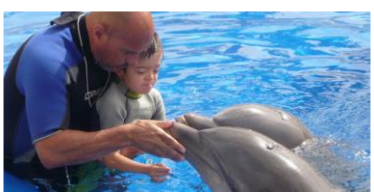


Figure 1. Dolphin Therapy

The exploratory study in [20] investigated an interaction program with dolphins and ten children diagnosed with ASD shows significant developmental progress. Subjects were evaluated using appropriate scales, like CARS, PEP-R, ATEC, ToM and a custom-designed 'Interaction Evaluation Grid'. Significant changes were observed on the children's 'Overall development score', as well as on their 'Fine motor development', 'Cognitive performance' and 'Cognitive verbal development'. The research shows a significant evolution in behavioural complexity and a statistically significant change on the 'Non-verbal Communication' item.

Still, Dolphin Therapy is extremely expensive, in some cases requiring over 1.000 euro per therapeutic session.

The challenge we would like to address with our smart dolphin is to offer a cost-affordable tool that enables the replacement of some animals-based activities, so reducing treatment costs while preserving the benefit of Dolphin Therapy.

III. Dolphin Sam: Technology

Dolphin Sam is a stuffed toy enhanced with complex system made up of several embedded sensors and actuators (Figure 1 a-b) and external components (Figure 1 c, Figure 2).

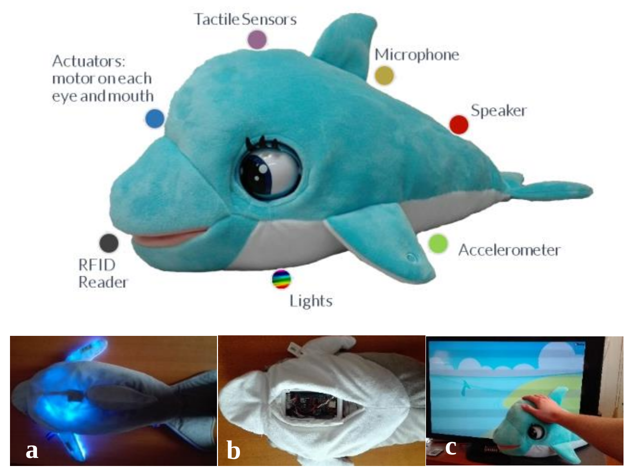


Figure 1. Up: Sensors and actuators embedded in the body of Sam; Down: a) body light; b) hardware board; c) integration with multimedia animations

Four parts of the body (head, stomach, right and left fins) are integrated with four touch sensors. There are light actuators on the stomach and a speaker and an RFID reader into the mouth. Eyes and mouth movements are controlled by two different motors. In addition, a low-cost ESP8266 chip is used for Wi-Fi communication.

All embedded components are connected and managed by an Arduino module which manages also the communication between the smart dolphin and the external components. The latter consist of commercial smart lights (Philips Hue), tagged RFID cards and a web application. The web application (Figure 5) manages the multimedia contents shown on digital displays or ambient projections, and the creation and customization functions to personalize the user activities.

IV. User Experience with Sam

The design of the user experience with Sam has been informed by some general goals of Dolphin Therapy in order to help persons with CD along multiple dimensions:

- to mitigate anxiety and reach the mental status of relaxation;
- to exercise selective and sustained attention (in particular towards audio and visual signals);
- to interpret visual stimuli at different levels of complexity;
- to explore and understand cause-effect relationships,
- to understand elementary abstract concepts;
- to exercise control and make choices;
- to build affective bonds with the (smart) dolphin and with caregivers.

Differently from PARO, Sam does not support sophisticated dialogic features. Still, the interaction with Sam goes beyond the manipulation of the smart toy and the generation of stimuli from it, and involves effects in the physical space – through lights in the ambient and multimedia contents shown on digital displays or projected on the walls.

A person can interact with Sam by touching or caressing its head, stomach and fins. He can also "feed" the dolphin by inserting a food card (a tagged RFID card with a food image or PCS symbol [9]) into its mouth. In response to these interactions, Sam emits different stimuli (sound, vibration, and lights) with its body to offer feedbacks, rewards, or suggestions for new tasks to be performed, while ambient lights are turned on or change color and intensity. Manipulations and movements of Sam also can also be used to control 2D or 3D multimedia animations or videos displayed on a screen or projected in the ambient.

In the rest of this section we briefly describe 3 examples of game-based activities that can be performed with Sam. They are inspired to activities performed during Dolphin Therapy e.g., waking up dolphins, feeding them, and swimming with them in the pool.

A. *Game 1: "Wake it up!"*

Sam is sleeping, his eyes are closed, and he is snoring. A video of a night seascape is shown in the environment while lights are blue (Figure 2). The user is asked to caress dolphin and wake it up it. Sam opens his eyes, emits "waking up" sounds, moves its mouth, while a sunrise on the sea is projected and environment lights turn to a carousel of sunrise colors.

Figure 2. Playing with Sam ("Wake it up!" game). An interactive video can be seen on: https://youtu.be/s_A8OET02fU

B. *Game 2: "I am hungry!"*

A screen displays the image of a small fish and Sam asks the user to give him this food. The person must select, among a set of RFID tagged cards, the one showing the image of that fish, and put it into Sam's mouth (Figure 4).

Figure 3 Playing with Sam: "I'm hungry" game

If the user performs this task correctly, the dolphin thanks him, moves the mouth like eating, and emits chewing sounds, while visual rewards are displayed in the ambient.

C. *Game 3: "Swimming together"*

The 3D animations are synchronized with actions performed on Sam. This will allow the user to understand that the puppet is "alive" and it is waiting for him, and it will increase the engagement. After a countdown of three seconds, the dolphin starts swimming on the display.

A rock appears and starts moving in the direction of the dolphin. The therapist invites the participant to tilt Sam in order to avoid the dolphin from hitting the rock. When the patient rotates Sam with the head up or down, the dolphin on the screen moves in the same direction. If the dolphin hits the rock, the activity ends and the animal returns in the waiting position. Otherwise, another rocks appear in the opposite position with respect to the previous one (i.e. if the first one was in the higher part of the screen, the second one will be in the lower one, and vice versa). If the participant manages to avoid three consecutive rocks, the activity ends and Sam exults (Figure 4).

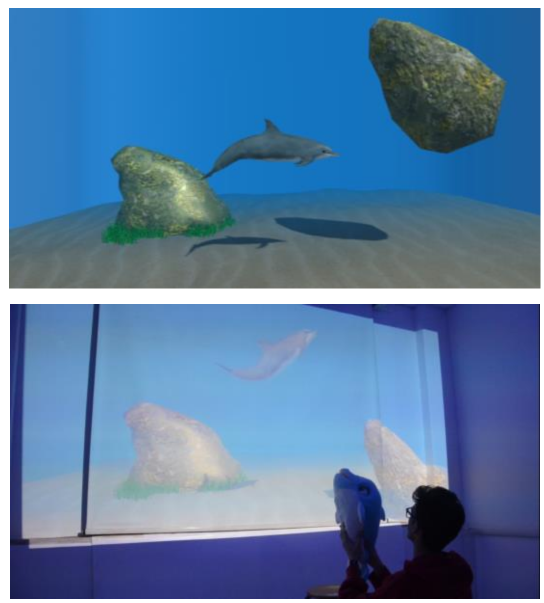


Figure 4. Playing with Sam: "Swimming together" game

V. Activity Creation and customization

Sam is integrated with a web application that enables therapists to create/personalize new or existing activities by defining specific behaviours of Sam in response to interaction and integrating them with multimedia contents that meet the specific needs of each single person.

Using a simple interface (Figure 5) therapists can include/replace any video, animation or image in an existing activity, include/replace any behaviour of Sam, or define a brand new activity. A library of build-in features are available that include events both on the dolphin (e.g., sensed by touch sensors, the accelerometer, or the RFID reader) and in the system (e.g., a therapist by pressing a button on the keyboard or a remote controller), as well as stimuli on the dolphin (e.g., sound, light, and vibrations generated by the embedded actuators), the screen (e.g. showing images and videos), and the ambient (e.g., turning lights on or activating the smart plug).

The tool offers a simple block-based authoring interface (Figure 5). It is implemented using Google Blockly, a visual, web based code editor that represents coding concepts as interlocking blocks [11]. The tool supports an event-driven programming paradigm, is compatible with all major browsers (Chrome, Firefox, Safari, Opera, and IE), lightweight (less than 1MB), and easily extensible with new functions should they be needed in the future.

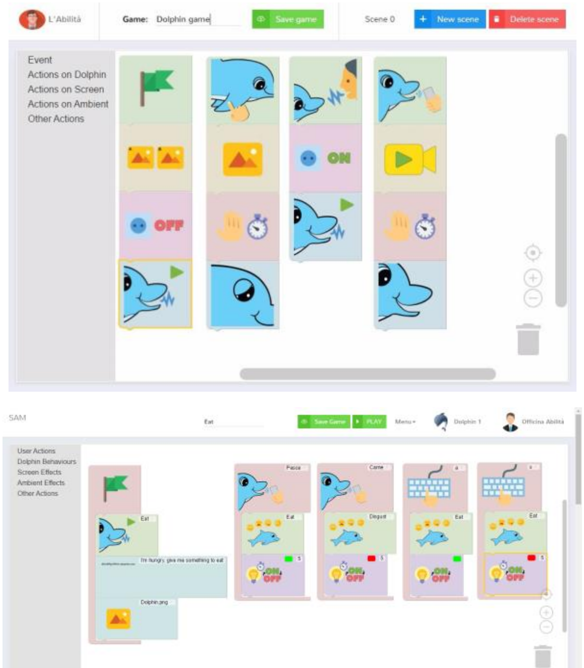


Figure 5. Creation and Customization Tool

VI. PRELIMINARY EVALUATION

In collaboration with a local care center, we performed a preliminary exploratory study devoted to gain an initial understanding of how persons with CD would interact with Sam. The study investigated the degree at which the *first exposure* to Sam triggers *engagement*, i.e., attracts and holds the attention of these subjects.

Engagement is widely acknowledged as learning facilitator for all persons. For subjects with CD, the role of engagement is even stronger. The deficits associated to CD create a persistent state of insecurity and uncertainty, a tendency to withdrawal and self-inhibition, and the "unknown" is often a source of distress, discomfort and psychological rigidity. This in turn hinders the willingness and capability to be involved in a task and to act upon the associated objects.

Among subjects with CD, reaching and maintaining a state of engagement is a *precondition* for any learning activity. Hence it is important to evaluate if and at which degree the interaction with Sam is effective from an engagement perspective, before proceeding to evaluate the actual learning potential of this instrument.

A. Participants

The study involved *5 medium-functioning adults* (aged 19-29) with different forms of cognitive impairments, their caregivers (experienced phycologists or special educators who have worked on a regular base with the subjects for at least one year) and 2 members of our technical team.

B. Procedure

Each participant attended one session that followed the protocol reported in this section. All sessions were video recorded. In the introductory phase, which took place outside the room for 3-5 minutes, the person's caregiver explained to the subject that (s)he was going to meet new friends, namely one robots and two humans. The two technical team members who supervised the sessions introduced themselves with the reassuring presence of the caregiver, and chatted with the subject for a while. Then the subject entered the room, and was invited to take a seat or move into the space according to their will. When the person was seated and looked comfortable, the robots were showed - one after the other. Each robot was placed on the table in front of the subject while the others remained hidden. The technical persons and the subject's caregiver invited the subject to play freely with the robot and explore it as (s)he desired. They sat side by side the subject but did not interfere with the robot experience in any form.

The average duration for the exposure to Sam was planned to last for 3-5 minutes. Still, when it happened that the subject showed an evident decrease in engagement or any sign of distress, the robot was removed and the session continued in the regular way as planned in the therapeutic program of the person.

This approach, avoiding specific requests or instructions during the exposure time to the intervention, was intended to spur an autonomous exploration of the robot and an active reaction to the robot stimuli.

C. Main Results

The video recordings of all sessions (approximately 30 minutes) were analyzed by a therapist who did not participate in the sessions. For each subject, he used the behaviours described in Table 1 as coding schema.

Table 1. Engagement-disengagement behaviours

Engagement Behaviours
Interacts with a purpose, e.g., waves the robot, shakes it, or talks, expecting a reaction
Holds the robot with both hands and manifests an arousing of positive emotions (e.g., laughs and smiles)
Grabs and hugs the robot with both hands and manifests positive emotions (e.g., smiles)
Moves the robot into the personal space (*), and explores physical contact
Sustains a visual contact with the robot and manifest minimal physical contacts, e.g., touches and caresses
Looks at the robot and sustains a visual contact with it
Disengagement behaviours
Doesn't pay attention to the robot
Ignores the robot and manifests irritation or frustration
Pushes the robot away
(*) The "personal space" is the region surrounding a person which is within the reach of any limb of an individual, and they regard as psychologically theirs.

The video analyst identified the start-end time (in minutes: seconds) of each behaviour and the Points of Engagement (or

"Latency Time"), i.e., the time elapse between the appearance of Sam in front of the subject and the subject's first manifestation of engagement. The values reported for *Latency time* (in seconds) are reported in *Table 2*) while the main findings on *Engagement* are reported in *Table 3* and in *Plots I-V*.

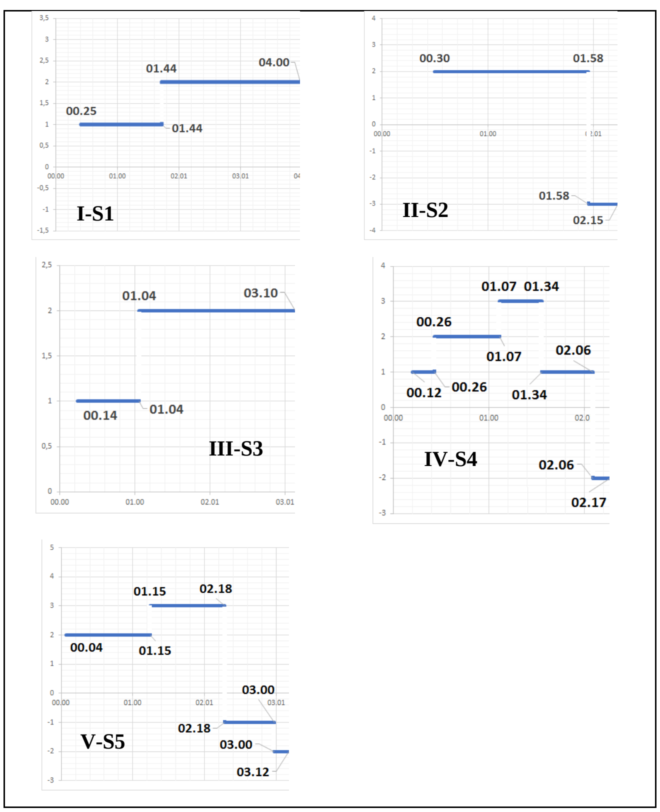
Table 2. Latency Time (Point of Engagement) for each subject $S_{i=1..5}$

S1	25s
S2	30s
S3	14s
S4	12s
S5	4s

Table 3. Sustained Engagement for each subject. TD: Total Duration (mm.ss). ED: Sustained Engagement Duration (mm.ss). E%: Sustained Engagement in percentage

	TD	**ED**	**E%**
S1	4.00	3.35	89,6
S2	2.15	1.28	65,2
S3	3.10	2.56	92,6
S4	2.17	1.54	83,2
S5	3.12	2.14	69,8

Table 3 reports the Total Duration TD (mm.ss) of the experience of each subject with Sam, starting from the Point of Engagement. Table 3 also shows 2 different values for Sustained Engagement for each subject. ED (Sustained Engagement Duration in mm.ss) is the sum of the durations of all engagement behaviours with Sam. E% provides the same value as a percentage of the Total Duration.



Plots 1-V: Behaviour Evolution for each Subject

To investigate the evolution of engagement/ disengagement behaviours along the time for each subject, we associated a *weight* (or *level*) to *each* engagement/disengagement behaviour, which correspond to a *level* of intensity of engagement/disengagement. Weights are in the range [-3; + 4]; negative values are associated to disengagement. In order to take into account the impairments of each person and better compare the results among the participants, the mapping "*behaviour → weight (level)*" for engagement was not the same for all subjects. The weights associated to each behaviour for each subject are reported in Table 4.

For example, "sustaining visual contact with a robot" is considered an engagement behavior for a subject with a severe form of autism (S2): it has weight 1 for this person but not for the other participants (who should at least manifest "minimal physical contacts, e.g., touches and caresses" in order to be considered as "engaged").

Table 4. Engagement-disengagement behaviours range and associated weight's by subject

Engagement Behaviours	**S1**	**S2**	**S3**	**S4**	**S5**
Interacts with a purpose, e.g., waves the robot, shakes it, or talks, expecting a reaction					4
Holds the robot with both hands and manifests an arousing of positive emotions (e.g., laughs and smiles)	4		4	4	3
Grabs and hugs the robot with both hands and manifests positive emotions (e.g., smiles)	3	4	3	3	2
Moves the robot into the personal space, and explores physical contact	2	3	2	2	1
Sustains a visual contact with the robot and manifest minimal physical contacts, e.g., touches and caresses	1	2	1	1	
Looks at the robot and sustains a visual contact with it		1			
Disengagement behaviours					
Doesn't pay attention to the robot	-1	-1	-1	-1	-1
Ignores the robot and manifests irritation or frustration	-2	-2	-2	-2	-2
Pushes the robot away	-3	-3	-3	-3	-3

Plots I-V describe the evolution of engagement/disengagement behaviours. The lines in a plot show the engagement/disengagement levels along the time for a specific subject. On the horizontal axis we find time values. Lines are tagged with 2 time values that denote the start/end of a behaviour, while the line length corresponds to a behaviour duration. On the vertical axis there are the engagement behaviours, represented by numbers corresponding to behavior levels. In this way, we can compare engagement results not in absolute but in weighted terms, taking into account the relative importance of a behavior for a specific subject.

The participants in this study were subjects with severe cognitive impairments and usually resistant to get "drawn in" educational activities at the center. The results of our study show that no subject manifested anxiety at the first exposure to Sam and in all participants, at different degrees, the interaction with this smart toy had the power of activating positive responses and triggering arousal through unstructured stimulation. According to the therapists, the participants manifest signals of engagement and maintained a basic level of attention much more quickly, and for a longer time than during regular activities.

VII. CONCLUSIONS

The design of our smart dolphin Sam is inspired by the practice of Dolphin Therapy and extends the capability of the existing robotic pets used for therapeutic purposes in a number of directions:

i) it provides multisensory stimuli both on the object and in the ambient;

ii) its play activities are not restricted to the interaction with the smart toy but also involve the experience of lights and multimedia contents in the physical space;

iii) it is integrated with a tool that offers powerful creation and customization features for new or existing goal-oriented activities addressing the fundamental need of offering personalized play experiences to each person.

Sam has been evaluated in a very preliminary exploratory study at a local therapeutic center. The study has many limitations (e.g., number of subjects and duration of the treatment) but it suggests that Sam can be used among subjects with severe forms of CD. From Summer 2017, Sam will be integrated with the Dolphin Therapy program at SAM Foundation (NL) for a systematic testing of its effectiveness for learning among children and adults with different forms of cognitive impairment.

ACKNOWLEDGMENTS

The authors warmly thank the team at SAM Foundation for the support to the design of Sam and all participants in the reported study.

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