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A PROPOSAL TO ACT ON THEORY OF MIND BY APPLYING ROBOTICS AND VIRTUAL WORLDS WITH CHILDREN WITH ASD

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The article proposes an intervention framed under a single-subject research design where robotics and a 3D virtual environment are used jointly to improve the development of Theory of Mind in children with ASD. The project aims at verifying if the use of a humanoid robot, with high interactive abilities and responses, along with a virtual robot in a social virtual world can enable an improved comprehension of emotions and perspective taking. Specifically the planned activities are designed to gradually support the subjects with ASD in interactional settings in order to make them acquire the needed self-confidence to finally interact with a classmate in the virtual environment.

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1 Introduction

In the present article, the authors describe the theoretical framework and the research design of a developing project. This project has the aim to verify if applying robotics together with virtual reality could improve the cognitive and emotional empathic ability and the cognitive flexibility of children with ASD, acting on the defective aspects of the Theory of Mind (ToM).

The authors believe that the development of an intervention, that includes gradual work sessions (both in complexity and level of abstraction), can first help children with ASD acquire and put into practice social abilities in specific and concrete contexts (use of robotics and social stories) and, then, transfer and use the same abilities in different contexts and with different perspectives (use of the 3D virtual world and social stories).

The literature analysis, reported in the present contribution, has guided the authors with useful suggestions for the application of robotics, social stories and virtual worlds in the development of social abilities in children with ASD.

Working with an interactive humanoid robot (adaptable to different complexity levels, depending on the most frequent requests and social responses, and highly predictable in its behaviours), enables to act in practice on: emotional states; comprehension of believes; imitative ability of the child and antecedents of the ToM, lacking on children with ASD (eye contact, shared attention; intentional proto-declarative communication; make-believe games).

The creation of interactive social stories (common work modality with children with ASD) will be the connection line between the interaction of the child, firstly with the physical robot, and then with the virtual robot to reach a final higher level of complexity and generalization in which the interaction takes place with peers as well. As it will be described, in the next paragraphs, the child will experience different perspectives: from being an external viewer of a scene in contexts where both the physical and the virtual robot are, in turn, the main actors, to reach the role of an active participant together with the robot and, finally, to participate in social stories with the robot and other children.

In addition, the virtual environment lets you create different scenes in which children can experience the same social ability (e.g. park, home, school, etc.) and promotes the development of hypothetical events that can act on different representations (dreams, belief, etc.), that are not necessarily linked with real external events, but that can make them more understandable. The flexible/adaptive virtual environment can satisfy the gradual needs of children with ASD in relation to the sensory stimulation and the amount of details to be provided.

Those children, in fact, need predictability, a low level of information to work with, simple emotional reactions, time to adapt to a new situation, as supported by the ethological paradigm (Tinbergen & Tinbergen, 1983).

In the virtual environment it is possible to create a starting situation, which can be gradually modified and made more complex soliciting a higher cognitive flexibility (Ozonoff, 1995), linked with the ability of socially acting in an adequate way. It is then possible to go back to the tangible/physical context, where the child is requested to transfer in the real world, with a peer or a restricted groups of children, the social and emotional behaviours that he has just learnt, through the interaction with the robot and then with the peers.

The above mentioned aspects justify the choice of implementing a research in which the use of robotics, virtual worlds and social stories is aimed at fostering the acquisition of ToM in children with ASD.

2 Background

International literature highlights how children with ASD present an irregular development of the ToM that makes it impossible for them to understand how other people can know, want and believe something (Baron-Cohen *et.al.*, 1985). This is a metarepresentational deficit, which determines difficulties in communication and in social behaviour, and that is usually seen as an affective problem (Hobson, 1990). That deficit is a consequence of not understanding behaviours in terms of "internal states" on a cognitive level (Baron-Cohen, 1995; Leslie, 1991).

This difficulty has repercussions on the possibility of reaching an adequate empathic ability on both its cognitive and emotional meaning. The cognitive level involves having a conceptual point of view (Shantz, 1983), recognizing someone else's thoughts and emotions; the emotional level determines the impulse of enacting an appropriate emotional reaction to the state on the other person (Davis, 1994), with consequences in the building of adequate social interactions.

As underlined by Happé (1997), the development of social rules themselves, when it happens only on an external level, it is not enough to direct the behaviour in an adequate way, as this requires the ability to interpret thoughts and affective-emotional states of others.

Some studies (Ozonoff *et.al.,* 1991; Ozonoff, 1995) also show difficulties in relation to Executive Function (EF) linked to the voluntary control of cognitive and motor behaviour (Job, 1998), needed to enable the highest behaviour flexibility possible and the interruption and correction of already started actions. Ozonoff (1995) correctly highlighted how behaviour in people with ASD looks rigid, inflexible, stereotyped, with a prevalent difficulty in postponing or inhibiting reactions.

In a 2012 study Oswald showed how the development of the ToM (mindreading, mentalization) in its cognitive and emotional meaning depends on FE, which is a set of cognitive abilities that enable the individual to control and regulate behaviour in reaching goals (Best *et.al.,* 2009). According to Oswald there are two fundamental domains in FE, which act in emergency and in ToM expression: inhibitory control, meaning the need to inhibit your personal perspective when you consider the one of other people; working memory (WM), because of the need to keep at the same time your own perspective and the one of others.

Starting with the detection of those difficulties, recent research (Ansuini *et al*., 2015; Cavallo *et al.,* 2016; Javed *et.al.*, 2019, Lytridis *et.al.*, 2019, Parsons *et.al*., 2002; Pennazio, 2015; 2017; Robins *et al.,* 2005, Robins, *et al.,* 2009; Scassellati *et.al.,* 2018) showed the importance of using robotics and virtual worlds in sustaining the improvements of socio-affective abilities in people with ASD.

2.1 Robotics and ASD

Recent studies demonstrated the usefulness of the application of robotics in the development of insufficient abilities connected to ASD. Such studies confirmed how social robots can open a communication channel (with children with ASD) by directing the attention (ocular contact) and by activating new social behaviours (Boucenna *et.al.,* 2014; Costa *et. al*., 2014; Diehl *et.al.*, 2012; Lytridis *et. al.,* 2019; Robins, 2005; 2009; Pennazio, 2019; Scassellati *et. al.,* 2018)

Robots, thanks to their certainty, emotional and interactive (adjustable) clarity, can be used to help children with ASD to learn social, emotional and imitative abilities, transferring those competencies in the interactions with human partners (Esteban *et.al.,* 2017; Kumazaki *et.al,* 2017; Short *et.al.,* 2017, Tapus *et.al.,* 2007). In some studies (Cunha Costa, 2014), the use of a robotic platform is meant by researchers as an attempt to shorten the distance between the stable and predictable environment of a simple toy and the complex and unpredictable world of communication and human interaction.

Experimental data highlighted how for children with autism is easier to “approach” and “interact with” a “peer-robot” (Pennazio, 2019). In fact the human interlocutor may have impredictable answers and behaviours while the robot can be programmed according to the children needs. In this way predictable and reassuring interaction scenes can be created (they don’t activate the anxiety connected to what the child doesn’t know) (Robins *et.al.,* 2005). Human social behaviour is, in fact, unpredictable and it can be seen as frightening by children with ASD; on the other side, the use of a robot offers a simplified environment that can support a gradual improvement in the complexity of the interaction, depending on the needs and the abilities of the single child.

Positive results were obtained with the use of robots on the following aspects:

- "The social acceptability" meant as the availability of the child with ASD to interact first with the robotic mediator and then with the human interlocutor (De Graaf *et. al.,* 2013; Dunst *et.al*., 2013);
- Learning "motor skills by imitation" that is the reproduction by the child of actions and behaviours done by the robot with communication objectives (Ansuini *et.al*, 2015; Cavallo *et.al.,* 2016; Duquette *et. al*., 2008);
- Maintaining joint attention (Robins *et.al.,* 2005), that is, the ability to keep the eye contact on the same object observed by more people" (Pennazio, 2019).

Such aspects are relevant since they represent some precursors of ToM.

In such studies the robot wasn't meant as a replacement of the human being (Lytridis *et.al.,* 2019), but a social mediator that is located between the child and either the adult or the peer (Cabibihan *et.al.,* 2013; Ferrari *et.al.,* 2009; Lee *et.al.,* 2012) and that covers the distance that generally lies between the predictable, safe and stable world (suitable for the child with ASD) and the complex and unpredictable world of the human communication and interaction (Costa *et.al*., 2014; Dautenhahn *et.al.,* 2004).

The robots used in such studies can be of various types: four-wheeled mobile (Dautenhahn *et.al.,* 2004), anthropomorphic puppets or dolls (Kozima *et.al.,* 2009), animal looking (Stanton *et. al*., 2008), humanoids (Robin *et al*., 2009). The choice of robotic support on the basis of specific characteristics becomes fundamental especially when working with children with ASD. Of course, using robots that do not resemble human looks can cause interesting interactions that stimulate creativity, avoiding the Uncanny Valley effect (Bartneck *et.al.,* 2007).

However, in children with ASD, humanoid robots with high interactive abilities and responses can enable a higher chance of generalization and a higher possibility of recognising and imitating emotions. For this reason the present article describes a research design with the support of the NAO robot.

Many of the studies run in the last years tried to face the deficits of the socio-emotional reciprocity, common in ASD, by acting mainly on single precursors of ToM: ocular contact, imitation, symbolic play, human interaction. A smaller number of investigations researched in a specific way the overall development of ToM, that is the ability of "mentalizing" (of considering the other's behaviour as a result of mental states similar to own, recognizing their existence and regulate own behavior according to them) by associating, for example, the robotics to the creation of social stories (Costa *et.al.,* 2014; Vanderborght, 2012) and to virtual worlds (Pennazio, 2019; Pennazio & Fedeli, 2019)

The proposal here presented is in line with the scientific evidences that demonstrated how the activity with an interactive humanoid robot makes it possible to act on emotional states (recognizing the emotions and the casual factors that determine them) (Costa *et.al.,* 2014; Barakova *et.al.,* 2010), on the comprehension of beliefs (what other people think and believe) and on the development of conceptual perspectives different from own perspectives (any element changes in its meaning if observed from different perspectives).

Moreover the small number of specific studies on transferability of acquired interaction abilities by the person with ASD (Tapus et.al., 2007) from the activity with robots to the human interlocutors is an additional input for the development of the present proposal. This is a relevant aspect for the chance to be properly able to participate in a social context. The learning output acquired in a situation that was specifically created with a robotic mediator is not per se significant; it becomes meaningful when it can be replicated in a real context with human interlocutor (Pennazio, 2019).

2.2 Virtual worlds and ASD

With the phrase "virtual world" we refer, here, to multi-user virtual environments (MUVE) that can be accessed by a computer with a dedicated viewer and in which the communication and the interaction among involved actors occur through an avatar, a graphical 3D representation of the user.

Avatars can be either anthropomorphic or represent non-human characters. In such online environments avatars have, mostly in socially oriented worlds, a strong power of action in the management of their movement in the space and in the creation of artefacts (from whole building to simple objects).

Users can be freely socially engaged in real time with avatars of different "shapes" and characteristics (e.g. human/robot; adult/child; male/female, etc.). Metaphor-free worlds shows a flexibility that can productively be used for users with different disabilities and for educational purposes; the deep immersion, thanks to the embodiment of the user (Fedeli, 2016), makes those environments a precious teaching/learning opportunity for both formal and informal context (Universities, schools, but also no profit organization and associations) as shown by a rich literature in the field (Fedeli, 2013; Gregory, Lee, Dalgarno & Tynan, 2016; Schlemmer & Backes, 2015).

One of the direct affordances of some worlds like edMondo (http://edmondo.indire.it/) is the presence, in the viewer interface, of a tool that lets you change point of view (POV) on the world, a camera control with preset views (front, rear, mouselook): you can focus the attention on a specific target and manage the perspective with which you need to look at the surrounding space for some reason (e.g. if you need your student with ASD slowly familiarize with the environment you can make him take a "mouselook view", that is, a subjective view in which he moves in the space without seeing himself or just seeing his feet when looking down and, later, let him take a rear/front view with a complete visualization of his avatar).

An interesting aspect to be investigated, connected to POV, is the development of the empathetic dimension (Fedeli, 2014) where the virtual world affordances play a relevant role in terms of self and other perception.

Specific projects with adults with ASD were developed (Stendal & Balandin, 2015), but young school students with disabilities seems an age range less explored in the virtual worlds that can be justified with the age barrier to register set by some virtual worlds (e.g. Second Life) or the safety requirements schools need and that cannot be satisfied by virtual environments with massive open access.

Researches in the field of special education in virtual worlds are encouraged by the level of immersion and embodiment of the users through the avatar:

"VCs [stand for Virtual Characters] have the advantage of realistic behavior capabilities on the one hand, and systematic manipulability on the other, hence allowing the simultaneous increase of both experimental control and ecological validity" (Georgescu, Kuzmanovic, Roth, Bente & Vogeley 2014).

The use of virtual characters were object of investigation also in terms of "mimicry" where participants with ASD showed to copy "the kinematics of the avatars' movements, despite being instructed only to copy the goal of the observed action" (Forbes, Pan, & Hamilton, 2016), this makes the interaction in the virtual world as real as the interaction in the natural setting and since mimicry is relevant in everyday social interactions (Chartrand & van Baaren, 2009) individual with ASD can successfully be involved in controlled interaction in the virtual world in order to develop a so called "social resonance", an interpersonal coordination (behaviour, belief, attitude) (Kopp, 2010).

In order to be able to use virtual worlds with children with disabilities it's necessary that all the staff involved (researchers/educators/teachers) provide a safe environment in terms of privacy and wellbeing and this is possible when: (1) the virtual environment interface is usable by the individual with specific disabilities (motor and/or cognitive); (2) the access to the interaction space is limited to people involved in the research/education actions; (3) the staff is aware of the downsides of such technology on a practical/technical level and able to predict them in order to avoid uncomfortable events for the child. For all this reason edMondo was selected as virtual world to be used in the research described in the following paragraphs.

Moreover the review by Parsons & Mitchell (2002) highlights, among the characteristics/affordances that a virtual environment should present in order to be used for the teaching/learning process of social comprehension with people with ASD, the possibility to act within realistic scenes where the same behaviour can be easily replicated in different contexts (home, school, etc.). But the application of such technology still remains a challenge for the school context, in fact "Whilst there has been some progress in testing the relevance and applicability of VR for children on the autism spectrum in educational contexts, there remains a significant challenge in developing robust and usable technologies that can really make a difference in real world classrooms" (Parsons & Cobb, 2011, p. 355).

3 Research design

The study is framed under a single-subject research design (Horner *et al.*, 2005) also referred to as Single-Case Experimental Designs (SCED) as a widely used in the educational setting (Kazdin, 2010).

The research implies a nonconcurrent multiple baseline method, that is, the researchers planned to implement the intervention to different participants in different time frames.

The structure of the process to be followed in the forthcoming experimentation is designed to be addressed separately to 9-year-old male pupils with similar profiles: having attended regularly school in Italy since pre-school with the support of special needs teachers; being diagnosed with high function autism (HFA); show cognitive and language deficits that could not preclude the use of different strategies and technological equipment.

The participation of pupils occurs after having discussed its effectiveness and appropriateness with all involved actors (teachers, parents, etc.) and information about the school history will be relevant to modulate the actions and the project objectives to the specific needs. The data on the pupils' profiles are necessary to test if such technological mediators (real and virtual robots) can jointly support the development of perspective taking and social interaction that can represent a barrier for the active involvement of children with ASD in the school community.

The participant's emotional development will be initially measured through a validated tool, the Italian version of the Test of Emotion comprehension (TEC) (Albanese & Molina, 2013; Pons & Harris, 2000), the same tool will be used during the experimentation steps.

Since pupils with different levels of abilities, like the emotion understanding, can react to the same inputs differently (Sherer & Schreibman, 2005) an early assessment can better help demonstrate the social validity of the intervention in the direction of a generalizability of the results across various participants.

The TEC is organized around 9 components: (1) recognition (labelling), (2) Understanding of external causes of emotions, (3) relationship between desire and emotion; (4) distinguish between own's knowledge and other's knowledge (5) the relationship between memory and emotions, (6) regulation (7) hidden emotions, (8) Understanding of mixed emotions, (9) emotional dimension of moral decisions. The component 7, 8 and 9 will not be applied in consideration of the age and cognitive abilities of the participants. The proposed components can be, in fact, categorized into three developmental phases and 7-9 components pertain to an age 8+. It's necessary, then, to consider the individual differences in the comprehension of the emotions, at affective and cognitive level.

The independent variables through which the 1-6 behaviours will be measured with TEC are:

- the use of an interactive robot in presence: the humanoid multifunctional robot NAO developed by Aldebaran Robotics and equipped with tools that let it develop social aspects of communication;
- the use of an interactive robot avatar at a distance: the social multi-user virtual environment "edMondo", the Italian open sim world developed by INDIRE (National Institute Documentation, Innovation, Educational Research) for educational purposes and only accessed by teachers and their students.

The robot NAO is internationally known in the field of robotics and we will, here, focus on the use of the virtual robot. The use of the virtual world has a twofold objective in the approach to emotions and perspective taking.

The environment can, in fact, be used to record social stories with the support of the participants' peers who will interact with the robot avatar (animated by one of the researcher) through their own child avatars, and finally involve the participant himself in the interaction with the robot avatar and, possibly, with peers' avatars within the virtual environment in real time.

In order to make the presence and the social interaction in the environment significant three settings were built: a school building, a home building and a park.

All settings are equipped with the related furniture and objects useful to make social stories like a birthday setting in the house living room with simple target objects (e.g. gifts) that can facilitate the implementation of a script (to give and receive a present with the related emotions to be codified and tested as component 2 of the TEC, "understanding of external causes of emotions").

Social stories (Gray & Garrand, 1993) are a well known strategy in literature to facilitate social skill development with children with ASD, so the video-modeling in all its different connotations (McCoy & Hermansen, 2007) and the recorded session in the virtual world follow paradigms widely accepted in the field and connected to the basic emotion: happiness, sadness, anger and fear.

In terms of primary quality indicators the data for each of the six TEC components will be collected three times during each intervention phase (baseline) (Horner *et al*., 2005).

The use of the technological devices implies an expertise that cannot be easily transferred to school teachers, but since the social validity of the project relies also on its transferability the researchers involved will have a training sessions with teachers and all students to describe the technology used and their use for the objectives of the project.

The research hypothesis are the following:

- Being the ToM deficit in children with ASD a major issue in the development of social interactions and recognition of others as emotional agents the researchers expect that an integration of mediators (humanoid robot, virtual robot and recorded virtual social stories) that offer an immersion in the interaction and, at the same time, a distancing posture could activate joint attention skills and improve the social interaction;
- Being the use of robotics with children with ASD widely discussed in the literature with positive results connected to the mediation of the robot in the social communication the researchers expect that a further additional mediation process between the use of robots and humans, represented by a robot avatar interacting at a distance through a computer interface, can improve emotion comprehension and perspective taking due to the embodiment affordance of the virtual world and the chance to use POVs;
- Being the use of virtual characters productive (Georgescu *et al.,* 2014; Vogeley & Bente, 2010) the researchers expect that the social communication that can occur with the support of the robot avatar, able to express itself orally, through written text and through extralinguistic codes (movement in the space, posture, gestures and facial expressions, use of objects), can offer a more flexible and adaptive learning environment to the pupils' needs.

4 Structure of the planned activities

In the current section, the structure of the plan of action is presented (Table 1). The different modules (5) are briefly described in order of complexity specifying where the use of robot NAO and the virtual world EdMondo are included.

Every module is divided into different activities of growing difficulties, which are considered as met in the moment when the child can execute the activity requests with a number of maximum mistakes allowed by the project plan.

Module 1 is an introduction and, other than enabling the development of the affective relationship between the child with ASD and the mediator (robot), it helps to work on ToM precursors: attention, eye contact, sustaining eye contact on a moving object. Modules 2 and 3 are more focused on the development of cognitive dimension of empathy; while modules 4 is oriented to the development of the emotional dimension of empathy. Module 5 is oriented to showing the child with ASD how to obtain the ability to adequately and immediately respond to different emotional situations, with different partners, generalizing then this ability in a tangible/physical context.

Specifically, activities in module 2, 3 and 4 follow the division suggested by Howlin and colleagues (1999), with the addition of a level focused on the robot and the virtual environment and a reflection on emotional states and the possibility of acting on them. In the first modules the child with ASD uses the virtual world as a viewer of social stories that have as participants the robot and, inside the virtual world, classmates of the child. In the last modules the child with ASD directly acts in the virtual world having the chance to interact with the environment, the virtual robot and the virtual peer.

The adults (teacher/s, researchers) are involved as facilitators during the activity. At the beginning and at the end of the intervention TEC is administered while during the process, in each step of each module, it will be used: (1) an observation grid to assess, for example, the changes in eye contact and the shift of interactions model to the human interlocutor following the indicators present in Robins *et al.* (2005; 2009; 2014); (2) an observation grid to monitor the quantity and kind of prompts given by the human interlocutor to the children and built according to the 7 steps by Vanderborgbt and colleagues (2012).

Table 1
PLAN OF THE ACTIVITIES

Module	Aims	Descriptions	Instruments
Module 1 Prerequisites	Creation of a relation with the robot; maintaining attention and eye contact	Free interactions between the child and the robot (presentation, short requests from the robot, imitation)	Robot NAO
Module 2 Emotions	Recognizing emotions	Structured interaction between the child and the robot, in which they work on recognizing emotional states in the robot.	Robot NAO

Module 3 Causes of emotions	Recognizing causes of emotions	Structured interaction between the child and the robot, in which they work on recognizing emotional states in videos, and in the robot; on the causes that determine an emotion (situations, desires, opinions).	Robot NAO Virtual world edMondo (the child watch social stories that were recorded in the virtual environment)
Module 4 Beliefs	Understanding how other people can perceive, know and believe in relation to specific situations.	Structured interaction between the child and the robot in which they work on: simple visual perspective (people can see different things depending on their positions); complex visual perspective (the same object can appear different to people in different positions), being aware means knowledge; making previsions based on a belief; influence of false beliefs in reality perception	Robot NAO Virtual world edMondo (the child watch social stories that were recorded in the virtual environment with different POVs)
Module 5 Me, protagonist	Ability to generalize learnt content	Social stories that directly involve the child with ASD interacting with the virtual robot and resuming content of modules 3, 4.	Robot NAO Virtual world edMondo (the child access the world and interact in real time with the virtual peer)

Conclusions

Children with ASD show a partial development of ToM, that is the comprehension of mental states and their attribution to people and objects (e.g. in symbolic play). The ToM deficit can explain the anomalies in social relations due not only to the lack of communication skills, but to the difficulty in conceptualizing the emotional states of others.

The proposed plan of research aims at investigating how the affordances of robotics and virtual worlds can affect the emotion understanding (identify, hypothesize, explain) by using different mediators (Damiano, 2016) (NAO/active; virtual environment/iconic; social stories/analogic).

The chosen approach leverages the potential of robots, which can be effectively used to activate communication and increase responses in children with ASD, and add a further step by introducing a virtual robot.

The studies on embodiment in social virtual worlds make it consistent the use of such mediator, but the results in the child's engagement in the virtual interaction need to be analysed taking into account several aspects: the child's confidence with the technological devices (in this case the pc and the mouse control); the connection between the POV feature and the level of immersion in the virtual environment and consequent involvement in the action; the relationship between the graphical representation (avatar) and the child's perception of embodiment (of himself and his classmate). By using an integrated approach from active and analogic mediators to iconic/representational ones it would be possible to test the attitude of the child in conceptualizing the others as emotional agents in their different occurrences, the humanoid robot and the further virtual interaction through avatars could, in fact, represent an highly adaptive method to simulate social stories that engage the child on a cognitive and emotional level.

Endnote

The article is the result of a common vision among the authors with the following responsibilities: Valentina Pennazio is the author of paragraphs: 1; 2; 2.1; 4; Laura Fedeli is the author of the paragraphs: 2.2; 3; 5.

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