Interactive technologies for autistic children: A review

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Abstract—**Recently, there have been considerable advances in the research on innovative Information Communication Technology (ICT) for the education of people with autism. This review focuses on two aims: (1) to provide an overview of the recent ICT applications used in the treatment of autism and (2) to focus on the early development of imitation and joint attention in the context of children with autism as well as robotics. There have been a variety of recent ICT applications in autism, which include the use of interactive environments implemented in computers and special input devices, virtual environments, avatars and serious games as well as telerehabilitation. Despite exciting preliminary results, the use of ICT remains limited. Many of the existing ICTs have limited capabilities and performance in actual interactive conditions. Clinically, most ICT proposals have not been validated beyond proof of concept studies. Robotics systems, developed as interactive devices for children with autism, have been used to assess the child's response to robot behaviors; to elicit behaviors that are promoted in the child; to model, teach and practice a skill; and to provide feed-back on performance in specific environments (e.g., therapeutic sessions). Based on their importance for both early development and for building autonomous robots that have human-like abilities, imitation, joint attention and interactive engagement are key issues in the development of assistive robotics for autism and must be the focus of further research.**

I. INTRODUCTION

Multimodal social-emotional interactions play a critical role in child development, and this role is emphasized in Autism Spectrum Disorders (ASD). In typically developing children, the ability to correctly identify, interpret and produce social behaviors (Figure 1) is a key aspect for communication and is the basis of social cognition [Carpendale J.I.M., 2004]. This ability helps children to understand that other people have intentions, thoughts, and emotions and act as a trigger of empathy [Decety J., 2004], [Narzisi et al., ec 8]. Social cognition includes the child's ability to spontaneously and correctly interpret verbal and nonverbal social and emotional cues (e.g., speech, facial and vocal expressions, posture and body movements, etc.); the ability to produce social and emotional information (e.g., initiating social contact or conversation); the ability to continuously adjust and synchronize behavior to others (i.e., parent, caregivers, peers); and the ability to make an adequate attribution about another's mental state (i.e., "theory of mind").

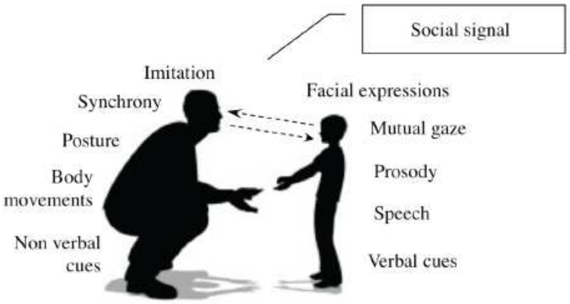

Fig. 1. Reception and production of social signals Multimodal verbal (speech and prosody) and non-verbal cues (facial expressions, vocal expressions, mutual gaze, posture, imitation, synchrony, etc.) merge to produce social signals [Chaby et al., 2012].

ASD are a group of behaviorally defined disorders with abnormalities or impaired development in two areas: (1) persistent deficits in social communication & social interaction and (2) restricted, repetitive patterns of behavior, interests, or activities (www.dsm5.org). An individual with ASD has difficulty interacting with other people due to an inability to understand social cues. For example, children with ASD often have difficulty with cooperative play with other peers; they prefer to continue with their own repetitive activities [Baron-Cohen and Wheelwright, 1999]. Persons with ASD evaluate both world and human behavior uniquely because they react in an abnormal way to input stimuli. They are problems to engage with human and difficulties to interact with the environment [Rajendran and Mitchell, 2000]. Although ASD remain a devastating disorder with a poor outcome in adult life, there have been important improvements in treating ASD with the development of various therapeutic approaches [Cohen, 2012].

Successful autism "treatments" using educational interventions have been reported as recently as a decade ago [Murray, 1997]. Since then, the literature devoted to the description and evaluation of interventions in ASD has become substantial over the last few years. From this literature, a number of conclusions can be drawn. First, there is increasing convergence between behavioral and developmental methods [Ospina et al., 2008]. For both types of treatment, the focus of early intervention is directed toward the development of skills that are considered pivotal," such as joint attention and imitation, as well as communication, symbolic play, cognitive abilities, attention, sharing emotion and regulation. Second, the literature contains a number of guidelines for treatments, such as:

- starting as early as possible
- minimizing the gap between diagnosis and treatment
- providing no shorter than 3/4 hours of treatment each day
- involving the family
- providing six-monthly development evaluations and updating the goals of treatment
- choosing among behavioral/developmental treatment depending on the child's response
- encouraging spontaneous communication
- promoting the skills through play with peers
- gearing towards the acquisition of new skills and to their generalization and maintenance in natural contexts
- supporting positive behaviors rather than tackling challenging behaviors.

Towards this direction, ICT may be beneficial in ASD therapy. Over the last few years, there have been considerable advances in the research on innovative ICT for the education of people with special needs, such as patients suffering from ASD [Konstantinidis et al., 2009]. Education is considered to be the most effective therapeutic strategy [Mitchell et al., 2006]. More specifically, early stage education has proven helpful in coping with difficulties in understanding the mental states of other people [Howlin et al., 1999]. In recent years, there have been new developments in ICT-based approaches and methods for therapy and the education of children with ASD. Individuals with autism have recently been included as a main focus in the area of Social Signal Processing (SSP is the ICT domain that aims at providing computers with the ability to sense and understand human social signals and communication) [Chaby et al., 2012] and Affective Computing (AC is the ICT domain that aims at modeling, recognizing, processing, and simulating human affects, or that relates to, arises from, or deliberately influences emotions) [Kaliouby et al., 2006], [Esposito, 2009], [Chetouani et al., 2009].

In this review, we focus on two aims: (1) to give an overview of the recent ICT applications that can be used in the treatment of ASD and (2) to focus on the early development of imitation [Thorndike, 1898], [Wallon, 1942], [Whiten and Ham, 1992], [Baldwin, 1902], [Piaget, 1977] and joint attention [Premack and Woodruff, 1978], [Emery, 2000] in the context of children with ASD as well as robotics.

In section II, we describe the state-of-the-art ICT used in the treatment of ASD. We show that both the ICT applications and treatment goals are very different. Regarding the ICT applications, we distinguish between interactive environments, virtual environments, avatars, serious games and telerehabilitation. The uses of these applications for the treatment of ASD can be classified according the main goal, which are as follows: (i) assistive technologies that counteract the impact of autistic sensory and cognitive impairments on daily life (close to occupational therapy); (ii) cognitive rehabilitation/remediation that attempt to modify and improve the core deficit in social cognition; and (iii) special education programs for bypassing ASD impairments to help children acquiring social and academic skills. In section III, we focus on robotics and ASD. The robotics platforms are interesting in the field of interventions in children with autism because robots generate a high degree of motivation and engagement in children with learning disabilities [Scassellati, 2007] and can be used to communicate, interact, display and recognize the "emotion", develop social competencies and maintain social relationships [Fong et al., 2003]. In this section, we focus on imitation and joint attention from a multidisciplinary viewpoint to investigate the contribution of social robotics on children with ASD because these two abilities are important during the development of the child and for the robots to be autonomous. We describe the state-of-the-art solutions proposed in social robotics for imitation and joint attention. Finally, we focus on the contributions of robotics on children with ASD and method to evaluate these architectures.

Many studies have been conducted using very different technologies that show an interest in a multidisciplinary research. However, as we will see technologies are limited in their performance and, from the practical perspective, they limit the success of experiments with people with ASD. Moreover, [Ricks and Colton, 2010]) underlined the unsignificant results in interactions between robot and ASD individual. A question as "What are the best roles for robots in therapy?" must be adressed to improve the research quality. In discussion (section IV), we propose a new experimental paradigm by asking the question of how the robot learning reacts to different participants (adults, TD children and children with ASD). This approach allows to analyze and to understand how cognitive models (cognitive computation) are influenced by groups of participants. Finally, we also discuss the key issues for improving ICT devices in the treatment of ASD.

II. ICT AND AUTISM: AN OVERVIEW

A. *Interactive Environments*

In recent years, the field of collaborative interactive environments, such as Virtual Environments (VE), has been of seminal relevance. The advances in this field are the control of the input stimuli and the monitoring of the child's behavior. The aim of interactive computer games is the improvement of the collaboration between multiple users such as children with ASD. Moreover, the Human-Computer Interaction (HCI) is regarded as a safe and enjoyable experience, which can be explained by the fact that the interaction with computers, unlike social interactions, does not pose severe expectations and judgment issues. Therefore, computer systems tend to offer a controlled environment with minimal distractions, and the use of computers is therefore attractive for the education of children with ASD [Green, 1993]. This finding is further supported by several reports that mention that this type of interaction elicits positive feelings, whereas communication with humans could be highly problematic for children with ASD [Hutinger and Rippey, 1997]. Furthermore, tutors often report that behavioral alterations during the educational process are a common phenomenon among persons with ASD [Jordan, 2001]. The personal state may be described by specific educational parameters, such as the time and the processes needed to complete a goal and the percentage of success. Moreover, the behavior monitoring during a period of time may reveal important factors for the children's progress. A large portion of the traditional educational tools employs real world environments, making the task of educating children with ASD more difficult [Frith et al., 1991] because it requires rapid and flexible thinking. Moreover, real world environments cannot be fully controlled because of the inability to provide the same set of conditions more than one time.

Various interactive environments have been developed for the rehabilitation of children with autism. In most of the cases, these environments are introduced through the means of software education platforms [Luneski et al., 2008], [Marnik and Szela, 2008]. To provide knowledge in an attractive way, these platforms use entertaining content in educational settings (edutainment). Photos or sketches of real objects (used in daily life) are presented on the monitor of a computer to encourage people with autism to distinguish objects based on their size, color, type, and so on. Moreover, this type of interactive learning platform motivates the children to correlate the objects with sounds and words. Platforms use animated pictures or videos to increase the attractiveness of displays. The comprehension of the task is supported by verbal and visual (usually makaton[1] symbols) guidance to minimize the role of the monitoring teacher [Lányi and A., 2004].

1) The use of a computer for individuals with ASD: Most computer applications designed for people with autism focus on the relationship between one user and one computer and aim to help with specific behavioral problems associated with autism. Authors in [Hileman, 1996] claim that computers are motivating for children with autism due to their predictability and consistency, compared with the unpredictable nature of human responses. In regard to social interaction, the computer does not send confusing social messages. Research on the use of computers for students with autism revealed the following [Jordan, 1995]: (a) increase in focused attention; (b) increase in overall attention span; (c) increase in sitting behavior; (d) increase in fine motor skills; (e) increase in generalization skills (from computer to related non-computer activities); (f) decrease in agitation; (g) decrease in self-stimulatory behaviors; and (h) decrease in perseverative responses. The importance of assistive technology for children with autism has been established by the fact that this technology can be used in rehabilitation for daily activities. Hetzroni and Tannous [OE and Tannous, 2011] have developed a program (I Can Word It Too) based on daily life activities in the areas of play, food and hygiene. The study was conducted on five children with autism between the ages of 7 and 12, and the focus was on the effects of using the program on the use of functional communication. The authors found that use of the program was effective in improving the communication of all participants and that the participants were able to transfer the lessons learned to their natural setting in the classroom. A DVD with educational software for emotions, called the Transporters, has been created at the Autism Research Centre (ARC), which is one of the most extensively used commercial applications for this purpose (http://www.thetransporters.com/, March, 2009). The Transporters is based on 8 characters, which are vehicles that move according to rule-based motion. Such vehicles, because of their mechanical nature, attract the attention of young children with autism. Real-life faces of actors showing emotions have been grafted onto these vehicles, and the expressions have been contextualized in entertaining social interactions between the toy vehicles. The aim of the Transporters is to determine whether creating of an autism-friendly context (predictable mechanical motion) could be learned more easily than is possible in the real world. The Transporters has been evaluated for effectiveness in children aged 4 to 8 with autism. The results are exciting. (a) In all tasks for which the children were tested, most children caught up with their typically developing peers. (b) The results suggest that the Transporters DVD is an effective way to teach emotion recognition to children with autism and that the learning generalizes to new faces and new situations. Children with autism who did not watch the DVD remained below the typical developmental levels [Golan et al., 2009].

2) Special Input Devices: touch screens and other technologies: While people with ASD enjoy interacting with computers, recent ICT developments allow more attractive forms of input to be used. In contrast to what has been described in the previous paragraph, most of the recent research projects use a touch screen for input feedback instead of a common mouse device [Konstantinidis et al., 2008]. A multi-user touchable interface that detects multiple simultaneous touches by two to four users was used by [Gal et al., 2005]. Each user sits or stands on a receiver (a thin pad) such that touching the table surface activates an array of antennas embedded in its surface (capacitive touch detection). People with ASD could easily use the screen, and big colored buttons allow for user selection. Moreover, studies in using Virtual Reality (VR) for the rehabilitation of people with ASD include visual devices that represent the 3D virtual world [Strickland, 1996]. Alternative interaction methods include remote controllers like

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[1] a very simple language based on a list of simple everyday words, which uses speech, gesture, facial expression, body language, signs, symbols and words to aid communication.

the Wii-mote (part of a commercial game console), as demonstrated in [Gonzalez et al., 2007]. This device is capable of monitoring not only the remote button selection but also movements (based on internal accelerometer). Furthermore, external devices are used to measure and monitor the user's internal and emotional state, such as wearable measurement devices [Konstantinidis et al., 2008]. In [Takacs, 2005], a web camera, an eye tracker and a data glove. In addition, scientists have attempted to provide more attractive virtual worlds by using video projectors and depicting the educational material on a wall of a room [Horace and Belton, 2006]. One of the first program to treat children with ASD was TEACCH (Treatment and Education of Autistic and related Communication handicapped CHildren). TEACCH principles involve changing the behavior and skill level of the person based on his or her personal unique needs. In order for a platform to achieve this goal, it has to be capable of recording the user's interaction/education process. By using all the records in the proper way, a longitudinal record may be achieved indicating a learning curve for each autistic person separately, thereby enhancing and normalizing the educational procedures toward each person's needs. Consequently, the educators can track each user's progress and modify the difficulty levels accordingly.

Recently, several Apple devices have been used with ASD patients. Authors in [Kagohara et al., 2013] conducted a systematic review of studies that involved iPods, iPads, and related devices in teaching programs for individuals with developmental disabilities. 15 studies examined covering the following five domains: (a) academic, (b) communication, (c) employment, (d) leisure, and (e) transitioning across school settings. 47 subjects contributed to these studies whose the aim was (a) delivering instructional prompts via the iPod Touch or iPad or (b) teaching the person to operate an iPod Touch or iPad to access preferred stimuli. The 15 studies were largely positive and showed that these devices are viable technological aids for individuals with developmental disabilities.

Authors in [Jowett EL, 2012] evaluated the effectiveness of a video modeling package to teach a 5-year-old boy diagnosed with an ASD basic numeracy skills. The treatment package consisted of iPad-based video modeling, gradual fading of video prompts, reinforcement, in vivo prompting and forward chaining. Authors showed clear gains in the participant's ability to identify and write the Arabic numerals 1-7 and comprehend the quantity each numeral represents in association with the lagged intervention. Generalization and maintenance data demonstrated the robustness of the treatment effects. This study confirmed that iPad-based video modeling, when used in a package, can be an effective technique for teaching numerical skills to children with an ASD.

Authors in [Flores et al., 2012] showed that Augmentative and Alternative Communication (AAC) interventions improve both the communication and social skills of children with ASD and other developmental disabilities. New forms of AAC, such as cell phones, MP3 Players, and personal computer tablets, are explored and evaluated. The authors investigated the utility of iPad as a communication device by comparing its use to a communication system using picture cards. Five school children (6-10 years old) with ASD and developmental disabilities who used a picture card system participated in the study. The results were mixed in that communication behaviors either increased when using the iPad or remained the same as when using picture cards.

Recently, [Murdock LC, 2013] used an iPad play story to increase the pretend play skills in 4 preschoolers with ASD. The story utilized a series of video clips depicting toy figures, engaged in a pretend play vignette, producing scripted character dialogue. Three of the participants demonstrated increases in the target behavior (the play dialogue), and the effects were largely maintained during generalization opportunities with peers and during a 3-week follow-up condition.

B. Virtual environments

VE have proven to be another active area of research for social interventions for autistic children [Bellani M, 2011]. Various successful software platforms with virtual environments for autistic people have been developed over the last decade [Enyon, 1997], [Eddon, 1992]. VE are able to mimic specific social situations in which the user can participate in role-play. The stable and predictable environment provides types of interaction that eliminate the anxiety [Parsons, 2000]. Moreover, VE offer safe, realistic-looking 3D scenarios that can be built to depict everyday social scenarios. The use of animation is also in line with research indicating that children with learning disabilities prefer programs that include animation, sounds and voices [Trepagnier C, 1999].

Recent works have demonstrated the ability of participants with ASD to use and to interpret VE successfully and to learn simple social skills using the technology [Strickland, 1996], [Parsons, 2000], [Parsons, 2006]. Additionally, one of the most important aspects of VE used by participants with ASD in educational settings is the participants level of enjoyment. Persons with ASD, especially children, are more interested in interacting with computers than other toys [Konstantinidis et al., 2009]. Moreover, virtual peers [Tartaro, 2007] are life-sized, language enabled, computer-generated, and animated characters that look like a child, which are capable of interacting, sharing real toys and responding to children's input. For example, a virtual peer accompanies a child with ASD during a game or a storing telling scenario. A number of researchers have developed interesting research contributions using storing telling scenarios. For example, [Mitchell P, 2007] developed and tested a virtual cafe for children with autism to address impairments in social interaction. The participants were required to perform specific tasks in the virtual cafe, such as ordering and paying for a drink and finding a place to sit. Again, navigation was achieved through the use of a mouse. A Virtual Reality social-understanding training program was administered to 6 adolescents, 14-16 years old, each with formal diagnoses of an autism spectrum disorder. During the training sessions, 4 types of activities were taught and practiced. These activities were graded in difficulty and created based on certain social conventions associated with finding a seat in an empty or crowded cafe, ordering, paying and engaging in appropriate conversation with others. The social understanding of these adolescents was assessed using ratings of their verbal descriptions of their decision-making process of how they would behave in two different social scenarios, which were: a cafe and a bus. The former was similar to situations encountered in the virtual cafe, while the latter assessed the generalizability of the participants' learned social understanding. The results were variable and only 2 participants showed gains in social knowledge in both scenarios. Actual performance in real situations was not assessed. Because real-cafe interactions usually require touching objects, such as money or coffee mugs, the integration of more complex haptics into this type of program may facilitate more realistic interaction between the user and VE.

Increased realism [Herrera G, 2008], [Bauminger N, 2007] would influence the degree of ecological validity achieved and subsequent degree of skill transfer. Increasing in complexity, touch-screen technology has facilitated human-computer interaction without a traditional mouse or joystick. Authors in [Herrera G, 2008] created a virtual supermarket on a flat screen monitor to teach 2 children, 8 and 15 years old, how to think abstractly and play imaginatively. The children explored the virtual supermarket through touching the screen. They interacted with the objects in increasingly more imaginative ways, such as transforming a pair of flying pants into a highway. The authors assessed the outcomes using a test of functional object use (i.e., how an object should be used), the Symbolic Play Test (SPT) (1976), the Test of Pretend Play (ToPP) (1997) and the Imagination and Magic Understanding Tests. Children improved on all tests except the SPT. The authors concluded that their virtual reality tool is useful in improving the symbolic thinking skills of these children and that these skills translate into concrete symbolic play behaviors. The touch-screen facilitated easy interaction between the children and the display interface and allowed the instructor to participate as well. This multidimensional interaction is naturally afforded by touch-screen technology; touch screen technology allows for interaction between the child and computer, instructor and computer, and instructor and child.

Diamond Touch (Circle Twelve Inc., Framingham, Mass., USA), a state-of-the-art multi-user and multi-touch display table, allows many people to interact with objects on the tabletop display screen simultaneously through touch. Similar to the touch-screen in [Herrera G, 2008], the Diamond Touch table immerses users in an imaginative scene where their actions and decisions have real time consequences within the virtual world. Diamond-Touch technology was integrated with the Story Table interface to allow multiple children to create an imaginative story together by selecting, combining and sequencing a series of on-screen virtual characters and events. Some story elements required 2 children to touch the screen before they were integrated into the story, reinforcing joint attention, communication and negotiation.Authors in [Bauminger N, 2007] evaluated this system with 3 dyads (a dyad is composed of 2 children with autism), aged 9-11 years old, to teach and reinforce key social skills, such as eye contact, turn-taking, sharing and joint directed behavior. During the intervention, the dyads were instructed to create and narrate stories using backgrounds and characters that were jointly chosen. The instruction was focused on three goals, which were: performing shared activities, helping and encouraging each other, and persuading and negotiating when creating the stories. Ratings of social behaviors from the videos of the Story Table sessions were completed; in addition, the authors assessed the generalizability of the children's social skills through a Lego-like assembly game, Marble Works. After the training sessions, the children were all rated as having more positive social behaviors during the use of the Story Table and more positive behaviors during the use of Marble Works. In addition to the improvements in the positive social behaviors, the quality of play of the dyads improved from simple parallel play without eye contact to complex, coordinated play. The authors concluded that the Story Table intervention increased both the quantity and the quality of social interaction between the dyads.

Both [Herrera G, 2008] and [Bauminger N, 2007] provide evidence that touchscreen technology shows great promise in promoting creative and imaginary play between multiple users. Authors in [Wang M, 2011] highlights that future studies should consider using typical peers, rather than atypical peers, as participants with this multiuser technology. In fact, research has shown that same-aged, typical peers serve as effective role models for children with autism to reinforce pro-social and age-appropriate behaviors [DiSalvo, 2002]. It is important to note that although devices such as the mouse, joystick and touch-screen cannot simulate real-life haptic interactions, such as feeling the texture of a surface, incorporating the sense of touch adds yet another layer of interaction within the program. Participating in real-time cause-and-effect behaviors may contribute to an overall sense of presence and motivation for the child during the intervention program.

C. *Avatars for autism and serious games*

Playing, in most cases, an essential role as the instructor, emotionally expressive avatars are among the most interesting options of the educating system. The current literature reveals that avatars, humanoid or not, advance the educational process [Konstantinidis et al., 2009] and improve the social skills of the participants [Hopkins IM, 2011]. Additionally, educators suggest that most of the time, persons with ASD can recognize the avatar's mental and emotional state from the facial expressions [Orvalho V, 2009], [Konstantinidis et al., 2009]. Avatars, as inhabitants of the virtual space, can enhance the interaction level in VE. Their behavioral capabilities are envisaged with emotional and facial expressions [Fabri, 2006]. The use of emotionally expressive avatars is of crucial importance in the educational process because their ability to show emotions and empathy enhances the quality of tutor-learner and learner-learner interaction [Fabri, 2007]. Therefore, emotionally aware computers are regarded as a considerable and valuable educational technique [Rajendran and Mitchell, 2000]. A significant effort has been undertaken to use emotionally avatars due to the findings in psychology and neurology that suggest emotions are an important factor in decision-making, problem solving, and cognition in general [Damasio, 1994]. The results of surveys among educators of autistic children in the recent literature illustrate that the childrens recognition of not only the avatars emotion but also the avatar's emotional state advances the educational process [Konstantinidis et al., 2009]. Moreover, the findings are better in the case of avatars that have voices [Konstantinidis et al., 2009]. Apart from the instructor form, the avatar is responsible for providing feedback to the user's action by means of the appropriate emotion (happy for success and sad for failure). Training studies in [Rosset, 2008] have suggested that children with autism show greater improvements in emotion recognition when programs include cartoons rather than photographs of real faces [Bekele E, 2013]. Moreover, clinical and parental reports also state that autistic children spend long periods of time looking at cartoons [Rosset, 2008]. Additionally, parents and professionals often report that ”autistic children know more about cartoons than about people” [Rosset, 2008].

Recently, [Serret, 2012] developed a serious game, ”Jestimule”, to improve social cognition in ASD. The authors attempted to develop the game with consideration for the heterogeneity of ASD. ICT was also used to facilitate the use of the game by young children or by children with developmental delays (e.g., haptic joystick for feed-back). They also evaluated the serious game for its effectiveness in teaching ASD individuals to recognize facial emotions, emotional gestures and emotional situations (figure 2). First, they showed that a group of 40 individuals (aged from 6 to 18) who used ”Jestimule” at the hospital twice a week one hour for four weeks of exploration could play and understand the serious game even when they had comorbid intellectual disabilities. They also showed that participants improved their recognition of facial emotions, emotional gestures and emotional situations in different tasks. These preliminary results have clear education and therapeutic implications in ASD and should be taken into account in future training.

D. Telerehabilitation for Autism

Telerehabilitation is an emerging method of delivering rehabilitation services that uses technology to serve clients, clinicians, and systems by minimizing the barriers of distance, time, and cost. More specifically, telerehabilitation can be defined as the application of telecommunication, remote sensing and operation technologies, and computing technologies to assist with the provision of medical rehabilitation services at a distance. Much attention has been paid to the efficacy of telerehabilitation in the effort to decrease the time and cost associated with the delivery of rehabilitation services.

Some studies have also compared telerehabilitation services with face-to-face interventions to evaluate whether these approaches are ”as good as” traditional rehabilitation approaches. However, telerehabilitation may in fact provide new opportunities that are more effective by increasing accessibility and creating the least restrictive environment. Technologies that enable telerehabilitation services, such as increased computer power and the availability of high-speed data transmission lines, have become more prominent in recent years [Diamond BJ, 2003]. Winters provides a comprehensive review of the conceptual models of telerehabilitation [Winters, 2002]. Authors in [Diamond BJ, 2003] explains that telerehabilitation falls under a broader category of services that use telecommunication to provide health information and care across distances, termed telehealth. Telehealth is broken into 3 subcategories, which are: telemedicine, telehealthcare, and e-health/education. Most of the research literature on telerehabilitation has focused on outcomes measures for decreasing costs, saving travel time, and improving access to specialty services and expert practitioners [Bashshur, 2002]. The rationale proposed to support the exploration and implementation of telerehabilitation has been essentially based on the use of various technologies to address geographic and economic barriers and potentially enhance cost effectiveness. There is also a significant impetus to support the value of medical rehabilitation services delivered in the home. Although much of this literature seems to be motivated by providing a rationale for expeditious discharge from the inpatient setting for cost-saving purposes, the research supports that the delivery of some home-based rehabilitation services is at least as effective as the delivery of those services in hospitals. In some cases, telerehabilitation adds contextual factors that enhance rehabilitation and outcomes. These findings support the development and implementation of telerehabilitation approaches to facilitate naturalistic rehabilitation treatment in the home. Intervention in the home or work environment has been provided remotely for numerous needs, including cognitive rehabilitation using the Internet, constraint induced movement therapy using a computer and sensors to guide the patient through exercises [Lum PS, 2006] and speech pathology for children with autism [Parmanto, 2005].

An interesting contribution is the use of telerehabilitation in children with autism. A number of researchers at the UC Davis MIND Institute are examining technology tools that will enable families to interact from their own homes with therapists and receive ”long distance” guidance for interventions with their children [Vismara LA., 2010]. At present, there are various challenges to delivering health care to families with ASD, such as long waiting lists and few specialist services. Barriers to service delivery and utilization are additionally exacerbated for families living in rural or remote areas, often resulting in limited access to preventative mental health services in general and parenting ASD interventions in particular. Telecommunication technology can support long-distance clinical health care; however, there is little information as to how this resource may translate into practice for families with ASD. The Vismara study examined the use of telemedicine technology to deliver a manualized, parent-implemented intervention for families of children with ASD, ages 12-36 months. It was hypothesized that telemedicine technology as a teaching modality would optimize parenting intervention strategies for supporting children's social, affective, communicative, and play development. Recruited families received 12 weekly one-hour sessions of

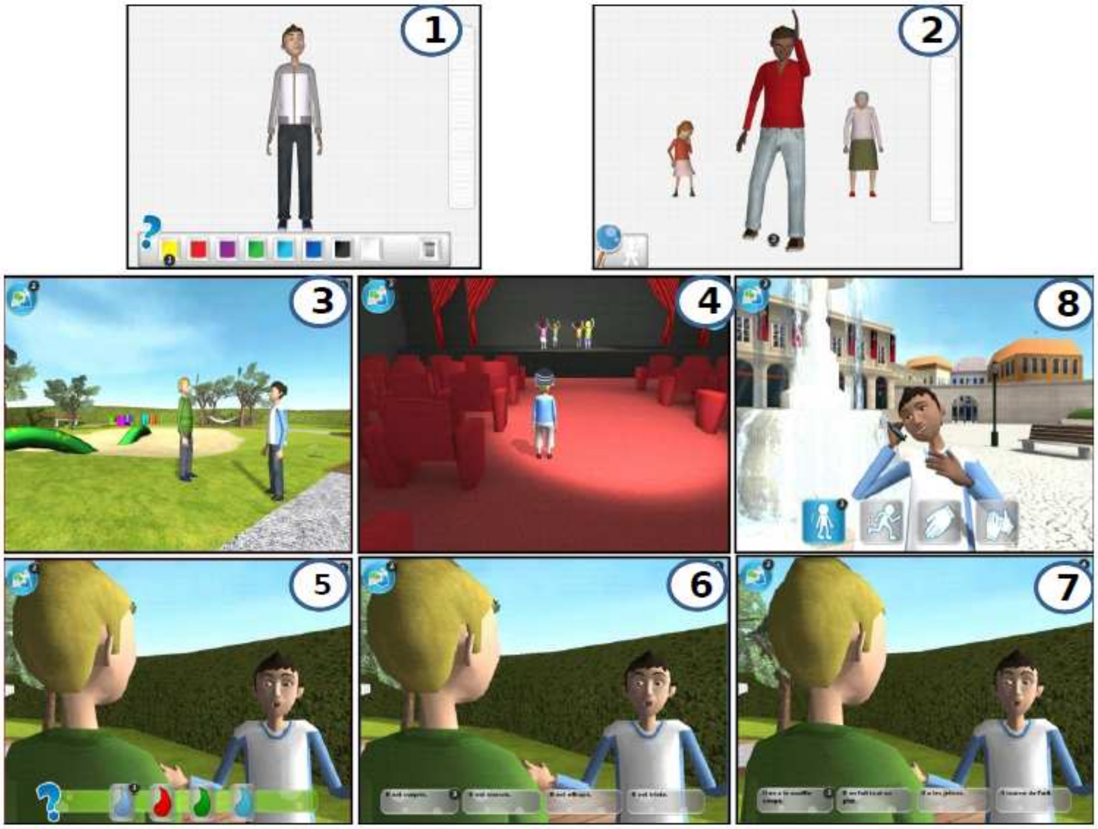

Fig. 2. Main principles of the serious games JeStimule. The games are divided into three phases. The learning phase is composed of a series of games with increasing complexity. The subjects will learn to recognize the facial (screen 1) and gesture (screen 2) emotions of avatars. During the practice phase, the child plays in a virtual environment and circulates in five different areas of life, which are: square (screen 3), theatre (screen 4), restaurant, garden and store. The participant should recognize or anticipate the expression of the emotional avatars in various social situations using the learning undertaken in the first phase. Interestingly, the game is adaptable for individuals with low and high functioning because, for the same social situation, it is possible to choose the best response modality appropriate to the cognitive skills of players. The modalities include a color code mode (screen 5) for non-readers, emotional words (screen 6) for readers, or idiomatic expressions (screen 7) for individuals with Asperger syndrome. For each social situation, the player should recognize or anticipate emotions. If the answer is correct, the player wins a puzzle piece and makes a choice of action. He or she must make a choice of action by selecting one of four proposed actions with a pictogram, which are: stay put, run away, assist or cheer (screen 8). If the answer is incorrect, the player does not win a puzzle piece and visualizes the scene again later. Then, the player runs a the gaming platform again to meet a new social scene. The goal of the game is very simple; the player wins a piece of a puzzle for each emotion recognized or anticipated. At the end of the module of the game, he or she has won 30 pieces. (courtesy of Sylvie Serret and Florence Askenasi [Serret, 2012])

direct coaching and instruction of the Early Start Denver Model (ESDM) [Dawson G, 2009]. A Parent Delivery Model was provided through an Internet-based video conferencing program. Each week, parents were coached on a specific aspect of the intervention through a video conferencing program and webcam, allowing the parent and therapist to see, hear, and communicate with one another. Parents were taught how to integrate the ESDM into natural, developmentally and age appropriate play activities and caretaking routines in their homes. Video data were recorded from 10 minutes of parent-child interaction at the start of each session and coded by two independent raters blinded to the order of the sessions and hypotheses of the study. The preliminary findings of this study suggested that integrating telemedicine as a teaching modality enabled the following: (a) parents to implement the ESDM more skillfully after coaching and (b) an increase in the number of spontaneous words, gestures, and imitative behaviors used by the children. The current findings support the efficacy and cost-effectiveness of using telemedicine to transfer a developmentally based, relationship focused, and behaviorally informed intervention (i.e., the ESDM) into parents' homes to be delivered within typical parent-child activities. Additional research is needed to confirm the promise and utility of telemedicine for transporting services to families with limited access.

E. Conclusion

ICT-based approaches and methods are used for the therapy and special education of children with ASD. ICT research has explored several approaches for the treatment of persons with ASD, which are: (i) counteracting the impact of autistic sensory and cognitive impairments on daily life (assistive technologies, e.g., [Murdock LC, 2013]); (ii) trying to modify and improve the core deficit in social cognition (cognitive rehabilitation/remediation, e.g., [Serret, 2012]); and (iii) bypassing ASD impairments to help children acquire social and academic skills (special education, e.g., [Lányi and A., 2004]). However, much has yet to be improved to attain significant success in treating individuals with ASD. From the practical perspective, many of the existing technologies have limited capabilities in their performance, which limits the success of ICT treatment in persons with ASD. Clinically, most ICT proposals have not been validated outside the context of proof of concept studies. Because most ICTs have limitations (e.g., the interaction is not natural, intuitive, or physical), emerging research in the field of autism is aimed at the integration of social robotics [Diehl et al., 2012], [Kozima et al., 2009], [Welch et al., 2010]. Social robots are used to communicate, display and recognize the "emotion" and develop social competencies and maintain social relationships [Fong et al., 2003]. Developed as interactive toys for children, humanoid robots are used as research platforms for studying how a human can teach a robot, using imitation, speech and gestures. Increasingly, robotic platforms are developed as interactive playmates for children. Recent literature reveals that robots generate a high degree of motivation and engagement in children with learning disabilities, especially in persons with ASD, including those who are unlikely or unwilling to interact socially with human educators and therapists [Scassellati, 2007]. In the next section, we will show how social robots can improve or help better understanding the condition of children with ASD.

III. WHAT IS THE CONTRIBUTION OF ROBOTICS TO CHILDREN WITH ASD?

In this section, we explore the contribution of robotics to children with ASD. The use of robots in special education is an idea that has been studied [Papert, 1980]. We will specifically focus on robotics and children with ASD according to what is expected from the robotics in the context of the specific experiment described. However, it is important to keep in mind that socially assistive robotics have at least three discrete but connected phases, which are: physical robot design, human robot interaction design and evaluations of robots in therapy-like settings [Scassellati et al., 2012]. Moreover, we focus on two abilities, imitation and joint attention because they are important during the development of the child [Jones, 2009], [Jones, 2007], [Carpenter et al., 1998], [Tomasello and Farrar, 1986] and core deficit in ASD [Dawson G, 2009]. To address these abilities from the point of view of both developmental psychology and ICT, we begin by briefly describing the different architectures developed in robotics for imitation and joint attention. Next, we review the available literature on robotics and ASD, differentiating between different lines of research, including: (i) exploring the response of children with ASD to robotics platforms; (ii) settings where a robot was used to elicit behaviors, or (iii) modelling or teaching a skill, and last (iv) providing feedback to children with ASD.

A. Robot imitation skills

Beginning with Kuniyoshi's studies [Kuniyoshi, 1994], [Bakker and Kuniyoshi, 1996], learning by observation has been shown to proceed in three phases: (1) observation, which is watching an action performed by a human, e.g., a human grasps an object and then moves it to another position; (2) understanding, which involves the construction and memorization of an internal representation of the observed task; and (3) reproduction of the observed task. This approach has been used in several studies in different contexts, such as household environments [Dillmann, 2004], labyrinths [Hayes and Demiris, 1994] and learning sequences [Berthouze et al., 1996], [Billard and Hayes, 1997]. In other studies, imitation has been used to reproduce an observed gesture (i.e., a low-level gesture).

Several research questions are thus centered on movement recognition (can the robot identify the human arm and characterize the human arm trajectory?), the form of the gesture (what should the robot imitate?), and the perspective being considered. A solution to the last issue might be to perform the gestures directly with a robotic forelimb, e.g., using a remote control [Campbell et al., 2006] to manipulate the hand [Calinon et al., 2007] or by fitting a robot model with sensors [Maurer et al., 2005], [Aleotti and Caselli, 2006] or an exoskeleton [Ijspeert et al., 2002]. Moreover, [Sadeghipour and Kopp, 2011] shows that the coupling of perception and action processes plays an important role in basic capabilities of social interaction. They attempt to endow artificial embodied agents with similar abilities, and, they present a probabilistic model for the integration of perception and generation of hand-arm gestures via a hierarchy of shared motor representations.

Imitation that involves interaction with the environment is more complex. The difficulty is in determining the relationships among the hands, arms and different objects. However, humans can aid the robot by specifying the relationships among the objects. The robot can also be endowed with primitive movements such as grasping an object. These primitive movements provide a vocabulary of actions for the robot, which the robot must then learn to combine to perform complex tasks [Pardowitz et al., 2007], [Pardowitz and Dillmann, 2007]. However, an important limitation is that the robot can only learn to perform tasks that require this primitive repertoire. Consequently, robotics with these designs have developed the following capabilities: (1) learning primitive movements such as grasping an object [Campbell et al., 2006] or putting it in a box [Hersch et al., 2008] and (2) performing gestures by adapting to the environment [Campbell et al., 2006], [Steil et al., 2004], [Guenter et al., 2007].

Authors in [Boucenna et al., 2010] investigated how robots learn to recognize facial expressions without having a teaching signal, allowing the robots to associate facial expressions with given abstract labels (e.g., the name of the facial emotional expressions for 'sadness', 'happiness', etc.). The authors also developed a sensory motor architecture for the recognition of facial expressions. The robot can learn facial expressions if it produces these facial expressions, and the human imitates the robot's facial expression to facilitate on-line learning (Figure 3 shows the human-robot interaction game).

These authors showed in their first series of robotics ex-

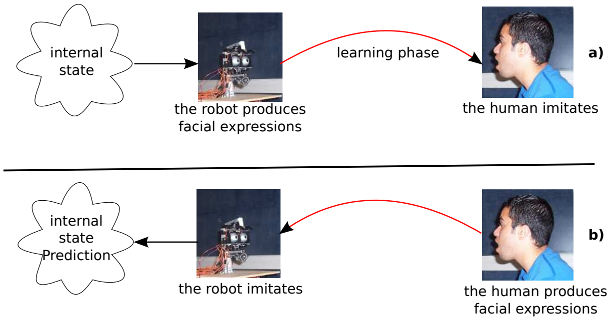

Fig. 3. Experimental protocol. a) In the first phase of the interaction, the robot produces a random facial expression (sadness, happiness, anger, or surprise) plus a neutral face for 2 s; then, the robot returns to a neutral face for 2 s to avoid human misinterpretation of the robot facial expression (the same procedure is used in psychological experiments). The human subject is asked to mimic the robot head. b) After this first phase, which lasts between 2 and 3 min according to the subject's "patience", the generator of the random emotional states is stopped. If the neural network has learned correctly, then the robot must mimic the facial expression of the human partner [Boucenna et al., 2014b].

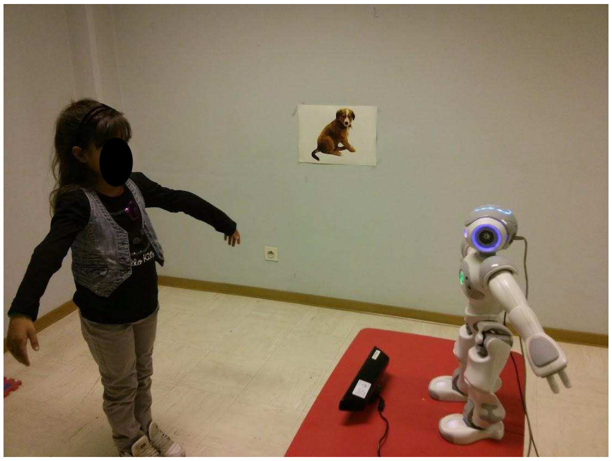

Fig. 4. Example of typical human robot interaction. In this case, the child with ASD imitates the robot [Boucenna et al., 2012].

periments that a simple neural network model could control the robot's head, and the robot could learn online to recognize facial emotional expressions (the human partner imitated the robot's prototypical facial expressions). Imitation was used as a communication tool instead of a learning tool; the caregiver communicated with the robot through imitation. Moreover, the same architecture could be used to learn posture recognition [Boucenna et al., 2012] and joint attention [Boucenna et al., 2011].

Figure 4 shows an interaction between the child with ASD and the robot during an imitation game. In the first phase of the interaction (learning phase), the robot produces postures and we ask to the child to mimic the robot posture. After this first phase, which lasts for approximately 2 min, the robot must mimic the postures of the child with ASD. Currently, we perform the learning of posture with children with ASD to show that the robot is able to learn this task with children with ASD. Moreover, we analyze the influence of the partners (children with ASD, typical children, and adults) who interact with the robot during this imitation game [Boucenna et al., 2014a].

Others studies have also proposed neural network architectures designed to exhibit learning and communication capabilities via imitation [Andry et al., 2001], [Andry et al., 2004], [de Rengervé et al., 2010]. An artificial system does not need to incorporate any other internal model to perform real-time and low-level imitations of human movements despite the related correspondence problem between humans and robots. A simple sensory motor architecture can perform such tasks. These sensory motor architectures and this type of paradigm are interesting because robots are able to learn online and autonomously, which allows for the creation of a real interaction between a human partner (e.g., a child) and robot. In this case, the human partner communicates with the robot through imitation.

B. Are robots able to develop joint attention capabilities?

The joint attention is essential for social interaction and for building robots that can interact in social environments, as successfully implemented using the Baron-Cohen model [Baron-Cohen, 1997] and a humanoid robot [Scassellati, 1999], [Scassellati, 2001]. According to Baron-Cohen, joint attention is based on the following two modules: (1) the Intentionality Detector (ID), which uses sensory modalities and can interpret the actions of other agents, for example, purpose, goal and desire; and (2) the Eye-Direction Detector (EDD), which can detect the presence and gaze direction of other agents. EDD allows the robot to infer that a person is looking at an object if his/her gaze is directed toward that object. ID allows for the interpretation of the gaze direction as a goal state and the interpretation of the gaze of others as intentions. More recently, other proposals have been made. The model developed by [Yucel et al., 2009] implements an effective model, which integrates image-processing algorithms into a robust estimation of the head pose and an estimation of the gaze direction. Other authors, such as [Marin-Urias et al., 2009], [Marin-Urias et al., 2008], [Sisbot et al., 2007] have focused on the capacity of shared attention in "mental rotation" and "perspective taking". These capabilities allow the humanoid robot HRP2 to acquire representations of the environment from other perspectives and to assimilate the concept of reason from the perspectives of others to obtain a representation of the knowledge of others.

Nagai [Nagai et al., 2003] proposed a developmental model, which would allow a robot to acquire joint attention capability without the assessment of the task. This model showed how a robot could interpret the gaze direction of humans to focus on objects in the environment. The robot acquired the ability of joint attention without any task evaluation from a human caregiver. Moreover, the robot attempted to reproduce the staged developmental process of infant joint attention. In another study, joint attention can emerge from a sensory-motor architecture [Boucenna et al., 2011]. In summarizing the challenges of joint attention, [Kaplan and Hafner, 2006] attempted first to define this mechanism as well as the unitary elements that constitute it. In line with Tomasello's views [Tomasello, 1995], [Kaplan and Hafner, 2006] argued that joint attention implies viewing the behavior of other agents as intentionally driven. In that sense, joint attention is much more than gaze following or simultaneous looking.

C. Robotics and children with autism

Since 2000, there have been an increasing number of clinical studies that have used robots to treat individuals with ASD. The robot can have two roles in the intervention, which are practice and reinforcement [Duquette et al., 2008]. At least three reviews of the literature have been conducted recently [Scassellati et al., 2012], [Diehl et al., 2012], [Thill et al., 2012]. Here, we choose to follow the plan proposed by Diehl and colleagues because it fits the main focus of our study regarding imitation and joint attention. Diehl et al. distinguished 4 different categories of studies. The first compares the responses of individuals with ASD to humans, robots or robot-like behavior. The second assesses the use of robots to elicit behaviors that should be promoted with regard to ASD impairments. The third uses robotics systems or robots to model, teach and practice a skill with the aim of enhancing this skill in the child. The last uses robots to provide feedback on performance during therapeutic sessions or in natural environments.

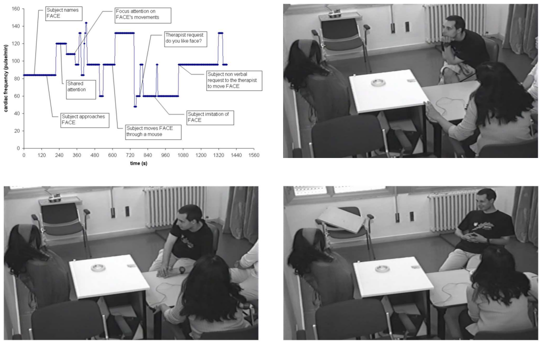

Fig. 5. As shown in screen 5a, the cardiac frequency of the patient increases after his attention is focused on the robot and remains fairly even until he is forced to focus on his emotional relationship with FACE. In screen 5b, the subject is shown to completely focus his attention to FACE; in screen 5c, the subject is spontaneously making eye-contact with FACE; screen 5d shows the non-verbal request of the subject through a conventional gesture (a wink) (from [Pioggia et al., 2008])

1) Response to robots or robot-like characteristics: Although most of the research in this field has been based on short series or case reports, the authors have insisted on the appealing effects of using robots to treat individuals with ASD. If we assume that individuals with ASD prefer robots or robot-like characteristics to human characteristics or non-robotic objects, we may wonder why individuals with ASD prefer robots as well as what is particularly appealing about these characteristics. Authors in [Pioggia et al., 2005] compared a child with ASD to a typically developing control child for his/her behavioral and physiological responses to a robotic face. The child with ASD did not have an increase in heart rate in response to the robotic face, which implies that the robotic face did not alarm the child. In contrast, the control child spontaneously observed the robot with attention and expressed positive reactions to it; however, when the robot's facial movements increased, the typical child became uncomfortable and exhibited an increased heart rate. In a case series, the same author [Pioggia et al., 2008] compared the responses of ASD children to the robotic face versus human interaction; most individuals with ASD showed an increase in social communication, some showed no change, and one showed a decrease when he interacted with the robotic face.

Authors in [Feil-Seifer and Mataric, 2011] showed in a group of eight children with ASD that there was tremendous variability in the valence of an effective response toward a mobile robot, depending on whether the robot's behavior was contingent on the participant or random. In this study, the robot automatically distinguished between positive and negative reactions of children with ASD. Individual affective responses to the robots were indeed highly variable. Some studies [Dautenhahn and Werry, 2004], [Robins et al., 2006] have shown that for some children with ASD, there is a preference for interacting with robots compared to non-robotic toys or human partners. However, [Dautenhahn and Werry, 2004] found individual differences in whether children with ASD preferred robots to non-robotic toys. Two of the four participants exhibited more eye gazes toward the robot and more physical contact with the robot than with a toy.

Other studies have investigated movements. Authors in [Bird et al., 2007] found a speed advantage in adults with ASD when imitating robotic hand movements compared to human hand movements. In the same vein, [Pierno et al., 2008] reported that children with ASD made significantly faster movements to grasp a ball when they observed a robotic arm perform the movement compared to a human arm. In contrast, typically developing children showed the opposite effect. Therefore, these 2 studies suggest increased imitation speed with robot models compared to human models [Bird et al., 2007], [Pierno et al., 2008].

Additionally, some studies have investigated the responses of children with ASD when exposed to emotional stimuli. Authors in [Nadel et al., 2006], [Simon et al., 2007] explored the responses of 3- and 5-year-old children to emotional expressions produced by a robot or a human actor. Two types of responses were considered, which were: automatic facial movements produced by the children facing the emotional expressions (emotional resonance) and verbal naming of the emotions expressed (emotion recognition). Both studies concluded that, after robot exposition, an overall increase in performance occurred with age, as well as easier recognition of human expressions [Nadel et al., 2006], [Simon et al., 2007]. This result is encouraging from a remediation perspective in which an expressive robot could help children with autism express their emotions without human face-to-face interaction. Finally, [Chaminade et al., 2012] investigated the neural bases of social interactions with a human or with a humanoid robot using fMRI and compared male controls (N=18, mean age=21.5 years) to patients with high functioning autism (N=12, mean age=21 years). The results showed that in terms of activation, interacting with a human was more engaging than interacting with an artificial agent. Additionally, areas involved in social interactions in the posterior temporal sulcus were activated when controls, but not subjects with high-functioning autism, interacted with a human fellow.

2) Robots can be used to elicit behavior: Some theoretical works have highlighted several potential uses of a robot for diagnostic purposes [Scassellati, 2007], [Tapus et al., 2007]. For example, a robot could provide a set of social cues designed to elicit social responses for which the presence, absence, or quality of response is helpful during diagnostic assessment. In [Feil-Seifer and Matarić, 2009], the robot could be programmed to take the role of a bubble gun[2]. The robot produces bubbles to elicit an interaction between the child and the examiner. Additionally, the robot can act as a sensor and provide measurements of targeted behaviors [Scassellati, 2007], [Tapus et al., 2007]. These measurements may be used to diagnose the disorder and to quote its severity on one or several dimensions. The robots could record behaviors and traduce social behaviors into quantitative measurements. Additionally, interaction between a robot and a child has been used to elicit and analyze perseverative speech in one individual with high-functioning ASD [Stribling et al., 2009]. Interaction samples were collected from previous studies in which the child interacted with a robot that imitated the child's behavior. Here, the robot-child interaction is used to collect samples of perseverative speech to conduct Conversational Analysis on the interchanges. This study suggested that robot-child interactions might be useful to elicit characteristic behaviors such as perseverative speech.

Finally, the robot can be used to elicit prosocial behaviors. Robots can provide interesting visual displays or respond to a child's behavior in the context of a therapeutic interaction. Consequently, the robot could encourage a desirable or prosocial behavior [Dautenhahn, 2003], [Feil-Seifer and Matarić, 2009]. For example, the robot's behavior could be used to elicit joint attention; first, the robot could be the object of shared attention [Dautenhahn, 2003], or the robot could provoke joint attention by looking elsewhere at an object in the same visual scene and asking the child with ASD to follow its gaze or head direction. In another study, [Ravindra et al., 2009] showed that individuals with ASD are able to follow social referencing behaviors performed by a robot. This study shows that social referencing is possible, but the results are not quantitative. Other studies [Robins et al., 2005], [François et al., 2009] have tried to elicit prosocial behavior, such as joint attention and imitation. However, the results were not robust because of the small sample size of children with ASD in these studies. Finally, several studies aimed to assess whether interaction between a child with ASD and a robot with a third interlocutor can elicit prosocial behaviors [Costa et al., 2010], [Kozima et al., 2007], [Wainer et al., 2010]. Unfortunately, no conclusion could be drawn due to their small sample sizes and the significant individual variation in the response to the robot.

3) Robots can be used to model, teach or practice a skill: Here, the theoretical point of view is to create an environment in which a robot can model specific behaviors for a child [Dautenhahn, 2003] or the child can practice specific skills with the robot (Scassellati speaks out "social crutch", [Scassellati, 2007]). The aim is to teach a skill that the child can imitate or learn and eventually transfer to interactions with humans. In this case, the robot is used to simplify and facilitate social interaction. The objective of Duquette [Duquette et al., 2008] was to explore whether a mobile robot toy could facilitate reciprocal social interaction in cases in which the robot was more predictable, attractive and simple. The exploratory experimental set-up presented two pairs of children with autism, a pair interacting with the robot and another pair interacting with the experimenter. The results showed that imitations of body movements and actions were more numerous in children interacting with humans compared to children interacting with the robot. In contrast, the two children interacting with the robot had better shared attention (eye contact and physical proximity) and were better able to mimic facial expressions than the children interacting with a human partner. [Fujimoto et al., 2011] used techniques for mimicking and evaluating human motions in real time using a therapeutic humanoid robot. Practical experiments have been performed to test the interaction of ASD children with robots and to evaluate the improvement of children's imitation skills.

4) Robots can be used to provide feedback and encouragement: Robots can also be used to provide feedback and encouragement during a skill learning intervention because individuals with ASD might prefer the use of a robot than a human as a teacher for skills. Robots can have human-like characteristics. For example, they can mimic human sounds or more complex behaviors. The social capabilities of robots could improve the behavior of individuals with ASD vis--vis the social world. The robot could also take on the role of a social mediator in social exchanges between children with ASD and partners because robots can provide feedback and encouragement [Dautenhahn, 2003]. In this approach, the robot would encourage a child with ASD to interact with an interlocutor. The robot would provide instruction for the child to interact with a human therapist and encourage the child to proceed with the interaction. However, this approach is only theoretical, as no studies have yet been conducted.

However, some attempts at using robots for rewarding behaviors have been made. [Duquette et al., 2008] used a reward in response to a robot behavior. For example, if a child was successful in imitating a behavior, the robot provided positive reinforcement by raising its arms and saying, 'Happy'. Additionally, the robot could respond to internal stimuli from the child; for example, the stimuli generally

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[2] When the child pushes one of the buttons, the robot blows bubbles while turning in place. When the child does not push one of the buttons, the robot does nothing (no bubbles, no turning).

used in biofeedback (e.g., pulse and respiratory frequency) could be used as indicators of the affective state or arousal level of the child to increase the individualized nature of the treatment [Picard, 2010]. This capability could be useful to provide children with feedback about their own emotional states or to trigger an automatic redirection response when a child becomes disinterested [Liu et al., 2008].

IV. DISCUSSION & CONCLUSION

Recent years have witnessed ICT-based approaches and methods for the therapy and education of children with ASD. Individuals with autism have lately been included as a main focus in the area of Affective Computing [Kaliouby et al., 2006]. Technologies, algorithms, interfaces and sensors that can sense emotions or express them and thereby influence the users' behavior (here individuals with ASD) have been continuously developed. Working closely with persons with ASD has led to the development of various significant methods, applications and technologies for emotion recognition and expression. Innovative wearable sensors along with algorithms for efficient recognition of human affective states are now available and applicable for individuals with ASD [Blocher K, 2002]. However, many improvements are needed to attain significant success in treating individuals with autism, which depends on practical and clinical aspects. From the practical perspective, many of the existing technologies have limited capabilities in their performance and thus limit the success in the therapeutic approach of children with ASD. This is especially significant for wearable hardware sensors that can provide feedback from the individuals with ASD during the therapeutic session. More studies must be performed to generate a reliable emotional, attentional, behavioral or other type of feedback that is essential to tailoring the special education methods to better suit people with autism. Clinically, most of the ICT proposals have not been validated outside the context of proof of concept studies. More studies should be performed to assess whether ICT architectures and devices are clinically relevant. To overcome some of the limitations of ICT proposals, social robotics have emerged in the field of autism.

Social robotics should enable more natural and physical interactions in terms of communication, emotion and social abilities. However, some authors (e.g., [Ricks and Colton, 2010]) have highlighted the anecdotal results of introducing robots into experiments or therapeutic sessions with ASD individuals. In particular, these researchers wondered why no one has yet studied the best way to integrate robots into therapy sessions. For this reason, they have remained very critical of the results obtained in the field of robotics and ASD. However, as an emerging field, there are several open questions that must be addressed to improve the research quality. What are the best roles for robots in therapy? How could we best integrate robots into interventions? Additionally, among individuals with ASD, who is best suited for this approach? These questions are some of the challenges future research will face. Taking into account the recent advances in early developmental approaches, we believe that focusing on two skills, such as imitation and joint attention, will have an important clinical impact because (1) they belong to the agenda of the intervention program with the best evidence in young children with ASD (Dawson and Rogers, 2002) and (2) both skills have already shown promising results in the field of social signal processing.

Moreover, in an other study [Boucenna et al., 2014a], we propose a new experimental paradigm by asking the question of how the robot learning reacts to different participants (adults, TD children and children with ASD). This new approach allows to analyze and to understand how cognitive models (cognitive computation) are influenced by groups of participants. We investigated posture learning through imitation between a human and a robot. Our specific aim was to assess the influence of participants on robot learning. First, the results showed that the robot could learn a task autonomously by interacting with groups of participants. The robot was able to learn, recognize and imitate many specific postures autonomously through an imitation game. Robot learning was based on a sensory-motor architecture whereby neural networks enabled the robot to associate what it did with what it saw. In this study, metrics were used to evaluate the behavior of different participants interacting with the robot. The metrics were used to assess the quality and complexity of the interaction to evaluate how the robot reacted to different groups of participants. The results showed that robot learning depended on the participants. Here, the complexity was assessed in terms of the number of neurons needed to learn. Learning this task has a "neural cost" or a "cognitive cost" for the robot, i.e., the robot needs more or less neurons. The results show that more neurons were recruited when the robot interacted with children with ASD than when the robot interacted with TD children (learning was easier with adults than with both groups of children).

The question of how to evaluate the interaction between a human and a robot (or between a human and another human) is crucial if we want to succeed in the challenges described above. To do so, we propose addressing the issues of interpersonal synchrony and multimodal integration during interactions because they appear to be key issues in applying ICT in children with ASD. One way to evaluate these interactions is to take into account the dynamics of communication, such as synchrony, which refers to individuals' temporal coordination during social interactions. Synchrony has received multidisciplinary attention because of its role in early development, language learning, and social signal processing [Delaherche et al., 2012]. Synchrony appears to be a key metric in human communication dynamics and interaction [Vinciarelli et al., 2009]. Evaluating human/robot interaction means analyzing, understanding and characterizing the communication between two partners. So far, few models have been proposed to capture mimicry in dyadic interactions. Mimicry is usually considered within the larger framework of assessing interactional synchrony, which is the coordination of movement between individuals, with respect to both the timing and form, during interpersonal communication [Bernieri et al., 1988]. The first step in computing synchrony is to extract the relevant features of the dyad's motion. Some studies [Campbell, 2008], [Ashenfelter et al., 2009], [Varni et al., 2010], [Weissman et al.,] have focused on head motion, which can convey emotion, acknowledgement or active participation in an interaction. Other studies have captured the global movements of the participants with motion energy imaging [Altmann, 2011], [Tschacher and Ramseyer, 2011] or derivatives [Delaherche and Chetouani, 2010], [Sun and Nijholt, 2011]. Then, a measure of similarity is applied between the two time series. Several studies have also used a peak-picking algorithm to estimate the time lag between partners [Ashenfelter et al., 2009], [Boker et al., 2002], [Altmann, 2011]. Authors in [Michelet et al., 2012] recently proposed an unsupervised approach to measuring immediate synchronous and asynchronous imitations between two partners. The proposed model is based on the following two steps: detection of interest points in images and evaluation of the similarity between actions. The current challenges to mimicry involve the characterization of both temporal coordination (synchrony) and content coordination (behavior matching) in a dyadic interaction [Delaherche et al., 2012].

Although a number of research issues need to be solved, we believe that the state of the art of social robotics should allow researchers, guided by multidisciplinary approaches, to develop new experimental settings that can integrate interactions between children with ASD and robots, with the aim of analyzing children's behaviors. We believe that the robotic scenario is an excellent way to elicit behaviors by interacting with the child and, in return, analyzing the child's behavior and adapting to it. In such a case, introducing robots into therapy would be of great clinical interest. From our view, creating experimental protocols and databases that contribute to the research of social signal processing for ASD, interdisciplinary approaches and teams are required. By gathering researchers from psychopathology, neuroscience, engineering and robotics, we may efficiently address some of the aforementioned challenges [Chaby et al., 2012].

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