Social Signal Processing and Socially Assistive Robotics in Developmental Disorders

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1.1 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 1.1) is a key aspect for communication and is the basis of social cognition (Carpendale and Lewis, 2004). This process helps children to understand that other people have intentions, thoughts, and emotions and act as a trigger of empathy (Decety and Jackson, 2004; Narzisi et al., 2012). 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").

1.1.1 Definitions and treatments

ASDs 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

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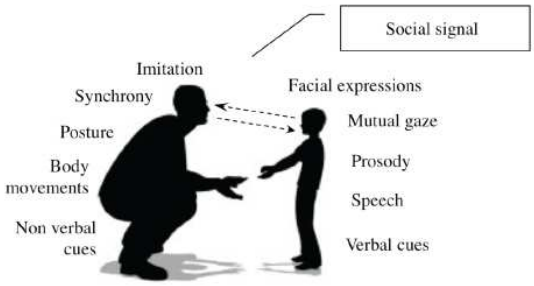

Figure 1.1 Reception and production of social signals Multimodal verbal (speech and prosody) and non-verbal cues (facial expressions, vocal expressions, mutual gaze, posture, imitation, synchrony, etc.) merge to produce social signals (Chaby et al., 2012).

social cues as well as others' behaviors and feelings. 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 while there is problematic human engagement and inability to generalize the environment (Rajendran and Mitchell, 2000). Although ASD remains 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: 1) starting as early as possible; 2) minimizing the gap between diagnosis and treatment; 3) providing no shorter than 3/4 hours of treatment each day; 4) involving the family; 5) providing six-monthly development evaluations and updating the goals of treatment; 6) choosing among behavioral/developmental treatment depending on the child's response; 7) encouraging spontaneous communication; 8) promoting the skills through play with peers; 9) gearing towards the acquisition of new skills and to their generalization and maintenance in natural contexts; and 10) supporting positive behaviors rather than tackling challenging behaviors.

1.1.2 Information Communication Technology and ASD

Towards this direction, computational models able to automatically analyze behaviors may be beneficial in ASD therapy. Over the last few years, there have been considerable advances in the research on innovative ICT (Information Communication Technology) 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).

In this chapter, we review two important domains such as Social Signal Processing (SSP) and Socially Assistive Robotics (SAR) for investigations and treatments in the area of developmental disorders. The chapter begins with a description of computational methods for measuring and analyzing the behavior of autistic children with a special focus on social interactions (section 1.2). The idea is not to investigate autism only by looking at children but also at social environment (parent, therapist). In section 1.3, we review robotics contributions applied to autism and we show that different point of views are followed by the research community. Finally, the chapter discusses a number of challenges that need to be addressed (section 1.4).

1.2 Computational methods for measuring and analyzing the behavior of autistic children during social interactions

In this section, we focus more specifically on three domains of impairments: i) language, ii) emotion and iii) interpersonal synchrony in social interactions.

1.2.1 Language impairment

Language impairment is a common feature in autism spectrum disorders that is characterized by a core pragmatic disorder, abnormal prosody and impairments regarding semantics skills (Kjelgaard and Tager-Flusberg, 2001; Tager-Flusberg, 1981). However, language functioning in ASD is variable. On one hand, there are children with ASD whose vocabulary, grammatical knowledge, pragmatics, and prosody skills are within the normal range of functioning (e.g. Asperger syndrome), while at the other hand a significant proportion of the population remains essentially non-verbal (e.g. AD with intellectual disability).

In a recent clinical work (Demouy et al., 2011), we tried to find differential language markers of pathology in autistic disorder without intellectual disability (AD), pervasive developmental disorder not otherwise specified (PDD-NOS) compared to specific language impairment (SLI) and to typically developing children (TD). Our findings suggest that expressive syntax, pragmatic skills and some intonation features could be considered as language differential markers of pathology. The AD group is the most deficient, presenting difficulties at the lexical, syntactic, pragmatic and prosodic levels; the PDD-NOS group performed better than AD in pragmatic and prosodic skills but was still impaired in lexical and syntactic skills.

In (Ringeval et al., 2011), we designed a system that automatically assesses a child's grammatical prosodic skills through an intonation contours imitation task. The key idea of the system is to propose computational modeling of prosody by employing static (k-nn) and dynamic (HMM) classifiers. The intonation recognition scores of typically developing (TD) children and language-impaired children (LIC) are compared. The results showed that all LIC have difficulties in reproducing intonation contours because they achieved significantly lower recognition scores than TD children on almost all studied intonations ($p < 0.05$). The automatic approach used in this study to assess LIC's prosodic skills confirms the clinical descriptions of the subjects' communication impairments (Demouy et al., 2011). Combined with traditional clinical evaluations, the results also suggest that expressive syntax, pragmatic skills and some intonation features could be considered as language differential markers of pathology (e.g. LIC vs. ASD), but also within LIC (e.g. AD vs. PDD-NOS vs. SLI).

1.2.2 Emotion

Interpersonal communication involves the processing of multimodal emotional cues, which could be perceived and expressed through visual, auditory and bodily modalities. Autism spectrum disorder is characterized by problems in recognizing emotions that affect day-to-day life (Chamak et al., 2008). Research into emotion recognition abilities in ASD has been limited by over-focus to the visual modality, specifically the recognition of facial expressions. In addition, emotion production remains a neglected area. However, understanding emotional states in real life involves identifying, interpreting and producing a variety of cues that include non-verbal vocalizations (e.g. laughter, crying), speech prosody, body movements and posture. In a preliminary work (Vannetzel et al., 2011), we recently have studied neutral and emotional (facial, vocal) emotional processing in children with pervasive developmental disorder not otherwise specified (PDD-NOS) that represents around two-thirds of autism spectrum disorders. Our results suggest that children with PDD-NOS present global emotional human stimuli processing difficulties (in both facial and vocal conditions), which dramatically contrast with their ability to process neutral human stimuli. However impairments in emotional processing are partially compensated using multimodal processing. Nevertheless, it is still not yet clear how children with ASD perceive and produce multimodal emotion in particular in function of ASD subtypes (i.e., autism, PDD-NOS, high functioning autism, etc.) and stimulus domains (e.g. visual, auditory, etc.).

Emotions play an important role on infant's development. Specifically motherese (Saint-georges et al., 2013; Mahdhaoui et al., 2011), also known as infant-directed speech (IDS), is a typical social emotion: produced by the mother towards the infant. We recently reviewed the role of motherese in interaction (Saint-georges et al., 2013) in various dimensions and among them: language acquisition and infants' attention and learning. Two observations were notable: (1) IDS prosody reflects emotional charges and meets infants' preferences, and (2) mother-infant contingency and synchrony are crucial for IDS production and prolongation. Thus, IDS is part of an interactive loop that may play an important role in infants' cognitive and social development. In (Cohen et al., 2013), we investigated this interactive loop for the development of both typical and autistic infants. We found that parentese was significantly associated with infant responses to parental vocalizations involving orientation towards other people and with infant receptive behaviours; that parents of infants developing autism displayed more intense solicitations that were rich in parentese; that fathers of infants developing autism spoke to their infants more than fathers of TD infants; and that fathers' vocalizations were significantly associated with intersubjective responses and active behaviours in infants who subsequently developed autism.

1.2.3 Interpersonal synchrony

Synchrony in social interaction is a complex phenomenon that requires the perception and production of social and communicative signals (speech, linguistic cues, prosody, emotion, gesture, etc.) and also a continuous adaptation to other. In adulthood, interactional synchrony has been shown to act as a facilitator to high quality interpersonal relationships and smooth social interactions (Kendon, 1970). The role of synchrony during child development is not well known, but seems to provide the children a secure base from which they can explore their environment, regulate their affective states, and develop language and cognitive skills (Delaherche et al., 2012). In addition, synchrony appears to be a key metric in human communication dynamics and interaction (Vinciarelli et al., 2009) that can be employed to assess children (Delaherche et al., 2013; Segalin et al., 2013) or either detect early signs of disorders (Saint-Georges et al., 2011).

Currently, 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; Weisman et al., 2013) 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; Ramseyer and Tschacher, 2011) or derivatives (Delaherche and Chetouani, 2010; Sun et al., 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). (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).

1.3 Robotics and 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 for a number of decades (Papert, 1980). We will specifically focus on robotics and children with ASD according to what is expected from the robotic systems 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, 2007; Carpenter et al., 1998; Tomasello and Farrar, 1986) and core deficit in ASD (Dawson et al., 2009). To address these abilities from the point of view of both developmental psychology and social signal processing, 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.

1.3.1 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 two reviews of the literature have been conducted recently (Scassellati et al., 2012; Diehl 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., 2012) 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.

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. (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 authors (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.

(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 motion. (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 two 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. (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.

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. 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.

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 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.

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-à-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 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).

1.4 Conclusions and main challenges

In this chapter, we reported works on Social Signal Processing and Socially Assistive Robotics in developmental disorders. Through this lecture, we identify several issues that should be addressed by researchers in these research domains.

The first issue, and surely the most important for the general public and families, relates to the treatments of pathologies. 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 the 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. 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, devices or either robots are clinically relevant over long periods of time.

The second issue is related to machine understanding of typical and autistic behaviors. Indeed, being able to provide insights on underlying mechanisms of social situations will be of great benefit for various domains including psychology, social science... In (Segalin et al., 2013), an interesting feature selection framework is employed to identify features relevant for the characterization of children pragmatics skills. This framework not only allows to propose automatic assessment but also makes it possible to identify micro-behaviors difficult to perceive by psychologists. In addition, computational models can explicitly take into account interaction during processing and modeling as in (Delaherche et al., 2013) for coordination assessment. In this particular case, it has been found a paradigm shift effect: it was possible to predict the diagnostic and developmental age of children given only the behaviors of therapists. Social signal processing is a promising tool for the study of communication and interaction in children with ASD if it will propose models that can be after interpreted and shared with non-experts of the field (Weisman et al., 2013; Pantic et al., 2006). In Boucenna et al. (2014), we have shown that Socially Aware Robotics combined with machine learning techniques could provide useful insights on how children with ASD perform motor imitation. Metrics provided by these computational approaches are of great help in clinical investigations.

The third issue is related to databases since very few databases are publicly available for research due to obvious ethical reasons. The USC CARE Corpus was recently proposed to study children with autism in spontaneous and standardized interactions and develop analytical tools to enhance the manual rating tools of psychologists (Black et al., 2011). In (Rehg et al., 2013), a corpus of children interacting with parent and therapist is introduced. The focus of this work is to promote behavior imaging, which can be easily related to SSP (Pentland et al., 2009). The research community should also promote challenges dedicated to impaired situations (Schuller et al., 2013).

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