An Android for Enhancing Social Skills and Emotion Recognition in People With Autism

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Abstract—It is well documented that the processing of social and emotional information is impaired in people with autism. Recent studies have shown that individuals, particularly those with high functioning autism, can learn to cope with common social situations if they are made to enact possible scenarios they may encounter in real life during therapy. The main aim of this work is to describe an interactive life-like facial display (FACE) and a supporting therapeutic protocol that will enable us to verify if the system can help children with autism to learn, identify, interpret, and use emotional information and extend these skills in a socially appropriate, flexible, and adaptive context. The therapeutic setup consists of a specially equipped room in which the subject, under the supervision of a therapist, can interact with FACE. The android display and associated control system has automatic facial tracking, expression recognition, and eye tracking. The treatment scheme is based on a series of therapist-guided sessions in which a patient communicates with FACE through an interactive console. Preliminary data regarding the exposure to FACE of two children are reported.

Index Terms—Autism, biomimetics, recognition of emotional expressions, robot-based treatment method, social attention.

I. INTRODUCTION

AUTISM is a developmental disorder characterized by qualitative impairments in social interaction and communication and a restricted range of activities and interests. It is in fact well documented that individuals with autism have impairments in processing social and emotional information. This is particularly evident in tasks assessing face and emotion recognition, imitation of body movements, interpretation and use of gestures and theory of mind [1]–[5].

Typically developing infants show preferential attention to social rather than inanimate stimuli; in contrast, individuals with autism seem to lack this early social predisposition [6], [7]. This hypothesis was recently substantiated in a neurofunctional study of facial perception in autism [8], in which adequate task performance was accompanied by abnormal ventral temporal cortical activities, which in turn suggested that participants had "treated" faces as objects. Klin *et al.* [9] created an experimental paradigm to measure social functioning in natural situations, in which they used eye-tracking technology to measure visual fixations of cognitively able individuals with autism. When viewing naturalistic social situations, people with autism demonstrate abnormal patterns of visual pursuit, consistent with reduced salience of eyes, and increased salience of mouth, bodies, and objects.

In addition, individuals with autism use atypical strategies when performing such tasks, relying on individual pieces of the face rather than on the overall configuration [10]. Alongside these perceptual anomalies, individuals with autism have deficits in conceiving other people's mental states.

According to the cognitive theory of mindblindness [11], this impairment is related to the difficulty that people with autism have in conceiving of people as mental agents. Mindblindness is, thus, the inability to perceive another person's mental state. Recent studies have shown that individuals, particularly those with high functioning autism, can learn to cope with common social situations if they are made to enact possible scenarios they may encounter. By recalling appropriate modes of behavior and expressions in specific situations, they are able to react appropriately. There are now a number of highly structured therapeutic approaches based on emotion recognition and social skill training using photographs, drawings, videos, or DVD-ROMs (e.g., Mind Reading, produced by Human Emotions, U.K.). Their aim is to enable individuals with autism to interpret meanings and intentions of people and to anticipate their emotional reactions to typical situations they may encounter during the course of their daily lives. These methods show that basic emotion understanding can be taught; however, since the learning process derived from these therapeutic approaches repeatedly uses a limited repertoire of predefined scenarios, it is biased toward the memorization of a scene, and its interpretation within a therapeutic setting, and so does not allow generalization or abstraction of the experience. In fact, the capacity of generalizing that learnt within a therapeutic setting is one of the principal problems of currently used treatments for autism. The literature regarding this aspect is increasingly focused on the new body of knowledge on the autistic disorder and on the recognition that precocious and individualized treatment can significantly improve the lives of patients [12]–[15]. It remains unclear, however, whether this type of treatment can influence core aspects of the disorder, such as social impairment. This implies that the effectiveness of a given treatment should be based on, amongst other criteria, a measure of social deficit. Unfortunately, several treatments described in the literature are beset by methodological problems which hinder the generalization of results for comparative purposes. For example, according to Kasari [15], treatment methodologies are characterized by elements such as a lack of coherent diagnostic procedures prior to the start of trials,

Fig. 1. FACE.

inappropriate measurements to evaluate the results, evaluation of solely short term effects, and, most seriously, a lack of evaluation of the most clinically significant characteristics of the autistic disorder.

Currently, the only robotic systems for therapeutic purposes are the autonomous robotic platform as a remedial tool for children with autism (AURORA) and the mobile robotic toys as therapeutic tools for autism projects. In these projects, mobile robots are used to encourage children with autism to take initiative and to become engaged with the robotic "toys" in a variety of different actions [16]–[18]. These robots are incapable of any biomimetic or emotional representation and do not include any three dimensional facial display.

We present here facial automaton for conveying emotions (FACE) [19] shown in Fig. 1, a facial automaton capable of expressing and recognizing basic emotions and describe an innovative robot-based treatment method which focuses on core aspects of the autistic disorder, namely social attention and the recognition of emotional expressions.

FACE acts as an interface between the patient and a trained therapist. A dedicated experimental setup enables both the creation of predefined social situations, as well as the possibility of the therapist rapidly setting up individualized scenarios during a session. Moreover, the flexible and interactive modular architecture of the control system allows each session to be recorded, repeated, or modified.

FACE could have greater visual impact for patients than other methods used for social training and could greatly reinforce them. It can also enable more complex and varied situations to be constructed during therapy. Moreover, as argued by Nadel, social imitation of a robotic experimenter can pave the way to the acceptance of social environment and human presence [20].

II. FACE, TOWARDS HIGHER BELIEVABILITY

The android consists of a passive articulated body equipped with an anthropomorphic head. For the past five years, the Interdepartmental Research Center "E. Piaggio" of the University of Pisa, Pisa, Italy, has been involved in an ambitious project to develop FACE: a believable facial display system based on biomimetic engineering principles. The underlying philosophy and design approach of the display is founded on the simulation of biological behavior using materials, structures, and control algorithms that can replicate some of the functions and responses of living systems. The architecture of the facial automaton consists of an anthropomorphic head and a facial tracking and expression recognition device. The head consists of an artificial

skull covered by an artificial skin which is a thin silicone-based mask equipped with sensory and actuating system. It is fabricated by means of life-casting techniques and aesthetically represents a copy of the head of a subject, both in shape and texture. FACE is able to express and modulate the basic emotions in a repeatable and flexible way, to quantitatively analyze the emotional reactions of individuals through optical analysis of facial expression, to track a human face over time, and to automatically store all data. FACE's control can be performed by an external supervisor or by an algorithm which implements a predefined design. The skeletal support structure is a resin based reconstruction of the head of a real adult subject, realized using CAD/CAM. Soft tissues of the head were fabricated from materials used for facial reconstruction in the world of animatronics and archeology [21].

The technical limitations of FACE derive from two main factors. First, technical limitations arise from the materials design and engineering and secondly the control strategy adopted. As far as the former is concerned, FACE employs state of the art materials and is currently capable of actuating the six basic expressions (happiness, sadness, surprise, anger, disgust, fear) and modulating them in small steps. For the moment, the control pathway is fixed. As the clinical trials progress, information regarding the response of children with autism upon interaction with FACE can be used to refine and enhance the control algorithms. If necessary, control pathways which can be redefined by a therapist in real time can be implemented, so that during a session, FACE can assume an appropriate expression tuned to an individual subject's response. Using this method, it is envisaged that the patient could have the sensation of a verbal and visual dialogue with FACE without being aware of the therapist's intervention.

A. Actuation

An artificial muscular architecture and servomotors are lodged inside in the soft tissue and the entire structure is covered with an artificial skin with a distributed sensor system. The artificial muscular architecture allows the movement of the skin and confers human-like dynamics to it. The eyes of FACE are specially made using animatronic techniques and their expressivity is effected through the artificial muscles surrounding the orbital region.

Our efforts devoted to the development of artificial muscles suitable for FACE are currently focused on linear actuators. These devices are conceived as pseudomuscular actuators, providing the necessary mechanical energy for the actuation of the artificial skin and showing static and dynamic characteristics similar to those of biological muscles.

The emulation of the functional characteristics of muscles is believed to be relevant in order to reach the intended believability of the system, in terms of recognizable human-like expressions. In particular, it is possible to demonstrate that actuators mimicking the nonlinear static force-length characteristic of a muscle following Feldman's muscle model [22], [23], can be controlled both in position and compliance (or stiffness) [24]. This can be advantageous for the believability of expressions
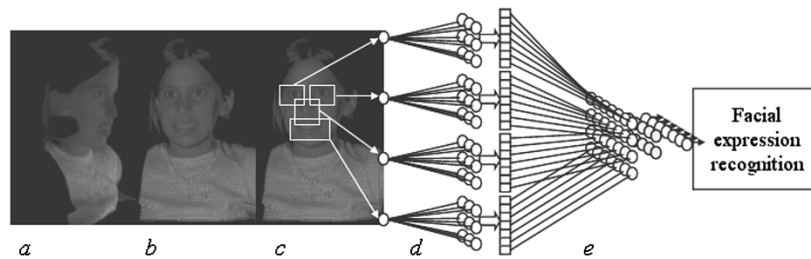
Fig. 2.   Facial tracking and expression recognition.

shown by FACE, owing to the possible modulation of the degree of compliance held by the skin/actuators system for any given state of the actuators.

For the implementation of such an artificial muscle, we have selected dielectric elastomers as soft materials with suitable actuating performances. Dielectric elastomer actuators consist of rubbery insulators coupled to compliant electrodes [25]–[27]. The application of a high electric field by means of electrically charged electrodes is responsible for the deformation of the elastomeric dielectric, which can be used to deliver mechanical energy to a load. This simple mechanism of actuation of dielectric elastomers, belonging to the general class of electroactive polymers (EAPs), is presently able to achieve the highest active strains (order of 10%–100%), as well as considerable active stresses (up to 1 MPa), among all available polymer-based actuation technologies [25]. These high-level performances are combined with low response times, high efficiency, high power/volume ratios, and low costs, contributing to the advantageous applicability of such materials to FACE.

B. Sensing

FACE "feels" the world through a sensorized artificial skin and "sees" using an artificial vision device. The former allows it to obtain a sort of primitive proprioceptive mapping, the latter an automatic facial tracking and expression recognition system.

The artificial skin of FACE is a three dimensional (3-D) latex foam, under which lies a sensing layer. The sensing layer responds to simultaneous deformations in different directions by means of a piezoresistive network, which consists of a carbon rubber mixture screen printed onto a cotton lycra fabric. These sensors are elastic and do not modify the mechanical behavior of the fabric.

The response of the skin is not easily reduced to a mathematical description; thus, in FACE, "proprioceptive" mapping is obtained approaching the final required expression by a process of supervised learning. The supervised learning protocol leads FACE through a trial and error procedure until the system converges to a desired expression.

FACE "sees" the world through a small video camera. Through a system of automatic facial tracking invisible to the patient, FACE is capable of recognizing facial expressions of subjects in front of the camera. A neural approach has been adopted to allow FACE to recognize the expression of a subject. It is based on the measurement of the average curvature that has been calculated using a 3-D contouring system based on an out-of-phase sinusoidal fringe pattern projection [28], [29].

This solution enables very fast infra-red image acquisition (about 40 ms), allowing us to obtain complete information about 3-D shape, curvature, and texture of a (not necessarily immobile) human face [Fig. 2(a)] from two images of the measured surface illuminated twice with infra-red sinusoidal fringe patterns shifted in phase mutually by 180°. The resolution of the applied camera (Dragon Fly type) is 480×640 pixels, with Bayer mosaic, and of 10-bit dynamics. An appropriate high-pass infrared filter is used to minimize disturbance to the patient. Once the curvature map of the head of a subject is obtained, it is normalized so as to obtain a data set which is independent of its motion [Fig. 2(b)]. This allows acquisition and recording of image data of the patient independent of the orientation or movement of his face. An eye tracking system which also allows real time capture of the position and orientation of the subject's pupils from the 3-D image is under development. Important information on the visual field which captures the attention of a patient with autism can be derived from the system.

A dedicated process detects a number of points (markers) from the curvature map, which are used to divide the human face into four main areas (left eye, right eye, nose, and mouth) [Fig. 2(c)]. The data of each area are processed by a hierarchical neural-network (HNN) architecture based on kohonen self organizing maps (KSOMs) [30] [Fig. 2(d)] and multilayer perceptron (MLP) [31] [Fig. 2(e)]. Curvature data of a zone are input to only one map; in this way, each KSOM is trained with the purpose of clustering data coming from the respective zones into crisp classes. The outputs of the KSOMs are used to form the input pattern for the MLP, which defines the group to which the facial expression belongs.

III. THERAPEUTIC PROTOCOL FOR AUTISM

A. Experimental Setup

The experimental setup is illustrated in Fig. 3. It consists of a specially equipped room, provided with two remotely orientable video cameras, in which the child, under the supervision of a therapist, can interact with FACE through an interactive software by means of a liquid crystal screen and a keyboard or mouse (Interactive Module). Both FACE and the interactive module are connected to a computer (PC1). The child wears a system for recording physiological data (BioPac) which can be saved in a database (DB). The commercial Biopac data acquisition system provides a versatile high performance, modular system that allows safe human measurement, such the electrocardiogram and skin temperature. The DB also contains data
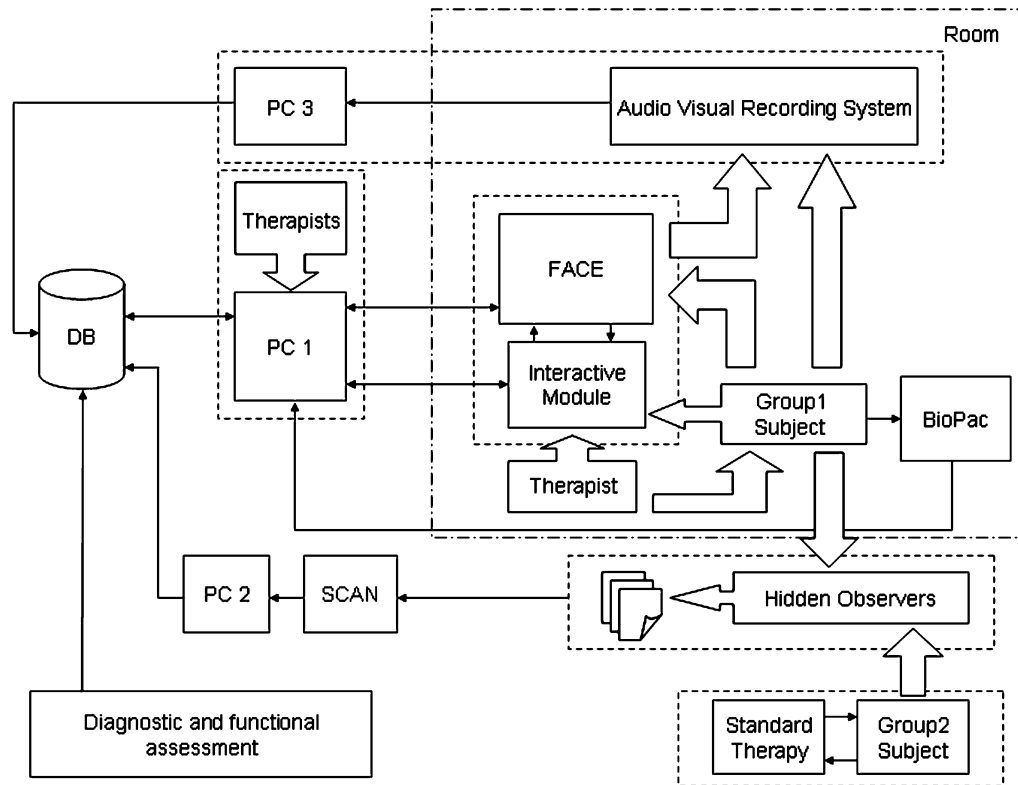
Fig. 3.   Experimental setup.

from the audio visual recording system present in the room and is connected to PC3. Other therapists or hidden observers can compile evaluation sheets during sessions, and the data scanned from these, can also be added to the DB and used for successive analysis. The interactive software, which both therapist and child can access, implements the treatment scheme.

B. Treatment Scheme

Fig. 4 illustrates the treatment scheme in the form of a flow diagram. Two distinct modalities are employed: the first is based on a repertoire of preselected social situations and the second allows the therapist to realize new situations as a consequence of the real time interaction between FACE and the child. The initial sessions are devoted to familiarization of the child with the robot, and will also serve to observe spontaneous reactions of the child when affronted with FACE. During the familiarization phase, it is possible to identify verbal and nonverbal expressions of the child, which can be used to ascertain the degree of social attention toward the robot. This can be done by hidden raters through an original grid for the assessment of social attention derived from a previous study on early autism at Stella Maris Institute [7], [32]. The grid is composed of a series of items (looking at FACE; looking at the therapist; looking at objects; orienting toward FACE; orienting toward the therapist; orienting toward objects; smiling at FACE; smiling at the therapist; smiling at objects; vocalizing to FACE; vocalizing to the therapist; vocalizing to objects) referring to behaviors representative of the child's social and nonsocial competencies. The raters compute the frequencies for each item, with the assistance

of a specific coding software (Noldus The Observer 5.0). Interrater reliability will be calculated using the Pearson coefficient. The first element to be evaluated during treatment is the capacity of the child to imitate the expressions of FACE. Factors such as spontaneous imitation or imitation upon presses by the therapist can be considered, as well as the "goodness" of imitation. It is also be possible to increase the degree of a given emotion on FACE to induce or potentiate imitation if necessary.

When exposing the child to the "collection of social situations," a series of lessons are prepared on the basis of selected emotions to enable the child to develop abilities in two particular spheres.

1) Facial Expression Association: This is the ability of the child to associate an emotion with that expressed by FACE. This is taught in the following two ways.
    a) Facial Matching: By allowing the child to select, among several images, an image of a human face expressing the same emotion as FACE.
    b) Emotion Labeling: Through verbal labeling of an emotion expressed by FACE after being presented with several labels.
2) Emotion Contextualization: This is the contextualization of an emotion by presenting the child with different social situations and then asking him to select an appropriate response for FACE.

After the initial training phase, patients will be encouraged to learn through a trial and error approach, and therapists will assign a score based on the number of correct responses during the training sessions.
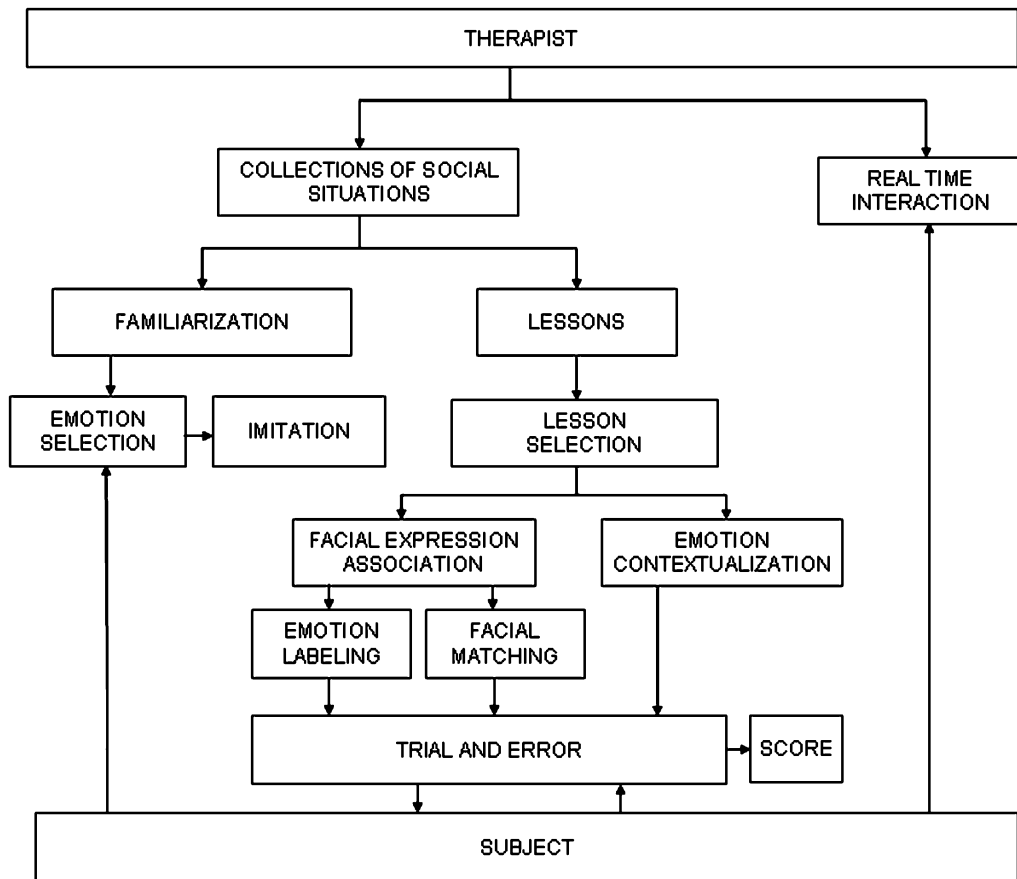
Fig. 4. Treatment scheme.

C. Evaluation of Treatment Effect

To enable a quantitative evaluation of the treatment under progress, two checkpoints for patient evaluation are foreseen: the first at the start and the second at the end of the treatment sessions. The following evaluation protocols are administered at the checkpoints.

1) A psychophysical test for evaluating face perception with emotive content. This test allows us to discriminate if facial expression processing is component-based or holistic and to verify its dependence on emotive content. Our aim is to compare the performance of children with autism, thought to be generally impaired in these tasks, with that of typically developing children. We present facial stimuli on a computer monitor and all participants are tested individually. Stimuli can be composed of two equal or different flanked faces. Different faces are obtained through the Thatcherization of only one feature of the face (i.e., eyes, nose, or mouth) [33], [34]. Both faces in the stimulus can be either neutral or expressing emotions. The children are required to indicate whether faces are the same or different in two-alternative forced choice procedures. We present 90 stimuli to each subject.

2) Tests to evaluate the ability to recognize emotions. The "reading-the-mind-in-the-eyes" test, revised version, is used for assessing this function [35].

3) ADOS-G to monitor the level of disability in the two areas addressed in this project: social skills and communication.
4) A grid to evaluate social attention as mentioned above.

The DB contains a log of all the information gathered and is extremely useful for a quantitative and statistical analysis of child behavior and response during treatment. For example, it is possible to correlate patient behavior (video images) with a given expression of FACE at a particular instant, and also determine physiological correlates (BioPac), verbal stimulus (audio information) and focus of attention (eye tracking) at the same instant. These variables can be related to information collected on the grid by trained observers, and used to provide an objective evaluation of the child being observed. The data can be analyzed using statistical methods, so as to confer a figure of merit to this method. Moreover, we evaluate the evolution of impairment level using ADOS-G and the other three tests described before and after treatment.

IV. PRELIMINARY RESULTS

In order to obtain a preliminary evaluation of the behavior of a child with autism when exposed to the robotic FACE, we set up a preliminary experiment in which the reactions of two children, one a typically developing child and the other with autism, were monitored and compared.

TABLE I
DIAGNOSTIC RATINGS FOR ADOS-G AND ADI-R MODULES

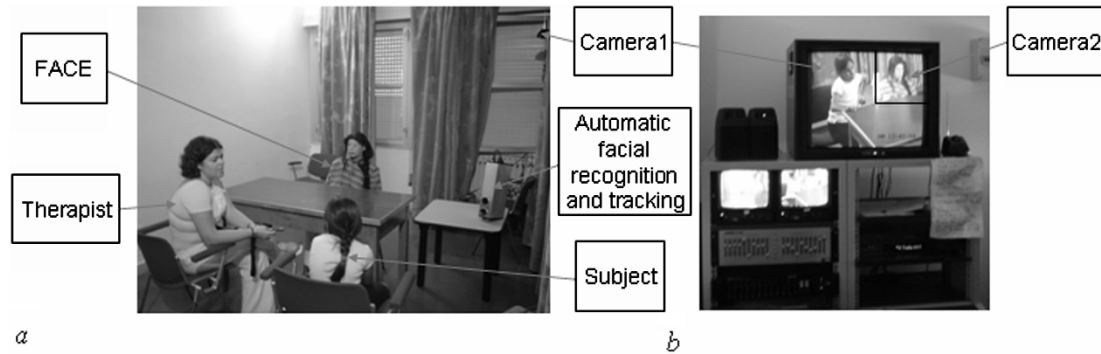|	Communication cut-off for autistic spectrum: 3 cut-off for autism: 5	Social interaction cut-off for autistic spectrum: 4 cut-off for autism: 6	Total score cut-off for autistic spectrum: 8 cut-off for autism: 12
ADOS-G	6	9	15
	Social interaction cut-off: 10	Communication cut-off: 8	Stereotyped behavior and restricted interests cut-off: 3
ADI-R	15	19	4

Fig. 5. (a) Experimental setup in the equipped room. (b) Adjacent recording room showing the monitors and recording system.

The child with autism was 7 years and 8 months of age and had been previously diagnosed with high functioning autism using the DSM-IV, ADI-R, and ADOS-G criteria [36]–[38]. He had been subject to psychological, neuropsychological, and linguistic tests by expert clinicians at the Stella Maris Institute (IRCCS) of the University of Pisa, where he has been under treatment since the age of 5. His treatment consists of twice weekly individual psycho-educational sessions and parallel counseling with his parents. The diagnostic ratings for ADOS-G and ADI-R modules are shown in Table I. An evaluation of cognitive abilities using the Wechsler scale (WISC-R) [39], resulted in a total IQ of 83, Verbal IQ and Performance IQ of 85.

The experimental setup consisted of FACE resting on a fully dressed passive wooden mannequin body, in a specially equipped testing room within the Stella Maris Institute [Fig. 5(a)]. The room was equipped with the following.

1) Two video cameras in two corners of the room: one oriented toward FACE and one toward the subject.
2) The volumetric acquisition system for face tracking and evaluation of the subject's expression.

The video cameras were operated by an engineer in an adjacent room in which the scenes recorded could be visualised on large screens [Fig. 5(b)]. FACE was seated behind a large desk in a corner of the room such that it could not be easily touched by the subject, who sat in front of the desk beside a therapist. A heart rate monitor with a digital remote display was attached to the subject's chest to record any physiological correlation associated with the presence of the robot and its facial and head movements, as well as during the verbal interactions with the therapist. The therapist's role was to probe the subject's emotional reaction to FACE and to mediate the interactions between

subject and robot, and if necessary to circumvent any reactions of fear or aggression. Fig. 5 illustrates the set during the session. The child in the photograph is the typically developing subject.

During the session with FACE, initially the child with autism did not show any interest in FACE. Successively, upon verbal suggestion by the therapist, he turned his eyes toward FACE and the therapist. When asked to express his opinion on FACE, he replied that it was a "damsel," as though from a fairy tale, and that it was sad, thus, attributing the robot with an emotion.

The control child was 8 years and 7 months. During the session, the child spontaneously observed FACE with great attention and expressed a positive reaction to it. When the robot's facial movements were increased, the child became uncomfortable. The typically developing child attributed the same emotion of sadness to FACE as did the child with autism. A time course of the physiological data correlated with the verbal suggestions of the therapist are plotted in Fig. 6. It shows the cardiac frequencies of the subject with autism [Fig. 6(a)] and the typically developing [Fig. 6(b)] subject during the session with FACE. The resting rate of the typically developing child was 83 beats per minute. Verbal stimuli or the behavior of the therapist are indicated in the text boxes. The boxes indicate the initiation of a verbal stimulus. The session for the child with autism was longer than that of the typically developing child; this is due to the shorter attention periods of the child with autism. From the figures, it can be seen that after a request of focusing attention on FACE or to describe FACE's movements and appearance, the patient did not suffer a rapid increase or oscillation of cardiac frequency as the typically developing subject did; in fact, it seems that the patient is relaxing. In first approximation, the patient did not consider FACE and its movements threatening or surprising, implying that the robot fitted into his scheme of
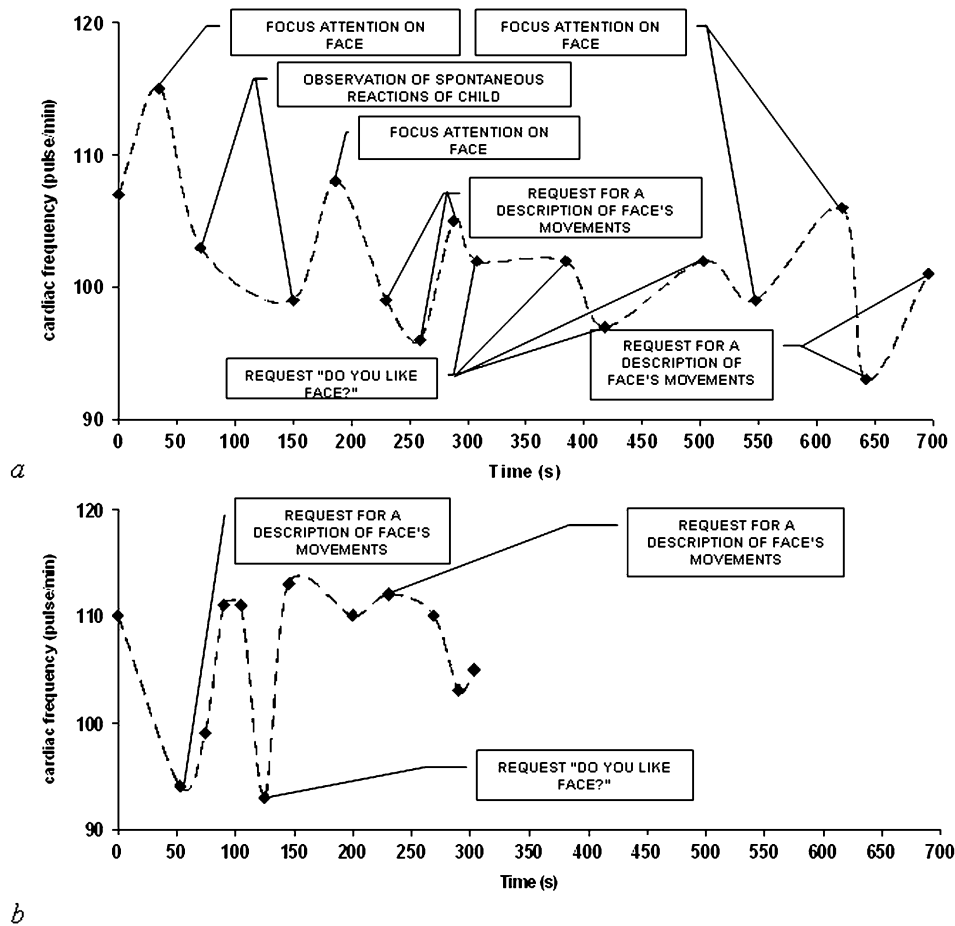
Fig. 6.   Heart rate during the preliminary evaluation. Labels show therapists verbal actions. (a) Autistic child. (b) Typical child.

the environment. This initial result suggests that children with autism can be led to interact proactively with an android and that their predilection for interaction with nonhuman artifacts can be exploited in a positive manner through the use of FACE and the protocol here described.

V. CONCLUSION

The concept of a believable humanoid display or even of its sub aspects has nevertheless far reaching implications and applications that could potentially span a wide variety of fields. These can include other possible medical applications such as presurgery study for facial reanimation transplant, speech therapy, or a new communication method for deaf people. It can also pose the basis to introduce new channels of interactivity in other "intelligent" artificial systems, spreading out over philosophical and psychosocial fields, including the exploration of possible areas of inter-exchange with the neurosciences.

During the next two years, a clinical study will be undertaken to determine the full potential of FACE and the protocol described in treating children with autism. It will involve 20 children with high functioning autism as diagnosed through ADI-R and ADOS-G; 10 children will be treated twice a week with this method over a period of six months and the others will undergo regular therapy. Halfway and at the end of this period, the patients will be evaluated using standard diagnostic and specific instruments for the evaluation of physiological and psycho-

logical data. Our hypothesis is that this method will diminish social impairment and increase expressiveness, facial mimicry, and shared attention, and, thus, it will lead to a better quality of life for children and adults affected by autism.

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