Autism assessment through a small humanoid robot *

Salvatore M. Anzalone Sofiane Boucenna
David Cohen Mohamed Chetouani

Institut des Systemes Intelligents et de Robotique
Universite Pierre et Marie Curie
Pyramide - T55/65, 4 Place Jussieu
75005, Paris, France
anzalone@isir.upmc.com

ABSTRACT
Children affected by Autism Spectrum Disorder (ASD) show early impairment in Joint Attention and Imitation. We propose in this paper to explore their behaviors through the use of a small humanoid robot. A small set of activities have been developed to elicit such behaviors as part of the standard Early Start Denver Model treatment. Results shown statistically relevant differences between the behaviors of children affected by ASD and typical development groups.

Keywords
Autism Spectrum Disorder, Early Start Denver Model, Joint Attention, Imitation, Social robots, Human Robot Interaction

1. INTRODUCTION
Psychology, neurosciences, robotics and machine learning are converging towards the common goal of understanding the mechanism behind the social interactions between humans [13]. From the perspective of the technical sciences, the progresses in social sciences give new hints on the development of new robotic architecture and more effective social behaviors. On the other hand, from the point of view of the social sciences and neurosciences, robots give the unique opportunity of studying social behaviors using controlled stimuli, allowing to focus on single phenomena and to obtain qualitative results. According to this paradigm, several researches focused on the use of robots during therapeutic sessions with impaired people [20]. It is possible to categorize such applications into four different kinds: a) robot vs humans behavior comparison [15, 9]; b) child behaviors elicitation [8]; c) active skills training [6, 4]; d) providing feedback on performances [19]. In the first case, the behavior of the child during interactions with a robot is compared with his behavior in the same interaction performed with a human therapist: here the focus is on how the human characteristics in influence the interaction. In the behavior elicitation case, the robot stimulates a social reaction of the child: its presence, absence, and more in general, the quality of this response is helpful during the therapy assessment carried out by the therapists. The robot is also able to model, teach and practice a skill: in this case the aim is to facilitate the learning of such skill by the child and its eventual transfer in interactions with humans. At last, robots can provide feedbacks to the child about his current activity, to reinforce the learning. Also, the robot can help the therapist on achieving a more natural interaction, by providing information regarding the internal stimuli of the child and increasing in this way the individualized nature of the therapy.

The focus of this paper is on the study of the behavior of children affected by Autistic Spectrum Disorders (ASD) using a robot. ASD refers to a range of neurodevelopmental disorders that impair social interaction, communication and language and implies stereotyped and restricted pattern of behaviors. While early symptoms of ASD are present since the childhood, its diagnosis usually takes place between the 3rd and the 5th year of age, when results clear to the family the difficulty they have on realizing a complete interaction with the child [11, 18]. Also if in adults the ASD syndrome still remains a very impairing condition, important improvements can be achieved through different therapies carried out during the development stage of the childhood.

Literature shows several treatments of ASD [14] involving both behavioral and developmental aspects, focusing on skills considered as ”pivotal” for the correct development of th child, such as joint attention and imitation, as well as communication, symbolic play, cognitive abilities, sharing emotion and regulation [23]. Here, the Early Start Denver Model (ESD) treatment proposes a set of activities performed by the autistic child with the help of a therapist aimed on stimulating him to act socially [16]. Through such performed activities, presented to the children as games, language and communication skills, adaptive behaviors, intelligence quotient and social skills will be focused and improved.

*Study funded by the European Commission: Project CoDyCo, FP7-ICT-2011-9, No. 600716; Project Michelangelo, FP7-ICT No. 288241. French National Agency of Research: Project MACSi, ANR-10-BLAN-0216; Investissiments d'Avenir program, Project SMART, ANR-11-IDEX-0004-02.

In this paper we propose a set of activities as part of ESDM therapy involving children with ASD. A small humanoid robot with simplified human-like features has been used to stimulate the interactions with children, eliciting joint attention and imitation in two separate experiments . We compared the behaviors of children affected by ASD in response to such stimuli with those obtained in similar sessions realized by children in a typical development stage (TD) of similar age and sex. Results shown significant behavioral differences between of the ASD group and the control group.

2. MATERIALS AND METHODS

We arranged at Pitié-Salpétrière hospital in Paris a playground room in which experiments have been performed. As shown in Figure 1, a small table with two chairs placed in the center of the room is used for the standard ESD session with the therapist. On the two sides of the room, on the left and on the right, an image of a cat and of a dog are used as focus of the induction during the joint attention experiment. Different toys are available to the therapist to perform a large variety of activities.

A small humanoid robot, Nao from Aldebaran, has been used to elicit behaviors in the children. The choice of such platform has been guided by its capability on arousing empathy in TD children: Nao has a cute shape that it is easy to be anthropomorphized. This plays a key role on the affection and on the projection of intelligence of the children towards the robot. From the point of children with ASD, human gestures and in particular human faces carry on a huge informative content. Attention, emotions, lips movements used for both verbal and non verbal communication and other facial mimics should be deciphered and interpreted by the children. This task could be extremely complex for ASD children and can affect the interaction with the caregiver. Our hypothesis is that the simplified body and the simplified human-like face of the Nao robot will help children to easily interpret its social signals and in particular to pay more attention to its non-verbal communicative cues.

During the experiments with the robot, the child is encouraged to stand over a small, colored platform placed in front of the table: its presence gives a sort of reference to the child on holding his position. This behavior is also facilitated by the placement of this platform nearby the wall: the child will use it to maintain his upright pose. The robot is placed over the table, in order to lie exactly in front of the robot within a distance of about 2 meters.

The room is full equipped by several cameras recording the experiments from different point of views. Such recordings are used on the evaluation of the children behavior during the standard ESD session. While the child is accomplishing the experiment with the robot, a RGB-D sensor placed close to its feet, over the table. This is used to perceive in real-time the presence of the child and his movements.

All the sensors are placed in the most convenient geometrical position in the environment in order to have the best point of view over it. All the data perceived by each of them is stored for off-line analysis.

2.1 Participants

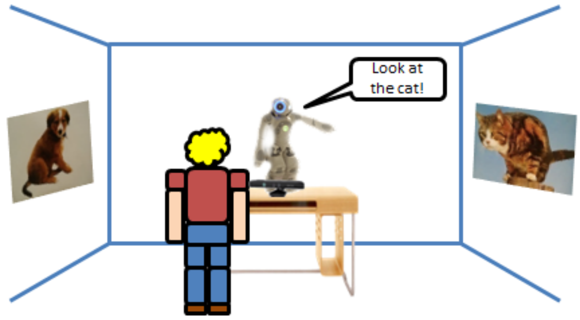

Figure 1: The playground arranged at Pitié-Salpétrière hospital.

The protocol was approved by the local ethical committee. All parents received information on the experiment and gave written consent before participation of their child. Thirty two children participated to the study: 16 of the children were followed in the day-care setting for ASD of la Pitié-Salpétrière hospital. Those children suffered from various social impairments including language disabilities and poor communicative skills. 16 TD children were recruited from several schools of Paris area.

Controls met the following inclusion criteria: no verbal communication impairment, no intellectual disability, and no motor, sensory or neurological disorders. Controls were matched to the children with ASD for developmental age and gender. For the control group, the developmental and chronological ages were considered to be the same.

Children with ASD were assessed with the Autism Diagnostic Interview-Revised (ADI-R) [37] to address ASD symptoms and the Gobal Assessment Functioning to assess current severity. The psychiatric assessments and parental interviews were conducted by three child-psychiatrist/psychologists specialized in autism (ET, JX, DC). The developmental age was assessed using cognitive assessment. Depending on children abilities and age we used either the Wechsler Intelligence scales, the Kaufman-ABC or the Psycho-Educational Profile, third version (PEP-III).

With both children with ASD and controls, we also performed a child-therapist interactive play session in which a JA task was incorporated to assess the ability of each child to interact using JA. The task was similar to that implemented for the Nao interaction, except that child and therapist were sited at a table. It also included 3 types of induction. The child-therapist interactive play session always occurred before the experiment with Nao, so that it offered some training for the child. All sessions were video-recorded for annotation of JA using ANVIL system. Each JA event was rated 1 (success) or 0 (failure). A total score was produced by simple addition (maximum score=6). An inter-rater reliability study was conducted on a subsample using 10 videos and 3 raters. Kappa was 0.98, showing perfect agreement.

2.2 Joint Attention Induction

Joint attention is a key aspect of social cognition. It can be defined as a triadic behavior that involves two individuals and an object. Each individual realizes that the other

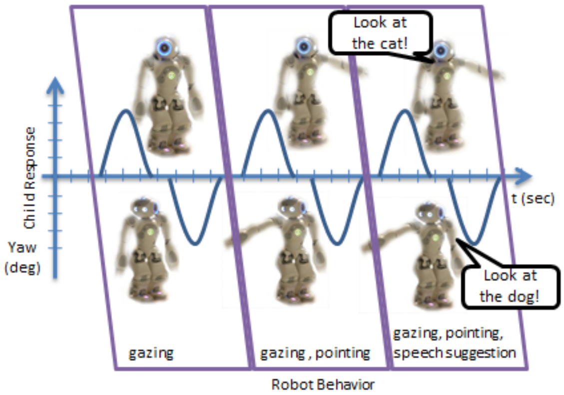

Figure 2: The robot Nao tries to induce Joint Attention by using several modalities.

is looking to the same object and perceives the shared attention over it: I know that you know that I know about the object [22, 7]. From the cognitive developmental of the children, JA can be interpreted as declarative gesture useful to build shared information between the child and the caregiver: as the pointing, it allows the two peers to focus over the same object to establish a mutual knowledge about it. Studies report as one of the main impairments in ASD children a lack of JA [12, 17, 5]. In particular, such children shown impairment if compared to Intellectual Disability (ID) and with TD.

In ASD children JA has been studied mainly using annotated videos of recorded interactions in both natural contexts and laboratory scenarios. In recent years such studies are taking advantage of ICT to carry out an automated and deeper analysis of such data. In this study we want to propose an analysis of the behaviors in children through the use of a small humanoid robot as tool for inducing JA. The robot acts as an autonomous, interactive partner, proposing to each child a set of simple activities focused on stimulating JA. The aim is to assess how differs the 4D exploration of the environment in children between children with ASD and TD children.

The robot tries to induce JA over the figures of a cat and of a dog placed on the walls at the two opposite sides of the room by switching its gaze between them and the child head. This correspond to the typical triadic behavior expressed in JA. As shown in Figure 2, the experiment is articulated in three different stages in which the robot increments the amount of information communicated to the children. In the first stage, the robot gazes between the participant face and one of the two images of animals, randomly chosen, for one time; then it repeats the same gazing behavior between the participant and the second image. In the second stage, the robot repeats the same behavior, integrating his gazing with the pointing gesture: the robot will gaze and explicitly declare the focus of its attention by pointing it. Finally, in the third stage, the robot will integrate gazing and pointing with verbal communication: "look the cat"; "look the dog".

Information related to the behaviors of the children is retrieved using the RGB-D sensor [1]. From the depth image

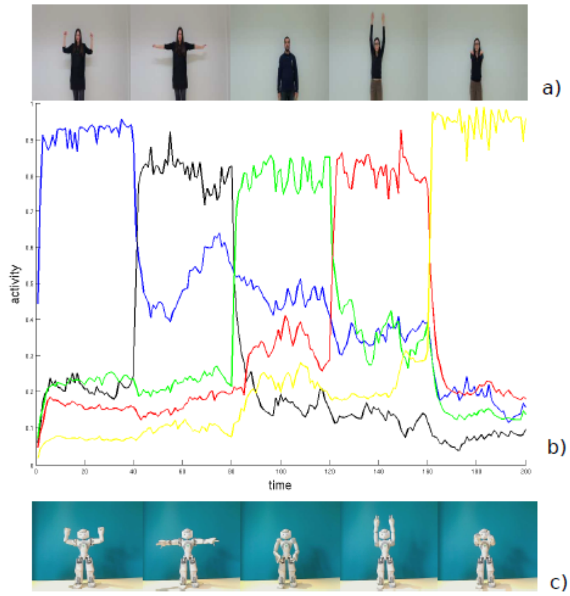

Figure 3: The visual features of each posture (a) active the neural network (b) that triggers in the robot the correspondent learned posture (c).

captured, by the use a standard skeleton tracking algorithm made by OpenNi, the presence of the participant and the pose and position of its libs are captured and tracked. This information is used to identify in the correspondent color image a crop in which the head should lie. From such crop, the pose of the head is retrieved by using a standard CLM algorithm [3]. In this process, noise is reduced by the use of a Kalman Filter over the joints positions retrieved by the skeleton tracking system. All those calculated information are stored and then analyzed a-posteriori, at the end of the experiment.

2.3 Imitation Elicitation

The parent-infant interaction is a highly dynamic face-to face interaction that requires a continuous mutual adaptation of behaviors. In particular, imitation is a specific dyadic behavior that plays an important role in infant development [10]. Despite several definitions of imitation have been proposed in the literature [21, 24], without no one universally accepted, here we define imitation as the process in which a learner trains behavioral characteristics from a teacher. Imitation is a core deficit in ASD [25]: a significant impairment of such skill has been reported on a large variety of task, including body movements, object use, facial expressions and vocalization.

In this study the role of the partner on imitation learning has been investigated in interactive sessions through the use of a robot. The aim is to show how different learning results are obtained according to the subjects involved in the interaction with the robot. In particular, the behaviors of two groups composed by children with ASD and TD children have been compared between them and with a third group of adults. In this case, our assumption is that in the context of learning, imitation reduces the search space of the learner, facilitating the interaction between the two peers. A

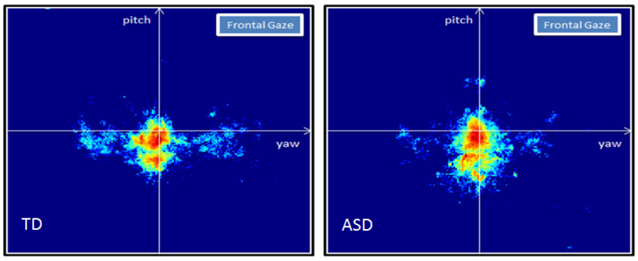

Figure 4: Average histogram of head pitch and yaw in TD children and in children affected by ASD.

developmental approach has been adopted: the robot learns how to recognize postures using an ad hoc sensory motor architecture [2], during an imitation game (Fig. **??**). The experiment is organized in two stages: during a learning phase, the robot produces random postures, selected from 4 basic postures, while the participant imitates the robot; here, the robot associates what it did, its motor parameters, with what it saw, its visual features. The architecture used exploited the learning without explicit teaching signals that associate a specific posture with the robot's internal motor state. In a second stage, after the learning, the robot can be leaded by the human peer: he will randomly produce the previously learned posture, while the robot imitates them (Figure 3). The first phase of the experiment employs between 1 and 2 min, after which the roles can be reversed, switching to the second step.

3. EXPERIMENTAL RESULTS

Experiments involving 16 TD children as control group, 16 children affected by ASD, and, in the case of imitation elicitation, 15 adults, have been performed at Pitié-Salpétrière hospital in Paris. Data obtained from the JA elicitation experiment and from the Imitation Elicitation experiment has been explored.

3.1 Joint Attention Experiment Analysis

Data collected during the JA experiment has been stored and then off-line analyzed in order to find behavioral cues able to discriminate children with ASD and TD children. Figure 2 shows using an heat map the average bi-dimensional histogram of occurrences of the yaw and of the pitch of the head for both the populations, the TD group on the left and the ASD group on the right. In the case of TD children are clearly visible hot spots on the two sides and on the center, corresponding to the head pose focusing over the robot, on in front of the child, in the center, and over the animal figures on the two sides of the room. The same histogram built using the ASD group data shows children less concentrated on the focuses. Using Linear Mixed Model to explore yaw and pitch variance shows a significant high variance of the yaw in the TD children rather than ASD group ($p=0.002$), with no significant effect of age and sex.

A similar analysis of the data has been carried out by exploring the differences over the three stages of the JA experiment. A significant effect of the induction modality has been found, with a lower variance in JA with gazing only, compared to JA with pointing ($p<0.001$) and compared to

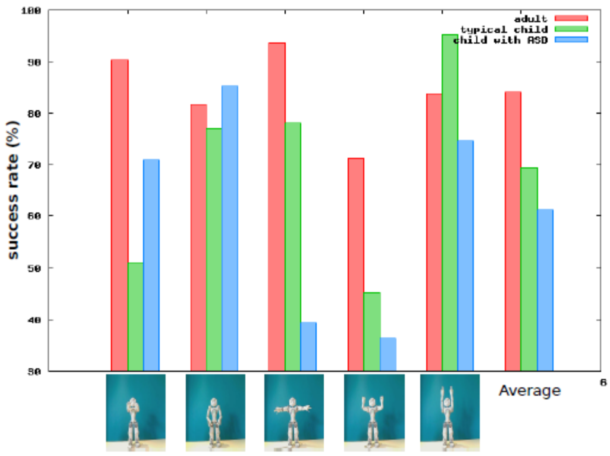

Figure 5:

JA with vocalizing ($p<0.001$). No significant effect on age has been reported in this case.

3.2 Imitation Elicitation Experiment Analysis

All the information stored during the imitation elicitation experiment has been analyzed off-line. Figure 3 shows the temporal activity of the neurons belonging to each posture category, after two minutes of learning stage. This activity will trigger the posture that the robot should assume, according to the visual features perceived.

The goal of our protocol is to investigate the impact of the participant on robot learning, their social signature. Our hypothesis is that different learning results can be obtained when the interactions is performed by different groups.

Data from experiments involving children with ASD and TD children have been integrated with the same data from 15 adult subjects. Significant differences on the response of the system to the three groups have been found: the success rate for each posture depends on the different participants that interacted with the robot, showing in this way the impact of the participant on robot learning. The success rate was 84% when the robot interacted with adults, 69% when the robot interacted with the TD children and 61% when the robot interacted with the children affected by ASD. The metrics used tried to depict the impact of the participant on robot learning, their social signature. Results obtained distinguish each groups by its social signature. Moreover, as shown in Figure 5, the measures retrieved shown how some postures are more or less hard to recognize for the different groups. In particular, the posture (4) is more misunderstandable than the other postures and the posture (1) is more recognizable than the others.

4. CONCLUSIONS AND FUTURE WORKS

Convergence between social sciences, neurosciences, robotics and artificial intelligence, allows the use of robotic platforms as therapeutic tools for impaired people. In this perspective, as part of the standard ESDM therapy for children with ASD, a small set composed by two activities aimed to the assessment of ASD has been presented. Such activities involve a small humanoid robot and are specifically developed to make it able to elicit joint attention and imitation during two separate tasks. Experiments presented performed with children affected by ASD, TD children and, in the case of imitation elicitation, adults, shown how the robotic system here presented is able to elicit behaviors and to exploit statistically relevant differences among the groups. Such encouraging results suggest us the development of a larger set of features related to the interaction between impaired people and the robot. In particular, in the JA experiment it will be possible to extract more information about the posture maintained and about the timing of the interaction. New measures can be extracted also in the imitation scenario, considering differences on the model of the neural network obtained after the training. Results obtained incite us to focus on the development of a more structured set of therapeutic activities involving both doctors, robots and children affected by Autistic Spectrum Disorder.

5. REFERENCES

[1] S. M. Anzalone and M. Chetouani. Tracking posture and head movements of impaired people during interactions with robots. In *New Trends in Image Analysis and Processing–ICIAP 2013*, pages 41–49. Springer Berlin Heidelberg, 2013.

[2] S. Boucenna, P. Gaussier, P. Andry, and L. Hafemeister. Imitation as a communication tool for online facial expression learning and recognition. In *Intelligent Robots and Systems (IROS), 2010 IEEE/RSJ International Conference on*, pages 5323–5328. IEEE, 2010.

[3] D. Cristinacce and T. F. Cootes. Feature detection and tracking with constrained local models. In *BMVC*, volume 17, pages 929–938, 2006.

[4] K. Dautenhahn. Roles and functions of robots in human society: implications from research in autism therapy. *Robotica*, 21(4):443–452, 2003.

[5] G. Dawson, A. N. Meltzoff, J. Osterling, J. Rinaldi, and E. Brown. Children with autism fail to orient to naturally occurring social stimuli. *Journal of autism and developmental disorders*, 28(6):479–485, 1998.

[6] A. Duquette, F. Michaud, and H. Mercier. Exploring the use of a mobile robot as an imitation agent with children with low-functioning autism. *Autonomous Robots*, 24(2):147–157, 2008.

[7] N. Emery. The eyes have it: the neuroethology, function and evolution of social gaze. *Neuroscience & Biobehavioral Reviews*, 24(6):581–604, 2000.

[8] D. Feil-Seifer and M. J. Matarić. Toward socially assistive robotics for augmenting interventions for children with autism spectrum disorders. In *Experimental robotics*, pages 201–210. Springer, 2009.

[9] D. Feil-Seifer and M. J. Mataric. Automated detection and classification of positive vs. negative robot interactions with children with autism using distance-based features. In *Human-Robot Interaction (HRI), 2011 6th ACM/IEEE International Conference on*, pages 323–330. IEEE, 2011.

[10] J. P. Flanders. A review of research on imitative behavior. *Psychological Bulletin*, 69(5):316, 1968.

[11] V. Guinchat, B. Chamak, B. Bonniau, N. Bodeau, D. Perisse, D. Cohen, and A. Danion. Very early signs of autism reported by parents include many concerns not specific to autism criteria. *Research in Autism Spectrum Disorders*, 6(2):589–601, 2012.

[12] S. Maestro, F. Muratori, A. Cesari, A. Paziente, D. Stern, B. Golse, and F. Palacio-Espasa. How young children treat objects and people: an empirical study of the first year of life in autism. *Child Psychiatry and Human Development*, 35(4):383–396, 2005.

[13] A. N. Meltzoff, P. K. Kuhl, J. Movellan, and T. J. Sejnowski. Foundations for a new science of learning. *science*, 325(5938):284–288, 2009.

[14] M. B. Ospina, J. K. Seida, B. Clark, M. Karkhaneh, L. Hartling, L. Tjosvold, B. Vandermeer, and V. Smith. Behavioural and developmental interventions for autism spectrum disorder: a clinical systematic review. *PLoS One*, 3(11):e3755, 2008.

[15] G. Pioggia, R. Igliozzi, M. L. Sica, M. Ferro, F. Muratori, A. Ahluwalia, and D. De Rossi. Exploring emotional and imitational android-based interactions in autistic spectrum disorders. *Journal of Cybertherapy & Rehabilitation, 1 (1)*, pages 49–61, 2008.

[16] S. J. Rogers and G. Dawson. *Early start Denver model for young children with autism: Promoting language, learning, and engagement.* Guilford Press, 2010.

[17] C. Saint-Georges, R. S. Cassel, D. Cohen, M. Chetouani, M.-C. Laznik, S. Maestro, and F. Muratori. What studies of family home movies can teach us about autistic infants: A literature review. *Research in Autism Spectrum Disorders*, 4(3):355–366, 2010.

[18] C. Saint-Georges, A. Mahdhaoui, M. Chetouani, R. S. Cassel, M.-C. Laznik, F. Apicella, P. Muratori, S. Maestro, F. Muratori, and D. Cohen. Do parents recognize autistic deviant behavior long before diagnosis? taking into account interaction using computational methods. *PloS one*, 6(7):e22393, 2011.

[19] B. Scassellati. How social robots will help us to diagnose, treat, and understand autism. In *Robotics research*, pages 552–563. Springer, 2007.

[20] B. Scassellati, H. Admoni, and M. Mataric. Robots for use in autism research. *Annual Review of Biomedical Engineering*, 14:275–294, 2012.

[21] E. L. Thorndike. Animal intelligence: An experimental study of the associative processes in animals. *Psychological Monographs: General and Applied*, 2(4):i–109, 1898.

[22] M. Tomasello. Joint attention as social cognition. 1995.

[23] K. Toth, J. Munson, A. N. Meltzoff, and G. Dawson. Early predictors of communication development in young children with autism spectrum disorder: Joint attention, imitation, and toy play. *Journal of Autism and Developmental Disorders*, 36(8):993–1005, 2006.

[24] A. Whiten and R. Ham. On the nature and evolution of imitation in the animal kingdom: reappraisal of a century of research. *Advances in the Study of Behavior*, 21:239–283, 1992.

[25] J. H. Williams, A. Whiten, T. Suddendorf, and D. I. Perrett. Imitation, mirror neurons and autism. *Neuroscience & Biobehavioral Reviews*, 25(4):287–295, 2001.