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How children with autism spectrum disorder behave and explore the 4-dimensional (spatial 3D + time) environment during a joint attention induction task with a robot

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ABSTRACT

We aimed to compare, during a joint attention (JA) elicitation task, how children with autism spectrum disorder (ASD) and children with typical development (TD) behave and explore their 4 dimensional (meaning spatial 3D + time) when interacting with a human or with a robotic agent.

We built a system that employed a Nao robot and a perception system based on a RGB-D sensor (Kinect) to capture social engagement cues. A JA induction experiment was performed in which children with ASD ($N = 16$) and matched TD children ($N = 16$) had a 3-min interaction with the robot or with a therapist. Nao induced JA by gazing; by gazing and pointing; and by gazing, pointing and vocalizing at pictures. Both groups of children performed well with the therapist. However, with Nao, both groups had lower JA scores, and the children with ASD had a significantly lower score than the TD children. We found that (i) multimodal JA induction was more efficient in both groups; (ii) the 3D spatial world gaze exploration showed less accuracy; and (iii) the trunk position in ASD showed less stability in the 4 dimensions compared to TD controls.

We conclude that, in ASD, JA skill depends on the interaction partner, and implies a higher motor and cognitive cost.

1. Introduction

The purposes of the work presented in this paper is: (1) to compute a robotic platform able to elicit joint attention (JA) during an interaction task; (2) to compare, during the JA elicitation task, how children with autism spectrum disorder (ASD) and children with typical development (TD) behave when interacting with a human or with a robotic agent; and (3) to assess

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how children with ASD explored their 4 dimensional (meaning spatial 3D + time) environment compared to children with TD.

1.1. ASD and JA

ASD is a developmental syndrome that implies impaired social interaction, communication and language as well as stereotyped and/or restricted behaviors. Despite evidence that some symptoms of ASD are present early in life (Guinchat et al., 2012; Saint-Georges et al., 2011), autism diagnosis is generally made between 3 and 5 years of age (Saint-Georges et al., 2013; Cohen, 2012). Achieving efficient interaction between humans and autistic children is a difficult task for their families as well as for well-trained therapists (e.g. Saint-Georges et al., 2011; Cohen et al., 2013). Although ASD remains a devastating disorder with a poor outcome in adult life (Roux et al., 2013; Howlin, Moss, Savage, & Rutter, 2013), there have been important improvements in the condition with the development of various therapeutic approaches. The literature on interventions in ASD has become quite extensive, with increasing convergence between behavioral and developmental methods (Matson et al., 2012; Ospina et al., 2008). The focus of early intervention is directed toward the development of skills that are considered to be "pivotal", such as JA and imitation as well as communication, symbolic play, cognitive abilities, sharing emotions and regulation (Toth, Munson, Meltzoff, & Dawson, 2006) (e.g. the Early Start Denver Model; Rogers & Dawson, 2009). One of the main problems when interacting with children with ASD is their deficit of social interaction. While playing a game or conducting other activities with a social partner, these children tend to not concentrate on what they are actually doing, switching to other, repetitive, stereotypical behaviors that are of interest to them but that usually have no or few relations with the actual social context. In other words, children with ASD can display concerted attention to toys or objects that they like, but they have difficulties in sharing attention or interests with others (Rogers & Dawson, 2009). For example, maintaining eye contact with the caregiver is especially complicated (Maestro et al., 2005; Saint-Georges et al., 2010). Specifically, they lack JA, which is a key element of social cognition. JA teaches us much about social relationships, and it is a critical precursor of theory of mind (Premack & Woodruff, 1978) and language acquisition (Dominey & Dodane, 2004). Emery defined JA as a triadic interaction that showed that both agents focus on a single object (Emery, 2000). Agent 1 detects that the gaze of agent 2 is not directed at him/her and, therefore, follows the direction of the gaze to look at the "object" of attention of agent 2. This definition highlights a unidirectional process, unlike shared attention, which appears to be a coupling between mutual attention and JA. In shared attention, the attention of both agents concerns not only the object but the other agent as well ("I know that you are looking at the object, and you know that I am looking at the object"). Some authors (e.g., Tomasello, 1995) have argued that JA implies viewing the behavior of other agents as intentionally driven. In that sense, JA is much more than gaze following or simultaneous looking. By 12 months of age, TD infants display all aspects of JA (Carpenter, Nagell, & Tomasello, 1998).

In children with ASD, JA has been studied mainly by the annotation of video-recorded interaction: in a natural context (e.g., home movies, Saint-Georges et al., 2010) or in a laboratory context that uses JA induction during interactive play (e.g., early social communication scales, (Mundy et al., 2003). Children with ASD showed impairment in social orienting compared to children with intellectual disability (ID) and with TD (e.g., Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998). They also showed impairment in sharing and proto-imperative JA (such as requesting) (Sigman, Mundy, Sherman, & Ungerer, 1986). Additionally, JA abilities at preschool ages predict language ability at the age of four years (Toth et al., 2006). In more recent years, social attention was explored using more sophisticated methods, including Information Communication Technology (ICT): 2-year-old toddlers with ASD showed the absence of preferential looking into the eyes of approaching adults, which predicted the level of social disability (Jones, Carr, & Klin, 2008), and there was a limited attention bias for faces (Chawarska, Volkmar, & Klin, 2010). Additionally, Klin, Lin, Gorrindo, Ramsay, and Jones (2009) showed that toddlers with ASD preferentially oriented visually to non-social contingencies rather than to biological motion.

1.2. ASD and robotics

ICT-based approaches and methods have been 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., Crittendon, Murdock, & Ganz, 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., Lanyi & Tilinger, 2004). Nonetheless, much has yet to be improved to attain significant success in treating individuals with ASD. From a 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 (Boucenna et al., 2014a). 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, Schmitt, Villano, & Crowell, 2012; Kozima, Michalowski, & Nakagawa, 2009; Welch, Lahiri, Warren, & Sarkar, 2010). Social robots are used to communicate, display and recognize the "emotion" and develop social competencies and maintain social relationships (Fong, Nourbakhsh, & Dautenhahn, 2003).

In recent years an increasing number of studies have focused on the use of robots with individuals who have ASD (Diehl et al., 2012; Scassellati, Admoni, & Mataric, 2012). These studies involve the robots mainly in two roles of intervention: