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Robot-based Therapeutic Protocol for Training Children with Autism

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Abstract— **Robots are commonly used artificial agents with powerful capabilities in navigation, perception and execution in the physical world. One interesting question is how well robots can assist and engage individuals with social and behavioral deficits (such as autism) to acquire new skills? Preliminary studies in autism research demonstrate that in many cases individuals with Autism Spectrum Disorder (ASD) interact more actively and engagingly with robots than humans. As there are limited investigations for utilizing robots in social and behavioral treatments of individuals with ASD, we designed and evaluated a robot-based intervention protocol using a social robot (NAO) to deliver behavioral training mechanism for children with ASD. Results of our pilot study on seven verbal children with high functioning autism show behavioral response improvement, including pointing and facial expression recognition in the majority of the participants as a consequence of the behavioral intervention delivered directly through the robot. Results also show that individuals were able to engage in these learned skills during human-human follow-up sessions.**

I. INTRODUCTION

Robots with unique mechanical capabilities and artificial intelligence features have been designed at much higher rates in last decade than before. Many of these robots have a small body with several sensors and Artificial Intelligence (AI) capabilities targeted toward human interaction. Such attributes have enabled researchers to utilize such robots in different applications, such as behaving like social companion-bots and personal assistants. Two of the robots that have been recently introduced to the market are Jibo (small table-top assistant robot) [1] and Pepper (humanoid robot that speaks in four languages) [2] that will be released in 2016. With this emergent number of companion-bots and improved hardware capabilities, researchers can investigate the uses of robots in a wider range of applications. As an example, health care and therapeutic treatments involving social aspects are categories where robots can potentially be applied in a large-scale. In this paper, we introduce a longitudinal robot-based therapeutic protocol to monitor the social engagement of individuals with autism and provide subject-dependent therapeutic feedback.

Autism Spectrum Disorder (ASD) refers to a developmental disorder that affects social and communicative behaviors. As reported by the Center for Disease and Control Prevention 2014, one in 68 American children has been diagnosed with ASD with an approximate annual increase of 10 to 12 percent [5]. According to *The Diagnostic and Statistical Manual of Mental Disorders* [3], individuals with ASD experience deficits in social-emotional reciprocity, verbal and nonverbal communication behaviors, and deficits in development and maintenance of relationships [3]. Characterized as an early brain developmental disorder, ASD can be diagnosed in an individual as young as 2 to 3 years of age [19], [7] and early intervention on social and communication skills at a young age result in better outcomes for children with ASD [24].

With this increase in prevalence and need for early intervention, various interventions have been developed for treating children and young adults with ASD [28]. In the 2014 National Autism Center Report, 27 interventions with well-documented evidence exist for behavioral intervention of ASD [28]. Each of these interventions consists of Applied Behavior Analysis (ABA) techniques using systematic ways of producing replicable procedures [28]. Although the majority of existing interventions are delivered through human-to-human interaction, the most recently accepted intervention utilizes Technology-aided Instruction, where technology is referred to as any electronic item/ equipment/application/or virtual networks [20]. While technology-based intervention has been a relatively new intervention procedure, it has been growing rapidly due to the recognition that many children with ASD show a collective interest toward technology [23]. With the advancement of robotic technology, investigation on the use of Socially Assistive Robots (SAR) for treatment of ASD has grown recently [11], [4], [6], [21]. Studies such as [16] have shown that children with ASD increase responsiveness and interaction with a human when paired with a robot rather than with another human or computer screen. As noted by [11], it is hypothesized that the robot's advantage is likely due to its simplified social complexity versus a human. Thus promising results in the use of robots for treatment of ASD has promoted further study of clinical applications for interactive robots.

A few quantitative studies have been published that investigate the use of robots for teaching or improving social skills [23]. Some of these include Duquette et al. [11] and Warren et al. [26]. [11] compared the efficacy of using either a human or robot mediator (Tito) for different social skills. Results show that the two children diagnosed with ASD were better capable to imitate body movements when interacting with a human mediator than those paired with Tito. However, [11] noticed that participants had a heightened interest to their robotic mediator than the human explained by the attracting characteristics of the robot such as lights, color,

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and movement. While studies about the use of robots for improving social skills show promise, research in this area is still exploratory and generally limited to short study durations [16].

In our study, we tested seven high-functioning verbal children diagnosed with ASD (ages 6-15 year) over the course of six to nine months. A time span of such duration was chosen to study the long term effects of the robot on specific social skills of the participating children. Children in this study were paired with NAO, a humanoid robot, to interact during several social tasks. These tasks were proposed to measure initial existing social skill deficits and provide feedback for improvement from those initial values.

II. DATA ACQUISITION AND PROPOSED PROTOCOL

This section describes the multi-session human-robot interaction sessions and the methodology we used for robot intervention.

A. Human-Robot Interaction Setting

We used Aldebaran's NAO, a 23-inch tall humanoid robot, to develop and deploy a set of interactive and attractive robot-based games meant to socially engage children with autism [13]. NAO has 25 degrees-of-freedom and can conduct human-like gestures and behaviors (see Figure 1), that were required for our study (e.g. speech synthesizes, body and head movement, simple and attracting appearance). We utilized off-the-shelf modules of NAO to design social tasks meant to activate social and behavioral responses in participants.

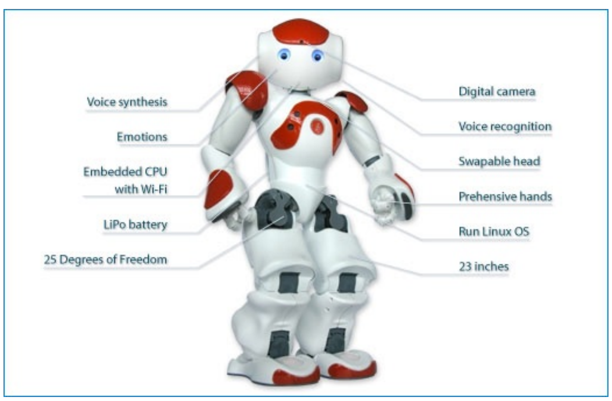

Fig. 1. NAO's electrical and mechanical modules

In our longitudinal study, seven (2 female and 5 male) high-functioning children with ASD in the age range of 6-15 years old (Mean=10.14; STD = 2.27) participated. All children with ASD were recruited from different autism treatment organizations from the state of Colorado (USA), including local autism schools and families associated with JFK Partners [1]. All of the participants had a high level of verbal communication capabilities. All parents of our participants signed an informed consent form and IRB approval was obtained for our study.

We installed four synchronized cameras on the four corners of the room to capture body gestures and facial behaviors of the child throughout the sessions. The height of these cameras was set to the eye level (about 3 feet high) of a sitting child. A researcher watched the entire interaction of child with the robot from a different room, using surveillance cameras. He annotated the social and behavioral responses and controlled the robot's response. In addition, the researcher observed and annotated the child's verbal communication skills, joint attention and expression recognition skills during the child-robot interaction.

B. Social Robot-based Tasks

One novelty of the proposed robot-based interaction is the adaptive capability of our intervention based on skill-level of each individual. Every session of child-robot interaction contains five tasks, each designed to practice and teach one social response (see Figure 2). The robot-based tasks were designed to be exciting and socially interesting for children. During each task, NAO engaged the child using five social questions or through various social behaviors. Correct and incorrect responses were scored for each child in every session. Throughout the entire game, NAO referred to the participant by his/her name and used simple words to instruct the child.

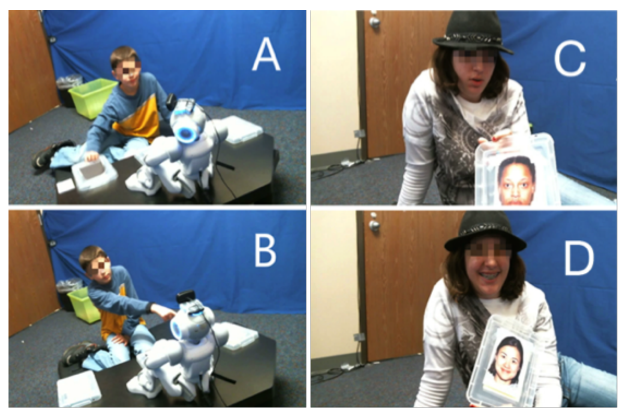

Fig. 2. Children are socially interacting with NAO: (A) NAO points and child follows. (B) NAO describes an object and child points to it. (C) Child recognizes and describe the emotions of facial expressions. (D) Child imitates the expression on the face

We focused on five areas which have been reported to be socially challenging for individuals with autism and used the robot as a motivator and trainer to practice these social concepts.

1) **Task 1: Verbal Communication**: In every session NAO starts to talk about his past week and ask the child a few questions. This helps to build a friendly relationship between the child and NAO, and encourages the child to speak about his experiences. During this interaction, NAO instructs the child to respond to five questions: 1) child's full name, 2) favorite colors,

[1]JFK Partners has collaborative relationships with numerous organizations that are a part of Colorado's developmental disability and special health care needs communities

3) number of siblings, 4) age, 5) time the child goes to bed. Before starting the task, we got the response to all of these questions from parents to evaluate how correctly and consistently each child responds to these questions (The results related to ”*Task 1*” are represented by ”T1” in subsequent results and figures).

2) **Task 2: Following NAO's direction of pointing and recognizing facial expression:** Children with autism may not be able to correctly recognize the points of interest from other individuals. In Task 2, we evaluate how accurately the participant can follow and pick up the direction of NAO pointing toward an object (T2.1). In addition we examine how well each individual can recognize different facial expressions (by providing a list of possible facial expressions) to identify which expressions the child is challenged with(T2.2).
3) **Task 3: Joint attention regulation:** For Task 3, we target the joint attention skills of children. In other words, we are interested in knowing how responsive the child's gaze and/or gesture would be, when NAO changes his point of attention. To investigate how a child regulates his point of attention toward an object of interest, NAO looked at a box and asked the child to bring the box to him. This is repeated various times and the child's response is recorded for each.
4) **Task 4: Facial Expression Recognition and Imitation:** Recognizing emotions of other individuals and being able to mirror others' facial expressions properly is an important aspect of having empathy; known to be a common challenge for individuals with autism. In the proposed scenario, boxes with head-shot photos depicting different facial expression are placed in the room. NAO points to one box and the child is asked to recognize the facial expression shown in the photo (T4.1) (contrary to T2, we did NOT provide a list of expressions). In addition NAO instructs every child to carefully look at the image and imitate the expression on his or her own face (T4.2).
5) **Task 5: Pointing:** Pointing is a critical aspects of child's speech and language development for children. For this part of the study (T5), NAO described a box in the room and asked the child to point toward that object (in contrast to T3, NAO has a fixed body posture and only describes the object without utilizing any head postures or hand gestures to describe the objects). We can measure how well the participant could understand the verbal commands of NAO and the child's ability to get the attention of NAO toward the described object using pointing gestures.

In every session, NAO practiced all of these tasks with the child (five times per task). After each task the child was given the opportunity to take a break for 5 minutes (if desired) to maintain his/her concentration for the next segment. This help us not to exhaust the child's attention span and keep him or her engaged for the rest of the session. The entire session for each individual took approximately 45-60 minutes. In every session a graduate researcher observed and annotated the responses of a child and calculated the accuracy of the responses for all five tasks within a range of [0-100]. This accuracy index is a quantitative measure to assess the participant's social skill learning progression over a six month interaction time period with NAO.

III. Robot-based Therapeutic Design

Collecting and modeling the longitudinal responses reveals the subject-specific affective deficits. It can also customize the pace and progression of intervention based on the learning curve of each individual. In evaluating the effectiveness of our proposed protocol, we employed a multiple baseline design [21] across the tasks. Using the multiple baseline design of treatment, the start of intervention treatment for each game was staggered across time for each individual. Intervention would only take place for one task at a time requiring that the child reach a certain minimum achievement on the task before starting intervention for the next task. This design allows evaluation of the treatment effect for each targeted behavior individually.

A. Three-step Therapeutic Procedure:

Within the 6-month child-robot interaction , NAO went through five defined tasks in every session. Each task consisted of the presentation of the prompt followed by either the independent or prompted performance of the target behavior, and the immediate presentation of social praise. All tasks started at the *Baseline* to figure out the level of expertise of each child before receiving intervention. For those tasks where the child had deficiencies we go to the ıIntervention and Treatment step. After training and practicing those skill-sets, we finalize the therapeutic procedure by *Follow-up sessions*, to evaluate how children can employ the learned skills in a human-human interaction setting. Through out the entire sessions, NAO used positive verbal reinforcer to engage and actively involve the child in the therapy sessions. More technical detailed information about each phase is provided below:

1: Baseline: The first 3 sessions of the child-robot interactions were used for baseline assessments. Baseline trials were conducted in an identical manner to treatment trials without the inclusion of re-prompting or reinforcement. In these sessions, we evaluated the current knowledge and accuracy response rate of every child by asking the child to interact with NAO in the five aforementioned tasks without any feedback to the child. The captured data from these child-robot interaction sessions served as baseline data to examine the developmental skills of each participant. If the accuracy of a task was less than an 80% threshold, we conducted the intervention sessions for that task. Otherwise no assisting feedback was given.

2- Intervention and Treatment: Based on the baseline results of each individual, we evaluated whether the child needed intervention sessions or not. If the child had a low level of performance (i.e. lower than 80% accuracy), a tailored treatment session was give. Therefore NAO engaged as a trainer to provide prompts based on the child's responses or actions. The corrective prompts for each task had positive tones and focused on assisting the child in improving the new skills. The same treatment procedure was repeated in multiple sessions, until the performance reached 80% or more, Thereafter, the intervention moved to the next task which needed intervention. Having intervention for only one task at a time allowed us to observe if the child's skill accuracy for any other task was also affected. For the tasks where intervention was needed, NAO provided verbal feedback and further explanation that could help the child better understand and respond to the questions or instructions of the game.

3- Follow-up: In the last phase of the therapy protocol, we conducted two follow-up sessions in the form of human-human interactions similar to the initial baselines, however using a human to conduct them. These sessions were purely designed to find out how well the child could sustain, generalize, and apply the learned concepts.

IV. Achievements and Results

The main objective of this paper is to shed light on the great potential of using (social) robots for engaging, conducting, and improving the social skills of isolated and less sociable individuals. This paper reports the results of our over 6-month robot-human interaction experiments in a therapeutic context. We designed and conducted a longitudinal robot-based therapeutic setting for 7 children with Autism spectrum disorder. Each individual participated in our study for at least 6 months and interacted in 6 to 17 sessions with NAO depending on the amount of sessions needed to reach an 80 percent skill level in all tasks.

In the majority of our participants we observed extreme excitment when initially meeting Nao for the first time. In some cases such excitement was overwhelming. Considering this evidence, prior to starting our one-on-one robot-based interactions, we allowed every child to freely play with NAO and build a rapport with him. Then in the next session, we started the baseline sessions to assess the initial social knowledge of every child. The assessment results indicated that 6 of the 7 children with ASD have some difficulties responding to one or more of the tasks (i.e. accuracy response lower than 80%). Our baseline data clarified that all the subjects responded to Task 3 (following NAO's head orientation) and Task 5 (pointing to the described object by NAO) with a high accuracy. However some of the subjects had difficulty responding to T1 (verbal communication), T2 (emotion recognition), and/or T4 (facial expression imitation).

Figure 3 demonstrates the responses of Subject SN05 for two tasks (T1, and T2) which needed intervention. The average baseline accuracy for T1 and T2 were 33.33% and 0%, respectively. After conducting 12 sessions of intervention by NAO, the accuracy of both tasks (T1 and T2) reached 80%. In the follow-up human-human session we observed that the responses of SN05 stayed in a similar accuracy range.

In our longitudinal study, six out of seven children had at least one social skill with some deficits, therefore NAO provided the robot-based interventions for them. One of the participants had an amazing response and engagement toward NAO and she had high baseline performance therefore we did not run the interventions sessions for her.

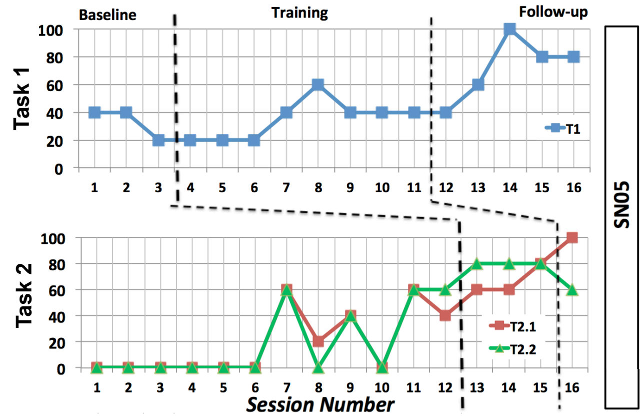

Fig. 3. The accuracy of behavioral responses of SN05 for Task 1 and Task 2: the dashed-line demonstrates the starting and ending of the intervention session for both tasks

Table I reports the overall performance (i.e. average and standard deviation of accuracy of responses for five social-behavioral tasks) of all children with ASD in the Baseline, Intervention, and Follow-up sessions. Comparing the baseline and intervention results confirms that for a majority of the social games, using the robot-based intervention can improve the desired social and behavioral skills of the children for all five tasks.

Task ID	Overall Response Accuracy: Average (STD)		
	Baseline	Intervention	Follow-up
Task 1	79.05 (27.84)	81.95 (30.05)	98.33 (25.07)
Task 2.1	80.00 (38.35)	80.49 (37.99)	100.00 (25.07)
Task 2.2	61.90 (36.23)	75.61 (38.68)	96.67 (15.74)
Task 3	82.86 (37.57)	-	96.67 (37.80)
Task 4.1	66.67 (36.23)	72.68 (44.57)	100.00 (9.76)
Task 4.2	65.71 (33.94)	60.98 (38.82)	80.00 (33.52)
Task 5	92.38 (18.44)	-	100.00 (0.00)

TABLE I

Behavioral response accuracy: Average (STD) of all seven children in three phases

The results of the follow-up human-human interactions indicate that when children gain new social concepts and skills through the robot, they are able to transfer the skills to human interaction. Such evidence confirms the importance of having a robot intervention and good influence of the proposed setting for applying the learned skills. These results suggest that robot-based human intervention is potentially a viable approach for teaching social skills to children with autism.

Results reported in Table I demonstrate the effectiveness of robot-based sessions for teaching various social skills.

For instance, considering the baseline scores for facial expression recognition (T2.2), the low average baseline score of 61.90% with high variability (STD=36.28) indicates that children initially have difficulty differentiating between the appearance of facial expressions. However, going thorough the intervention sessions helped them improve by an average of a 15% accuracy. In human-human follow-up sessions, results show they were able to maintain the same level of heightened accuracy in a human interaction.

V. Conclusion

The objective of our study was to design, conduct and evaluate a set of customized robot-based treatment to teach behavioral skills to children with autism and improve their social and communication skills. We began our treatment procedure by conducting a comprehensive assessment of the children's developmental status. Results from this evaluation helped us measure the social and behavioral responses of each participant. We developed a robot-based treatment program that was tailored to each child's strengths and needs. We designed and conducted a set of therapeutic tasks where the robot, NAO, responded and commanded the child to help the child if required during each task. To evaluate how NAO is capable of teaching new social and behavioral skills to each participant, (after finishing the intervention sessions) we followed up our investigation with a human-human interaction. The results show that, all of the children understood and responded properly and followed the head orientation of NAO (T3) and properly pointed to an object described (T5). However, the majority of them lacked the ability to consistently respond to verbal questions (T1) and also had deficiencies in recognizing and imitating facial expressions (T2 and T4). Results reported in Table I confirm that overall the robotic treatment can be a viable approach for helping individuals. Knowing exactly what the core deficits of each individual are and personalizing a set of tasks can help individuals with autism practice and learn new skills. Based on observations for this longitudinal study, we listed a set of questions that can help researchers in the area of robot-based interaction for designing relevant therapeutic sessions (see Appendix).

APPENDIX

During conducting multiple robot interaction sessions and after analysis of the recorded videos of child-robot interactions, we found interesting evidence that can be helpful for other researchers who are using robots for treatment purposes.

- Some of the participants were very engaged with NAO and they often talked and communicated with the robot well, but they would become frustrated if NAO took too long to respond or repeated an instruction after the child had already completed the task.
- In terms of facial expression recognition (task T2.2 and T4.1), most of the subjects were highly capable in detecting an expressions. However for couple fo subjects they recognized netural face as sad and a sad face as angry. Knowing such information for every child with ASD can be very helpful for parents and care givers to know what emotions may confuse the child.
- For facial expression imitation (T4.1) two subjects (out of seven) had trouble maintaining an expression on their face for an extended time (about couple of seconds). They oftentimes flipped between expressions very quickly. For instance one participant jumped between happy and sad faces while trying to mimic happy, or throwing in bits of surprise (raised eyebrows) when trying to maintain a neutral or sad face.
- Coding behavioral and social responses of children with ASD could be very challenging. For instance, some of the subjects were over-active and interested to move around a lot. Sometimes they hit NAO's face and body repeatedly or looked at NAO very closely to the camera.These types of behaviors made it difficult to observe and annotate the child's facial behaviors.
- During our longitudinal study for over 6 months, we had very cooperative families who willingly came to the University of Denver campus (every other week) to have 45-60 minutes of interaction with NAO. However sometimes they could not come to us because of some family issues or being far from the campus. Therefore they needed to cancel some of their appointments. Considering the great engagement of children while interacting with robot, and promising results of our experiments, it will be great to see much affordable robots that are provided in schools and therapeutic centers so more children can interact with the robots and can consistently focus on their behavioral and social skills.

We list a couple of questions that will shed more light on the area of therapeutic robots for Autism research:

1) Do individuals with ASD have similar behavioral and social responses when a robot has a dynamic (emotional) face? In our experiment we used NAO, a humanoid robot with a static face. However, would a facially expressive robot (e.g. Zeno (Hanson, et al., 2009)), improve and accelerate the social learning skills of the children?
2) Do children with ASD, ever moved around or hit the robot, either as a sign of frustration (on difficulty levels) of the tasks, or just because the interlocutor partner (i.e. robotic or human) responded fast or not quickly enough to the children?

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