REVIEW ARTICLE

Autism and Social Robotics: A Systematic Review

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Social robotics could be a promising method for Autism Spectrum Disorders (ASD) treatment. The aim of this article is to carry out a systematic literature review of the studies on this topic that were published in the last 10 years. We tried to address the following questions: *can social robots be a useful tool in autism therapy?* We followed the PRISMA guidelines, and the protocol was registered within PROSPERO database (CRD42015016158). We found many positive implications in the use of social robots in therapy as for example: ASD subjects often performed better with a robot partner rather than a human partner; sometimes, ASD patients had, toward robots, behaviors that TD patients had toward human agents; ASDs had a lot of social behaviors toward robots; during robotic sessions, ASDs showed reduced repetitive and stereotyped behaviors and, social robots manage to improve spontaneous language during therapy sessions. Therefore, robots provide therapists and researchers a means to connect with autistic subjects in an easier way, but studies in this area are still insufficient. It is necessary to clarify whether sex, intelligence quotient, and age of participants affect the outcome of therapy and whether any beneficial effects only occur during the robotic session or if they are still observable outside the clinical/experimental context. ***Autism Res** 2016, 9: 165–183*. © 2015 International Society for Autism Research, Wiley Periodicals, Inc.

Keywords: autism spectrum disorder; social robotics; autism therapy; humanoid robots; autism diagnosis

Introduction

Autism Spectrum Disorders (ASD) are neurodevelopmental conditions characterized by persistent significant impairment in the social-communication domain along with restricted, repetitive patterns of behavior, interests and activities [American Psychiatric Association, 2013, p. 50]. ASD clinical features typically arise in the early developmental period, and can be associated with other conditions such as intellectual disability, epilepsy, and genetic syndromes. While biological markers and specific causes for ASD have yet to be found, very early diagnosis and intervention are still the main approach to the condition.

Although several intervention programs for ASD have been developed, many of them lack sound evidence with regard to their efficacy [Maglione, Gans, Das, Timbie, & Kasari, 2012] and due to the large heterogeneity of the autism spectrum, a single approach is difficult to be established and to be proven as the best one.

Rapid progress in technology, especially in the area of robotics, offers promising possibilities for innovation in ASD intervention. Social robots can be a very powerful support for children with ASD who show a clear attraction for technological systems and intact or even enhanced “systemizing” skills [Baron-Cohen, 2002, 2006].

However, studies conducted with the specific purpose of testing the effectiveness of the use of robot as a support tool in therapy in improving ASD symptoms are still limited and inconsistent. To date, robotics has been applied in the autism field to the following targets: assisting in the diagnostic process, improving eye contact and self-initiated interactions, turn-taking activities, imitation, emotion recognition, joint attention (JA) and triadic interactions [Cabibihan, Javed, Ang, & Aljunied, 2013; Ricks & Colton, 2010].

Cabibihan et al. [2013], provided a brief technical datasheet of all the social robots used so far in ASD intervention. The work takes an engineering perspective and addresses three key concepts: the robot design features that need to be optimized to the meet the needs of individuals with ASD (physical appearance, functionality, level of autonomy, etc.), the different roles to be

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carried out by the robot (diagnostic agent, playmate friendly agent that elicits behaviors, social mediator or social actor) and the set of behaviors to be stimulated in the child during the therapy. Ricks and Colton [2010], in their study focused on whether robot anthropomorphism has an impact on therapy outcome measures such as generalization and engagement. The Authors contrasted humanoid robots vs. non-humanoid robots, and found that humanoid robots were able to elicit a better generalization of the skills the child learned during therapy, whereas the maximum child engagement was found with non-humanoid robots.

Furthermore, Robins, Ferrari, and Dautenhahn [2008] explored the game scenario and made two types of distinctions, the first one between solitary and collaborative game, and the second one between sensory-motor play, symbolic play, constructive play and game with rules. Diehl, Schmitt, Villano, and Crowell [2012] conducted a review of the literature organizing the studies into four categories according to: the response of the participants to the robots or robot-like characteristics (these studies have no direct clinical application, but provide insight on how children with ASD respond to a robot or to an interlocutor with robot-like characteristics); the ability of the robot to elicit the target behavior in children with ASD (these studies describe a robot that performs an action to induce a target behavior in children with ASD); the results obtained using the robot to model, teach or make the child perform a specific skill (in these studies the robot is used as a tool for learning a target behavior, it engages in interaction with the child to practice a skill) and finally the results obtained using the robot to provide feedback or encouragement to the participant. In a more recent work, Diehl, Crowell, Villano, Wier, Tang, and Riek [2014] after analyzing the literature on the use of robots for the diagnosis and therapy for autism, proposed a roadmap that takes into account multiple factors that need to be considered separately when evaluating this approach.

In the light of the previous research work in the field, this article is a systematic and critical review of the studies dealing with robot-mediated intervention in ASD.

The purpose of this review is quite different from all the previous ones which, in our opinion, gave a rather "robot focused" perspective.

Our main effort aims to provide a clinical perspective by focusing our attention on the different studies' design, the clinical sample characteristics (when available) such as age, intelligence quotient (IQ), ASD symptoms severity, the neuropsychological measures tested and the experimental results interpretation. Last but not least, we tried to make our research systematic, using the PRISMA checklist. Thus, the present review is not that centered on the needs of designers (although it may be useful to them); the main purpose of this review is to evaluate the feasibility of an optimized robot-mediated therapeutic approach in ASD.

The questions that we will attempt to answer are the following: does the use of robot in therapy help the therapist? If it does, does it fit better a specific subgroup of ASD subjects? Which are the parameters that have been/should be used to test robot-mediated effectiveness? Our research, in short, is speculative, but, hopefully, it will also have some practical implications in future research, suggesting perhaps novel experimental settings to be used in the treatment of ASD.

As we will see in §3, in our sample robots covered different functions. In some cases they were used to carry out measurements on subjects with ASD and test whether there were any abnormalities compared to TD subjects; in other cases they took the role of playmates; in others they were used to play actions that are normally played by the therapist, such as giving prompts to the children. But the way we chose to examine the studies of our cross section only considers one function of the robot: a tool that the therapist can use to optimize the therapy.

However, it should be noted that it is sometimes very difficult to place a study in a category rather than another: starting from a work created to satisfy the questions that interest designers, for example, it is often possible to infer observations that are useful to clinicians, support staff or to the philosophers, and so forth. Many studies taken into account in this review have put us in front of this challenge. We decided to serve a conceptual tool that allows, in our opinion, a more fluid shift between categories: the Dautenhahn's triangle. In Dautenhahn's triangle of human robot interaction (HRI) approaches [Dautenhahn, 2007], we place ourselves on the human-centered view vertex.

Methods

Protocol Registration

The protocol of this review was registered within the PROSPERO database, with the following code: CRD42015016158.

Eligibility Criteria

The present study is a systematic review on the use of social robots in autism therapy. We conducted an electronic database search of Scopus, Science Direct, PubMed (simple terms and MeSH Terms), Isiweb and LILACS for "autism" and "robot" in all fields (title, abstract, keywords, full text, and bibliography) until 3 November 2014. We found 998 results. After removal of 240 duplicates, we had 758 results for the screening.

Included and excluded studies were collected following Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [Moher, Liberati, Tetzlaff, & Altman, 2009]. See flow diagram (p. 8.).

Screening criteria. All titles and abstracts were initially screened by one author to exclude studies that contained even one exclusion criteria.

We included studies meeting the following inclusion criteria. First, the study must be focused on autism. Second, the study should test the efficacy and/or the efficiency of the use of one or more robots in diagnosis, study and/or rehabilitation of autism or, in general, pathologies into the autism spectrum disorder (ASD). Third, to include the study in the screening, it is necessary for it to include at least an experiment, a pilot study or a trial with at least one group of participants constituted homogeneously by subjects with ASD. Finally, we only admitted in our review the studies that declared (or at least provided a comprehensive description of) the robot model used for the experiment.

Thus, we excluded 525 results and tested 233 articles for eligibility.

Eligibility criteria. After the screening, we selected 3 categories of exclusion criteria: focus, design and accuracy criteria. We excluded 15 articles because our scientific institutions database does not have access to them.

Focus criteria of exclusion:

Our main focus is human-centered, therefore we excluded from our review all the studies that

1. Do not describe the function of robot in therapy but focus exclusively on the technological descriptions of the robot (n=19),or
2. Test exclusively robot's skills (n=11).

Design criteria of exclusion:

Since the primary purpose of this study is to understand whether the use of robot in therapy as a support tool has a positive effect on the prognosis of individuals with ASD and possibly to understand which techniques are the most successful for individuals with ASD:

1. we excluded from our research all the studies that had no original experimental perspective, thus we have excluded surveys, or generally all theoretical studies in which there are no trials or scientific experiments associated (n=75);
2. we excluded from our research all those studies in which the experiment did not include at least one group in which participants were all with ASD (n=25);
3. to ensure a minimum of statistical significance of the data, we excluded the case studies and research in which the number of participants with ASD was less than 3 (n=10)

Accuracy criteria of exclusion:

One of our goals was to identify some guidelines to improve the effectiveness of the use of robot in therapy for individuals with ASD.

1. To suggest more effective techniques, we excluded from the review any items that fail to clearly explain the data relevant to the replicability of the technique employed. Thus, we excluded all studies in which the exact age of the participants was not present, for example, *adolescents* or *participants are between x and y years old*, or –finally– those in which it is impossible to distinguish participants' with ASD and other groups of participants' mean age (n=40)
2. All the studies that have not been exhaustive in reporting the results obtained; or that only have insufficient preliminary results (n=9)

Variable Definitions

We coded eight identical variables in articles related to participants' characteristics, methods and study results. We coded four variables related to the participants of each study. First, we coded child diagnosis and size of participants' groups. Second, we coded the mean age of the participants and provided a standard deviation and/or range when possible. Third, we reported the participants' sex and finally, we reported the participant's skill level by IQ, when possible. All these variables are reported in Table 1.

Within the method we reported the name of the robot we used, the type of measurement and the study design (Table 1). After that we categorized the experiments on the basis of the skills that were tested (the articles that test more skills have been included in several categories): social behaviors (eye contact, liking, manipulation, touch); JA; imitation; language and stereotyped behaviors. For each tested ability, we pose some questions, for a total of 10 questions (Table 1).

In Supporting Information, we show method, findings and conclusions of our interest about all selected articles.

Results

Social Robots Used in Experimental Researches

For a classification of robots based on aesthetic characteristics see Figure 2.

As we can see in Table 1, the most widely used robot for autism therapy is Nao [Anzalone et al., 2014; Bekele, Crittendon, Swanson, Sarkar, & Warren, 2013; Peca, Simut, Pintea, Costescu, & Vanderborght, 2014; Shamsuddin, Yussof, Ismail, Mohamed, Hanapiah, &

Table 1. Social Behavior[a]

Study	N° participants*	Robot	Age (m.a.ASD [SD ASD; *r* ASD]; m.a.TD [SD TD; *r* TD])**	IQ (ASD IQ m.; TD IQ m)	Sex (ASD males; ASD females/TD males; TD females)	Type of measurement	Study design	Our question 1. Can a robot be considered a better stimulus than a human agent to improve social behaviors in children with ASD?	Our question 2. Do children with ASD manifest social behaviors toward robot?	Our question 3. Does a robot improve (like a mediator) social behaviors of subjects with ASD toward other subjects (with or without ASD)?
Chaminade et al. [2012]	12 ASD, 18 TD	Bioloid robot	21 [2,7;?]; 21,5 [4,9;?]		?;?/18; 0	fMRI	Cross sectional with control	Yes	Yes	No answer
Damm et al. [2013]	9 ASD; 15 TD	Flobi	21 [?; 10]; 23,4 [?; 10]	112,5; 111, 65	9; 0/?;?	eye-tracking	Cross sectional with control	Yes	Yes	No answer
François et al. [2009]	6 ASD	Sony Aibo ERS-7	8,5 [1,38; 3]		5; 1	Behavioral observation	Longitudinal study ($\geq$10 sessions)	No answer	Yes	Yes
Giannopulu [2013]	4 ASD	GIPY-1	8,3 [?; 2]		3; 1	Time spent (second).	Cross sectional without control	Yes	Yes	Yes
Lee et al. [2012]	6 ASD, 6 TD	Touch Pad	9,83 [2,32;?]; 9,83 [1,72;?]		6; 0/3; 3	Pressure force in three dimensions (*x*, *y*, *z*) by Touch Ball connect with PC.	Cross sectional with control	No answer	Yes	No answer
Lee et al. [2012b]	6 ASD	Ifbot	9,33 [2,25; 5]		5; 1	point scale	Cross sectional without control	Yes	Yes	No answer
Lee et al. [2013]	4 ASD	Touch Pad, Parlo	10,25 [1,5; 3]		?;?	Pressure force in three dimensions (*x*, *y*, *z*) by Touch Ball connect with PC.	Cross sectional without control	Yes	No	No answer
Pioggia et al. [2007]	4 ASD	FACE	12,2 [5,67; 12,5]	82,25	3; 1	ECG, cardiac frequency and CARS	Cross sectional without control	No answer	Yes	Yes
Puyon et Giannopulu [2013]	11 ASD	POL	7,3 [0,42; 1,2]		8; 4	Time spent and number of words	Cross sectional without control	No answer	Yes	No answer
Robins et al. [2005]	4 ASD	Robota	7,75 [2,62; 5]		?;?	behavioral observation	Longitudinal study (101 sessions)	No answer	Yes	Yes
Shamsuddin et al. [2012]	5 ASD	Nao	8,6 [0,83; 7,2]	48,4	4; 1	GARS-2	Cross sectional without control	Yes	Yes	No answer
Wainer et al. [2010]	7 ASD	Lego NXT	9,85 [2,11; 6]		7; 0	behavioral observation	Longitudinal study (12 sessions)	No answer	No answer	Yes

Table 1. Continued

Study	N° participants*	Robot	Age (m.a.ASD [SD ASD; r ASD]; m.a.TD [SD TD; r TD])**	IQ (ASD IQ m.; TD IQ m)	Sex (ASD males; ASD females/TD males; TD females)	Type of measurement	Study design	Our question 1. Can a robot be considered a better stimulus than a human agent to improve social behaviors in children with ASD?	Our question 2. Do children with ASD manifest social behaviors toward robot?	Our question 3. Does a robot improve (like a mediator) social behaviors of subjects with ASD toward other subjects (with or without ASD)?
Wainer et al. [2014]	6 ASD	Kaspar	6,5 [0,83; 2]		5;1	behavioral observation	Cross sectional without control	Yes	Yes	Yes
Wainer et al. [2014b]	6 ASD	Kaspar	7,28 [0,54; 1]	73,67	5; 1	behavioral observation, spoken words, eye gaze	Cross sectional without control	Yes	Yes	Yes
Yee et al. [2012]	5 ASD	Rofina	4,8 [0,44; 1]		4; 1	behavioral observation	Cross sectional without control	No answer	Yes	Yes
Yin et al. [2013]	5 ASD	Robot A, more humanoid and Robot B	9,8 [1,3; 3]		5; 0	Behavioral observation	Longitudinal study (8 sessions)	No answer	Yes	No answer

Joint Attention

Study	N° participants*	Robot	Age (m.a.ASD [SD ASD; r ASD]; m.a.TD [SD TD; r TD])**	IQ (ASD IQ m.; TD IQ m)	Sex (ASD males; ASD females/TD males; TD females)	Type of measurement	Study design	Our question 4. Do children with ASD improve theirs performances in JA tasks if experimenters use a robot?	Our question 5. Do children with ASD have better performance than TD children in JA tasks if experimenters use a robot?	Our question 6. Do children turn their attention to the robot?
Anzalone et al. [2014]	16 ASD, 14 TD	Nao	9,25 [1,87;?]; 8,06 [2,49;?]	73; >80	13; 5/9; 6	3d motion tracking system	Cross sectional with control	No	No	Yes
Bekele et al. [2013]	6 ASD, 6 TD	Nao	4,7 [0,7; 2,12]; 4,4 [1,15; 2,78]		5; 1/4; 2	Number of prompts, eye gaze, targets identified	Cross sectional with control	No	No	Yes
Duquette et al. [2008]	4 ASD	Tito	5 [0,45; 1,1]		3; 1	behavioral observation	Longitudinal study (22 sessions)	Yes	No answer	Yes
Michaud et al. [2007]	4 ASD	Tito	5 [0; 0]		3; 1	behavioral observation	Longitudinal study (22 sessions)	Yes	No answer	Yes
Warren et al. [2013] Zheng et al. [2013]	6 ASD	Nao	3,46 [0,73; 1,86]		6; 0	Number of prompts, eye gaze, targets identified	Longitudinal study (4 sessions)	No answer	No answer	Yes

Table 1. Continued

Imitation									
Study	*N*° participants*	Robot	Age (m.a.ASD [SD ASD; *r* ASD]; m.a.TD [SD TD; *r* TD])**	IQ (ASD IQ m.; TD IQ m)	Sex (ASD males; ASD females/TD males; TD females)	Type of measurement	Study design	Our question 7. Do children with ASD improve theirs performances in imitation tasks if experimenters use a robot?	Our question 8. Do children with ASD have better performance than TD children in imitation tasks if experimenters use a robot?
Bird et al. [2007]	16 ASD, 15 TD	Robotic hand	34,9 [13,2;?]; 33,2 [11,4;?]	110,3; 112,6	15; 1/15; 1	EMG	Cross sectional with control	Yes	No answer
Cook et al. [2014]	10 ASD, 12 TD	Robot simulation by virtual reality	41,07 [14,22;?]; 37,6 [8,92;?]	114,36; 118,93	11; 3/13; 2	Vision motion tracking system	Cross sectional with control	No	Yes
Duquette et al. [2008]	4 ASD	Tito	5 [0,45; 1,1]		3; 1	behavioral observation	Longitudinal study (22 sessions)	No	No answer
Michaud et al. [2007]	4 ASD	Tito	5 [0; 0]		3; 1	behavioral observation	Longitudinal study (22 sessions)	Yes	No answer
Pierno et al. [2008]	12 ASD, 12 TD	prototype of robotic arm	11,1 [1,1; 3]; 11,2 [1,17; 3]	101,83	6; 6	Vision motion tracking system- and motion tracking system	Cross sectional without control	Yes	Yes
Robins et al. [2005]	4 ASD	Robota	7,75 [2,62; 5]		?;?	behavioral observation	Longitudinal study (101 sessions)	Yes	No answer

Language								
Study	*N*° participants*	Robot	Age (m.a.ASD [SD ASD; *r* ASD]; m.a.TD [SD TD; *r* TD])**	IQ (ASD IQ m.; TD IQ m)	Sex (ASD males; ASD females/TD males; TD females)	Type of measurement	Study design	Our Question 9. Does the robot help to improve language better than a human agent or other object in a interaction with ASD children?
Kim et al. [2013]	24 ASD	Pleo	9,4 [2,4; 8,2]	$\geq 70; \geq 70$	21; 3	Number of utterances during experimental condition	Cross sectional without control	Yes
Puyon et Giannopulu [2013]	11 ASD	POL	7,3 [0,42; 1,2]		8; 4	Time spent and number of words	Cross sectional without control	Yes

Table 1. Continued

Language								
Study	N° participants*	Robot	Age (m.a.ASD [SD ASD; r ASD]; m.a.TD [SD TD; r TD])**	IQ (ASD IQ m.; TD IQ m)	Sex (ASD males; ASD females/TD males; TD females)	Type of measurement	Study design	Our Question 9. Does the robot help to improve language better than a human agent or other object in a interaction with ASD children?
Wainer et al. [2014b]	6 ASD	Kaspar	7,28 [0,54; 1]	73,67	5; 1	behavioral observation, spoken words, eye gaze	Cross sectional without control	Yes
Yin et al. [2013]	5 ASD	Robot A, more humanoid and Robot B	9,8 [1,3; 3]		5; 0	behavioral observation	Longitudinal study (8 sessions)	No answer

Stereotyped Behaviors								
Study	N° participants*	Robot	Age (m.a.ASD [SD ASD; r ASD]; m.a.TD [SD TD; r TD])**	IQ (ASD IQ m.; TD IQ m)	Sex (ASD males; ASD females/TD males; TD females)	Type of measurement	Study design	Our Question 10. Are repetitive and stereotyped movements be reduced during a human-robot interaction rather than during a human–human interaction in children with ASD?
Giannopulu [2013]	4 ASD	GIPY-1	8,3 [?; 2]		3; 1	Time spent (second).	Cross sectional without control	Yes
Michaud et al. [2007]	4 ASD	Tito	5 [0; 0]		3; 1	behavioral observation	Longitudinal study (22 sessions)	Yes
Pioggia et al. [2007]	4 ASD	FACE	12,2 [5,67; 12,5]	82,25	3; 1	ECG, cardiac frequency and CARS	Cross sectional without control	Yes
Shamsuddin et al. [2013]	6 ASD	Nao	8,7 [3; 8,2]	63	5; 1	GARS-2	Cross sectional without control	Yes

[a] Eye contact, liking, and touch.
*Number of participants effectively involved in the experiment.
**In years.

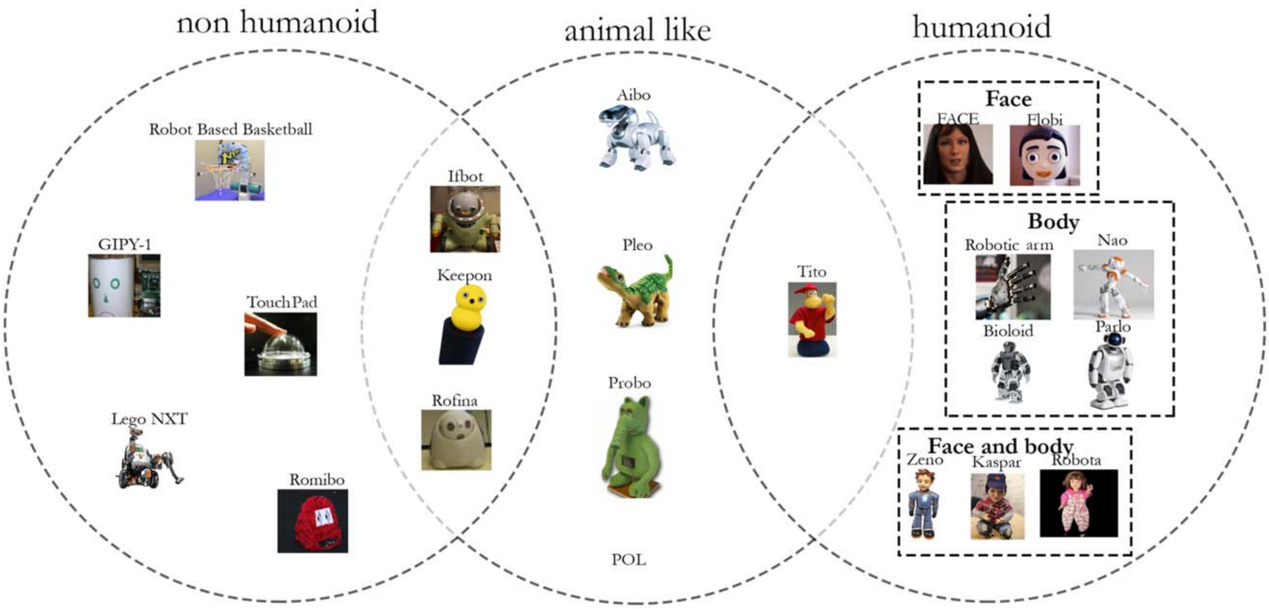

Figure 1. Number of subject for each question. Decreasing order of positive responses.

Zahari, 2012; Shamsuddin, Yussof, Mohamed, Hanapiah, & Ismail, 2013; Warren et al., in press/Zheng et al., 2013[1]]. Nao is a commercially available (Aldebaran Robotics Company) child-sized humanoid robot (58 cm in height, 4.3 kg). Its body is made in plastic and it has 25 degrees of freedom (DoF) (4 joints for each arm; 2 for each hand; 5 for each leg; 2 for the head and one to control the hips). Nao is able to capture a lot of information about the environment using sensors and microphones. Nao can speak and, thanks to its wide motility and to its luminescent eyes, it can assure a certain degree of non verbal communication.

KASPAR [Peca et al., 2014; Wainer, Dautenhahn, Robins, & Amirabdollahian, 2014; Wainer, Robins, Amirabdollahian, & Dautenhahn, 2014] is a child sized (60 cm in height), minimally expressive, humanoid robot, used in 3 studies taken into account in our cross-section. It has 6 DoF on the head and neck, 6 on the arms, 2 in the eyes and its face is a silicon-rubber mask. KASPAR's face can show a range of simplified expressions but in a less complex way than real human face. It is able to respond to the touch of children and can move its arms, head and eyes.

Pleo [Kim, Berkovits, Bernier, Leyzberg, Shic, Paul, & Scassellati, 2013; Peca et al., 2014] is a dinosaur pet toy (2 studies of our cross-section). It has 16 DoF, a camera-based vision system for light detection and navigation, microphones, touch sensors, ground foot sensors, force-feedback sensors, an orientation tilt sensor for body position; thus it is able to move itself autonomously and can express emotions by motions and sounds in response to children's touch or various interactions such as caresses or giving food. It is projected for growth.

Tito [Duquette, Michaud, & Mercier, 2008; Michaud et al., 2007] is a robot mediator, 60 cm tall, made in soft material. It uses wheels to move, has two arms that can be moved up and down; it can turn its head right and left and up. It has two eyes and a mouth by which it can smile (there are leds). Tito can speak by prerecorded vocal messages. Tito has a small microphone-camera and can also be controlled by a wireless remote control.

The TOUCH PAD [Lee & Obinata, 2013; Lee, Takehashi, Nagai, & Obinata, 2012; Lee, Takehashi, Nagai, & Obinata, & Stefanov, 2012] is a touch ball with a force sensor which measures three axial forces and which, depending on pressure, lights up different colors.

The robotic arm [Bird, Leighton, Press, & Heyes, 2007] was presented to participants in photo (black and white).

Bioloid Robot [Chaminade, Da Fonseca, Rosset, Lutcher, Cheng, & Deruelle, 2012] is produced by ROBOTIS, and it can be assembled in various configurations (scorpion, spider, dinosaur, puppy, and humanoid robot). In the cited article it was assembled as a humanoid robot. It can have 18 or 16 DoF, thus it has a wide body mobility, but its face is inexpressive. It does not speak.

RBB [Conn, Liu, Sarkar, Stone, & Warren, 2008] is an undersized basketball hoop attached to a robotic arm

[1]They described the same experiment, but we have integrated the information to have a most complete idea of the study.

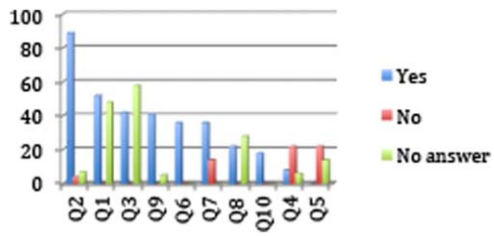

Figure 2. Classification of robots based on aesthetic characteristics.

that can move the hoop in different directions with different speeds.

Flobi [Damm et al., 2013] is a robotic head, designed to use a comic-like human face. Hair, eyebrows, lips, and frontal face are easily replaceable. The platform features stereo vision, stereo audio and a gyroscope for motion compensation. Flobi has 18 DoF.

Sony Aibo ERS-7 [François, Powell, & Dautenhahn, 2009] is a robotic dog with five tactile sensors (head, chin and three back sensors), so it can react to environment and move itself autonomously. Aibo can also recognize voice commands.

GIPY-1 [Giannopulu, 2013] is a cylindrical robot (20 cm diameter and 30 cm tall) created for the experiment. It has two green circles for the eyes, a green triangle for the nose and a red oval for the mouth. The robot can move forward, backward, and turn on itself at low speed and it is controlled by a wireless remote control.

Ifbot (Lee, Takehashi, Nagai, Obinata, et al., 2012) is a robot (Height 45 cm; weight 9.5 kg) equipped with a camera, speaker, sound-direction recognition microphone, voice recognition microphone, wheels, obstacle sensor, a step sensor, and a handshake sensor in its hands. It can record, sing, dance and playback voice messages. It has blinking eyes and 108 LEDs on its face that light up in a variety of patterns to simulate expressions.

Parlo (Lee & Obinata, 2013) is a social robot developed by Fujisoft (40 cm tall, it weighs 1.6 kg), it can dance, play games, and recognize human voice.

Keepon [Peca et al., 2014] is a small yellow robot (12 cm diameter, 25 cm tall; weight 898 g) developed by Hideki Kozima. It has four motors on the whole body, rubber skin, two cameras in the eyes and a microphone on the nose. It has two modes: touch mode and dance mode. In touch mode, it reacts to human touches, in dance mode, it dances in synchronized rhythm with music.

Probo [Peca et al., 2014] is a robot (58 cm tall) developed by Vrije Universiteit Brussel. It has 20 DoF. It is designed to provide a natural interaction with humans and it is controlled by a user friendly Robotic User Interface.

Romibo [Peca et al., 2014] is a robot developed by Origami Robotics (28 cm tall). Its body is covered with Velcro, thus it is possible to change the appearance of the robot. It is thought to be a social playmate and it is able to roll around the room.

FACE [Pioggia, Sica, Ferro, Igliozzi, Muratori, Ahluwalia, & De Rossi, 2007] is an android developed by Università di Pisa. It is a passive body with an active head. It has 32 motors to simulate and modulate six basic emotions (happiness, sadness, surprise, anger, disgust and fear). FACE is not able to speak; it has microphones and cameras by which it can analyze the emotional reactions of individuals, react to them and store all data.

POL [Puyon et Giannopulu, 2013] is an animal-shaped robot, a mobile chicken controlled via wireless by a teleoperator. The robot can move forward, backward, and turn on itself at low speed.

Robota [Robins, Dautenhahn, Te Boekhorst, & Billard, 2005] is a humanoid robot (45 cm tall; weight 500 g) that has 1 DoF on each arm, leg and on the head. Using a motion tracking system, Robota can copy movements of user's arms. It reacts to touch, says its name and describes its behavior.

LEGO Mindstorms NXT (Wainer, Ferrari, Dautenhahn, & Robins, 2010] is a programmable robotics kit developed by LEGO (11.7 cm; 38.1 cm; 38.4 cm; 2.1 kg). The main component (NXT brick) can receive input from a maximum of 4 sensors and controls 3 motors. It can reproduce sampled sounds.

Rofina [Yee, Kee, Limbu, Jian, Dung, & Yuen, 2012] is a teleoperated robot (30 cm tall). With a 2 DoF on the head, it can display basic emotions.

Considerations Generalizable to all Tested Abilities

After our eligibility test, we obtained a cross-section of 29 studies that describe 28 studies because Warren et al. [2013] and Zheng et al. [2013] are complementary descriptions of the same experiment. Our results are all collected in Table 1 and Supporting Information.

Some of our observations were generalizable to all tested abilities:

1. Participants with ASD often had better performances in *robot condition* (RC) rather than in *human condition* (HC);
2. in some cases, ASD patients had, toward robots, behaviors that TD patients normally had toward human agents;
3. to benefit the positive effects of the use of robot in therapy, higher levels of stimulation were better than lower levels of stimulation.

Below, we will analyze these results in detail.

1. Participants with ASD often have better performances in RC rather than in HC

In Anzalone et al. [2014], Bekele et al. [2013], Bird et al. [2007], Chaminade et al. [2012], Cook et al. [2014], Damm et al. [2013], Duquette et al. [2008], Kim et al. [2013], Lee, Takehashi, Nagai, Obinata, et al. [2012] and Lee and & Obinata, [2013], Michaud et al. [2007], Pierno, Mari, Lusher, and Castiello [2008], Shamsuddin et al. [2012, 2013] and in Wainer, Dautenhahn, et al. [2014] and Wainer, Robins, et al. [2014] there is a comparison between HC and RC. Of these 16 studies: two showed worse results in RC than in HC [Anzalone et al., 2014, Bekele et al., 2013]; other two studies showed similar findings for RC and HC [Chaminade et al., 2012, Cook, Swapp, Pan, Bianchi-Berthouze, & Blakemore, 2014]; all other 13 studies found better performances in RC than in HC.

Anzalone et al. [2014] found that children with ASD had a significant decrease in their JA score with Nao and Bekele et al. [2013] showed that both participants with ASD and TD participants spent more time watching the administrator during RC than HC, thus both the groups needed more prompts during RC in a JA task.

Chaminade et al. [2012] performed a fMRI investigation and Cook et al. [2014] tested automatic motor imitation pattern that we cannot judge as better or worse in RC.

Bird et al. [2007] and Pierno et al. [2008] also tested motor automatic imitation but they showed that in RC the automatic imitation pattern of movements was in the normal range in ASD patient (see discussion).

Damm et al. [2013] show that, in a JA task, patients with ASD had fewer diminished fixations and reduced eye contact in HC as compared to RC.

Duquette, Michaud, and Mercier [2008] divided participants (4) into two groups: the first one interacted with a human agent, the other one with a robotic agent: children paired with the robot mediator showed more shared attention, more visual contact and proximity with their mediator and more imitation of facial expressions than the ones paired with the human mediator; reduced repetitive plays with inanimate objects were found, as well as no stereotyped behavior toward the robot. However, the same study showed that to pair an autistic child with the robot mediator had a negative influence on the imitation of words. Kim et al. [2013], a study that involved 24 participants with ASD showed that participants expressed more spontaneous utterances in RC than in HC.

Lee, Takehashi, Nagai, Obinata, et al. [2012] and Shamsuddin et al. [2012] measured participants' score during play session and registered higher score in robotic session in all tasks: eye contact, verbal response and facial expression and Shamsuddin et al. [2013] found lower rates of stereotyped behaviors. Michaud et al. [2007], Wainer, Dautenhahn, et al. [2014], and Wainer, Robins, et al. [2014] with qualitative observations found similar results in RC.

Finally, Lee and Obinata [2013] found that the robot could be a more efficient stimulus than a computer display or a parent.

2. ASD individuals had, toward robots, behaviors that TD individuals normally had toward human agents

Two studies [Chaminade et al., 2012 and Pierno et al., 2008] showed that ASD individuals had, toward robots, behaviors that TD individuals normally had toward human agents. Chaminade et al. [2012], within a fMRI study, found that the posterior superior temporal gyrus, a region of cortex involved in social cognition, is more active when controls, but not ASD patients, believe they interact with an intentional vs. a nonintentional agent. This suggested that ASD patients represent interacting robots differently than TD participants. Temporal areas had the same level of activity when ASD patients interacted with a robot and with a human, implying that they failed to represent intentional and artificial partners differently. In contrast, the two agents' response profile, in lateral and medial frontal lobe clusters, implied that ASD patients use, when interacting with artificial agents, resources controls that TD employed with intentional agents.

Pierno et al. [2008] showed that facilitation effects during an imitation task were evident only in HC for TD children and only in RC for ASD children.

3. Higher levels of stimulation are better than lower levels of stimulation

Two studies analyzed the influence of a high level of robot interactivity in children with ASD [Anzalone et al., 2014 and Puyon et Giannopulu, 2013]: both studies showed that higher levels of stimulation are better than lower levels. In particular, Anzalone et al. [2014], that tested JA, found that multimodal JA induction (gazing, pointing and vocalizing) was more efficient in both groups (ASD and TD participants). Puyon et Giannopulu [2013], instead, compared a with game play condition with a without game play condition and found that during with game play condition eye contact, touch, manipulation and posture toward robot were better and all children pronounced more words than in the other condition.

Another interesting result in this direction was found by Yin and Tung [2013]: here, a comparison among two robots, Robot A (more humanoid and more complex) and Robot B, was performed. Both robots were able to guide autistic children to complete the experimental tasks and to generate basic social behaviors, but children's levels of precision were lower when imitating Robot B than Robot A.

Another important result is the one obtained in Conn et al. [2008]. This study, actually shows that an intelligent stimulation, that is, based on the emotional state of the subject, is most appreciated by children with ASD rather than a random stimulation.

Does the Use of Robot Improve the Performances of ASD Children?

All the experiments collected in Table 1 are heterogeneous by number, age, sex, and IQ of participants, as well as by robot used, type of measurement and study design. We divided all studies on the basis of tested ability, and after that we posed some specific question to each study[2]:

Q1. Can a robot be considered a better stimulus than a human agent to improve social behaviors in children with ASD?

Q2. Do children with ASD show social behaviors toward robot?

Q3. Does a robot improve (like a mediator) social behaviors of subjects with ASD toward other subjects (with or without ASD)?

Q4. Do children with ASD improve their performances in JA tasks if experimenters use a robot?

Q5. Do children with ASD have better performance than TD children in JA tasks if experimenters use a robot?

Q6. Do children turn their attention to the robot?

Q7. Do children with ASD improve their performances in imitation tasks if experimenters use a robot?

Q8. Do children with ASD have a better performance than TD children in imitation tasks if experimenters use a robot?

Q9. Does the robot help to improve language better than a human agent or another object when interacting with ASD children?

Q10. Are repetitive and stereotyped movements reduced during a human-robot interaction rather than during a human–human interaction in children with ASD?

We found that:

- social behavior (16 studies)

Q1. Eight studies showed that in some cases a robot can be a better stimulus than a human agent to improve social behaviors in children with ASD. Other 8 studies did not address the issue in these terms;

Q2. Fourteen studies illustrated that **children with ASD show social** behavior**s toward robot**; 1 of them illustrated that children did not show social behavior toward robot, but the experiment involved Touch Pad that is a non humanoid robot, inappropriate to a display of social behaviors. The other study did not address the issue in these terms;

Q3. Nine studies showed that robots improve (like a mediator) social behaviors of subjects with ASD toward other subjects (with or without ASD). Other 7 studies did not address the issue in these terms;

- JA (5 studies)

Q4. Two studies showed that **children with ASD did not improve their performances in JA tasks if experimenters used a robot;** other two studies showed the opposite; the last study did not address the issue in these terms. The two studies that showed negative effects of the use of robot in a JA task are cross sectional and have a bigger number of participants and a more precise type of measurement compared to the other two, so we are incline to consider their results more reliable;

Q5. Two studies showed that children with ASD did not have better performance than TD children in JA tasks if experimenters used a robot. Other 3 studies did not address the issue in these terms;

Q6. All studies showed that children turn their attention to the robot.

- Imitation (6 studies)

Q7. Four studies showed that **children with ASD improve their performances in imitation tasks if experimenters use a robot.** Two studies show the opposite;

Q8. Two studies showed that children with ASD have better performance than TD children in imitation tasks if experimenters use a robot. Other 3 studies did not address the issue in these terms;

- Language (4 studies)

Q9. Three studies showed that the robot helps to improve language better than a human agent or other object in an interaction with ASD children. The last study did not address the issue in these terms;

- Repetitive and stereotyped behaviors (4 studies)

Q10. All studies showed that repetitive and stereotyped movements were reduced during a human-robot interaction rather than during a human–human interaction

Observation About Different Procedures

Procedures to test or improve JA. Supporting Information shows the method, the findings and the conclusions of our interest of each article.

Anzalone et al. [2014] and Bekele et al. [2013] both tested JA and used a similar method. In Anzalone et al. [2014] Nao or a therapist tried to induce children to look toward some figures placed on the sides of the experimental room, while a perception system recorded their posture and gaze; conversely, in Bekele et al. [2013], each child sat on a Rifton chair between two

[2]See Table 1 and Figure 1.

monitors and Nao or a therapist tried to induce the child to turn his/her head toward the stimulus. In both cases, the robot—just because it excessively attracted children's attention, became an obstacle to the achievement of the target; in fact, in both cases reaching the target was more difficult with the robot than with humans and in both cases, there was no difference between ASD and TD children.

Bekele et al. [2013] were replicated in a very similar way in Warren et al. [2013]/Zheng et al. [2013]. In these last two articles the experimental procedure was the same but, unlike Bekele et al. [2013], there was not a control group, there was not a HC and experimenters limited themselves to tell that children reached all experimental targets and that the interest in robot did not diminish in the various sessions. Thus, the same experiment without a HC provided positive results, but such positive results were essentially unreliable.

Also in Damm et al. [2013] there was a very similar experimental procedure; in this case participants were asked to pick a card from the table and the prompt was exclusively a gaze direction of robot. This difference in results should be linked to two variables: the choice of a card is normally more engaging than simply turning the head toward the stimulus, this might keep the participants partially more focused on the task; second, contrarily to Nao, Flobi can turn his eyes. In Damm et al. [2013], the HRI works better than human–human interaction (HHI). Experimenters have highlighted as good results the improvement in eye contact in HRI; however, in the article they do not give the results of JA task (do children have to turn their eyes toward the card?) because they focused on gaze behavior. Our hypothesis is that in procedures in which the robot invites the child to look at another object, the robot can be a distractor because it canalizes the attention of the child.

Within other experimental setups, Duquette et al. [2008] and Michaud et al. [2007] partially tested robot capability of eliciting JA in ASD children with satisfying results, but both experiments did not have a control group and had a very small sample (4 children with ASD).

In summary, despite ambiguous results of Anzalone et al. [2014], Bekele et al. [2013] and Warren et al. [2013]/Zheng et al. [2013], the other three studies that tested JA in children with ASD by robot [Damm et al., 2013, Duquette et al., 2008, and Michaud et al., 2007] showed the possibility to use robots to elicit JA in subjects with ASD, but it is necessary to study the optimal conditions to reealize it. Nao is undoubtedly a strong attractor for children with ASD, however probably the shape of his face is not the most suitable to stimulate this kind of ability. In 1995, Baron-Cohen sustained that the Eye Direction Detector (EDD) in ASD is fully functional; if this hypothesis is true, our observation on the difference between Flobi and Nao would be plausible. In this case, it could be more functional to elicit JA robots with a certain ocular motility, such as Zeno or Flobi.

Motor imitation. Cook et al. [2014] tested, conversely, automatic motor performances, that were assessed, with different results, also in Pierno et al. [2008] and Bird et al. [2007]. This last study showed that, measuring a response speed, the compatibility effect for both ASD and TD was greater when participants responded to a human than when they responded to a robotic agent; moreover, it was also shown that ASD group had greater compatibility effect in response to observed human action. Authors explained this phenomenon by resorting to the theory that connects the inability to inhibit motor responses with that of applying the theory of mind: in this perspective, a minor inhibition would be a good target for therapy. Conversely, Pierno et al. [2008] showed that facilitation effects were evident only when the agent was human in TD and only when the agent was robotic in ASD. More recently, Cook et al. [2014], testing the participants capability of plan movements during the observation of congruent and incongruous movements of virtual human and robotic agent and real human agent, showed, as in the case of Pierno et al. [2008], that individuals with ASD did not exhibit the modulatory effect of human form, but they did not find any evidence to sustain that the visuomotor priming is greater for ASD children in RC. Authors explained this difference observing that in Pierno et al. [2008], the reach-to-grasp procedure used in RC was the same for all trials, thus, it may be possible that this predictability contributed to the facilitation effect.

The three mentioned experiments provided a partial idea of the effect of motor inhibition or facilitation that the movements of the robot can trigger in individuals with ASD, but it is clear that this field of investigation should be studied more deeply. It is possible, indeed, that the motor interference of robots on subjects with ASD partly inhibits autistic symptoms; this hypothesis deserves to be thoroughly tested by future research.

The fMRI study. In our cross-section, there is only one study employing fMRI [Chaminade et al., 2012]. It showed that the posterior superior temporal gyrus, usually involved in social cognition, was more active in TD patients than in ASD patients (the activation of this area does not vary in ASD patients when interacting with intentional agent), when they believed they were interacting with intentional agents rather than nonintentional agents. Moreover, temporal areas had the same level of activity when ASD patients interacted with a robot and with a human. In contrast, the response profile of two agents, in lateral and medial frontal lobe clusters, implied that ASD patients used, when interacting with artificial agents, the brain areas that TD children used with intentional agents.

These findings suggested to authors that ASD patients may consider artificial agents as social interacting partners just as control participants consider humans. A partial confirmation of this observation could possibly arise from Peca et al. [2014] that, by a task of photo association, showed that both children with ASD and TD children associate robots with toys, but a large part of participants with ASD categorized robots with machine.

Free or semifree interactions. Observing comparatively methods and results, it seems that the most interesting descriptive observations arose from studies dealing with free interactions between children and robots. In our cross-section, we found eight studies based on free or semifree dyadic or triadic interactions between children and robots. Among these, the only one that uses a scientific system of measurement (ECG, cardiac frequency and CARS) was conducted by Pioggia et al. [2007], and involved participants in a 20-min interaction with robot mediated by therapist showing a decrease in participants' CARS score and an increase in participants' cardiac frequency during the HRI. Other studies generally showed three kinds of improvements: children's interest in interacting with robot, expressed by cognitive social behaviors like touching, manipulating, posture, eye contact [Giannopulu, 2013; Michaud et al., 2007; Puyon et Giannopulu, 2013], decrease of repetitive and stereotyped behaviors [Giannopulu, 2013; Michaud et al., 2007; Shamsuddin et al., 2013] and linguistic communication [Giannopulu, 2013; Kim et al., 2013; Puyon et Giannopulu, 2013; Shamsuddin et al., 2012].

A longitudinal approach could be of good interest in this context; Robins et al. [2005], for example, showed that repeated trials over a long period of time increased basic social interaction skills in children with autism. Duquette et al. [2008] found that robots appeared to be an interesting way to help children to initiate contact, because they do what typically developing children do when meeting strangers. Similarly, François et al. [2009] found that robots are able to simplify the initial interaction and to create a relatively predictable environment to play.

All other studies required a very specific task for participants (such as playing "Snakes and Ladders" or pressing the Touch Ball modulating its strength), the results, therefore, were difficult to generalize because they were closely related to the task. In general, all participants in all the experiments achieved the task. Some interesting observations are mostly related to how the task was achieved and what the task demanded to the participants, but all these studies showed that robots can be good motivators because they attract children's attention toward the task [Lee, Takehashi, Nagai, & Obinata, 2012; Lee, Takehashi, Nagai, & Obinata, et al., 2012; Lee & Obinata, 2013; Wainer et al., 2010; Wainer, Dautenhahn, et al., 2014; Wainer, Robins, et al., 2014; Yee et al., 2012; Yin et al., 2013].

Social Robotics and ASD Diagnosis

None of the papers in our sample explicitly speaks about the use of robots as support tools for clinicians in making a diagnosis of autism; however, some research may provide useful data for future use of social robots in this way. Scassellati [2007] emphasized the advantages that robots could bring in the diagnosis of autism: structured interactions with robots could create standardized social situations to elicit particular social behaviors; in this way it will be possible to compare responses of different subjects in standardized situations and different response of the same subject across time.

Anzalone et al. [2014] showed that the combined use of Nao with a 3D motion tracking system revealed difference in patterns of behavior: the visual exploration was less accurate in children with ASD than in TD and movements of the first group showed less stability than TD group. Chaminade et al. [2012] showed, by the fMRI, that ASD group had a very specific pattern of activation in interacting with a non intentional agent, suggesting that their beliefs to interact with an intentional or non intentional agent had more influence than the aesthetics features of robots. Cook et al. [2014] showed an atypical interference effect between human and robot stimuli and Pierno et al. [2008] showed that, in an imitation task, ASD children react to a robot partner in the way in which TD children react to a human partner. Finally, Lee et al. [2012] showed that, unlike, TD children, ASD children had no patterns of behavior in modulation of social touch.

Each of this data could in future be measured in toddlers considered at risk of autism to test if they are present in children that will receive a diagnosis of autism. At the current state of the art, in our opinion, social robots cannot be considered support tools in the diagnosis of the disease; but if one or more of the behavioral alterations shown in patients that have already been diagnosed with autism will also be shown in children at risk that are later diagnosed with autism, robot could become a precious tool in helping clinicians in the diagnosis.

Discussion

Generally, the interaction of individuals with ASD and robots is profitable for prosocial behaviors, maintenance of attention, induction of spontaneous linguistic behavior, decrease of stereotyped and repetitive behaviors. These behavioral observations have some scientific evidence.

Because of the small number of subjects of each experiment in our cross section, this review can not be considered a demonstration of the assumptions that have exposed in our results. We think that our assumptions could become (can, in general), hypothesis for future studies.

Social behaviour Q1, Q2, and Q3

Due to the higher number of subjects involved in the experiments the most supported hypothesis is that children with ASD show social behaviors toward robots (Q2). That is because the experiments related to this hypothesis involved a larger number of subjects. The need to create a limited number of categories under which organize data led us to standardize three parameters in the category social behaviors: eye contact, liking and touch. So, the major number of subjects in this category is due to the higher degree of generalization of this category compared with the other categories.

Most important evidence about the improvement of social behaviors thanks to social robots derives from studies that have a higher number of participants and a more rigorous type of measurement. In this sense, maybe the most important study in this category is Chaminade et al. [2012] (12 ASD; 18 TD) that suggests that ASD subjects use, when interacting with artificial agents, cerebral resources that TD subjects use when interacting with intentional agents. (Effectively,) Damm et al. [2013], (9 ASD; 15 TD) actually confirm this assumption because they show that the eye contact that subjects with ASD have with robots is the same that TD children have with human agent. As we will see in § 4.3, Pierno et al. [2008] found analogous results in imitation tasks). The assumption that subjects with ASD show social behaviors toward robots is very important from a philosophical point of view: it gives us a very interesting starting point for a reflection on the disease. But what does it tell us about the use of social robots in therapy? We can speculate that a children that shows no eye contact (the most basic social behavior) with a therapist, could be successfully stimulated by social robot. A very interesting experiment could test the effectiveness of social robots in stimulating eye contact in low-functioning ASD that have a strong deficiency in eye contact. Second, a longitudinal study in this sense could test if the acquisition of eye contact toward robot can be then extended toward the therapist (and subsequently toward other people). Both Q1 and Q2 will receive a more rigorous answer from an experiment of this kind. What robot for this task? To study eye contact, the robot must have clearly distinguishable eyes with some kind of animation (movement, possibility to be closed, etc...). These conditions restrict field of possibilities to Ifbot, Pleo, Kaspar, FACE, Flobi, Nao, and Zeno. From our data it is not possible to infer what robot is the best for this task, so a very useful study on eye contact could make a comparison between these robots.

Q3 has the highest number of no responses, nevertheless, the article with the higher number of participants [Wainer et al., 2010] involves 7 subjects with ASD. These studies support the idea that robot can be a good mediator between children with ASD and other people. Wainer, Ferrari, Dautenhahn, and Robins [2010] showed that robot can improve collaboration among children with ASD. The procedure of this experiment is very original and gives us precious suggestion about the use of robot like a mediator in group contest, but it is not easily replicable in therapy. Wainer, Robins, et al. [2014] clearly showed that after a robotic session, children had major eye gaze, more expansive attitude and spoke more to their playmates. Wainer et al. [2014] give more controversial results from this point of view because it seems that in the session with a human playmate subsequent to the first robotic session (H2), children take more initiatives in the choice of shapes (instead of just listening to partner's suggestions). Moreover, from Wainer, Dautenhahn, et al. [2014] it emerges that there is a negative correlation between the social involvement of subjects and their capacity of successfully select shapes (the game task). In Wainer, Dautenhahn, et al. [2014] the average of successfully selected shapes is higher in H2 than in the first session with a human playmate (H1). These two experiments are alike in the construction of the procedure and in the number of participants, but Wainer, Robins, et al. [2014] had a more accurate type of measurement. François et al. [2009] give positive response to our question, the most important result of this experiment is that all children showed interest toward robot, however, experimenters only collected qualitative data.

From our point of view, social robots could become exceptional mediators in autism therapy, but more data to support this hypothesis is needed. Particularly future experiments could adopt a similar procedure to the one adopted by Wainer, Robins, et al. [2014] who measured eye gaze and words toward playmate in H2 (and H1 for a comparison). Probably, to better simulate a real playmate, the robot for this task should be humanoid and should have a face, so we restrict field of possibilities to FACE, Flobi, Nao, Bioloid, Parlo, Zeno, Kaspar, Robota.

This ideal experiment could compare some or all these robots.

Joint Attention: Q4, Q5, and Q6

Studies on JA are the most controverse. According to our data it seems clear that subjects turn their attention toward the robot (Q6). Duquette et al. [2008] have 4 participants with ASD and made 4 subgroups, so results are not statistically significant. A similar consideration can be made for Michaud et al. [2007] that made two subgroups with 4 participants with ASD. Moreover, both articles only made a qualitative analysis.

The most rigorous procedures and types of measurement are in Anzalone et al. [2014], Bekele et al. [2013], and Warren et al. [in press]/Zheng et al. [2013]. From our point of view, these three studies clearly show that there is a wrong way to use a robot in autism therapy. Surely, robot is a very strong attractor (Q6), but this attractiveness can become a distractor for the task. These three articles show that robot needs more prompts to canalize children's attention on a third object.

In our opinion, it can be very useful to change the role of robots in experiments that test JA. These three articles use robot like a therapist that induces children to look at another stimulus, but we think that the best role of robot in this sense is a target role. In other words, therapist must try to induce children to turn their attention toward the robot. Probably this use of robot can be very useful for children with ASD that have a strong deficit in JA tasks. This ideal experiment could compare more robots.

Imitation: Q7, Q8

Studies on imitation are perhaps the most difficult to interpret. Duquette et al. [2008], Michaud et al. [2007], and Robins et al. [2005] have a very small number of participants and collect only qualitative data. Bird et al. [2007] and Cook et al. [2014] both test the imitation of non intentional movements. Pierno et al. [2008] test imitation of goal-directed action. Usually in autism therapy a great importance is given to imitation of facial expressions, but none of these three articles deals with it.

If we compare results of Bird et al. [2007] and Cook et al. [2014] we find an interesting analogy. Bird et al. [2007] found that in both groups compatibility effects are stronger in HC rather than in robot condition; similarly Cook et al. [2014] found that in both groups there is not compatibility effect in RC. But this last data is in contrast with a finding of Pierno et al. [2008]. Pierno et al. [2008] found that facilitation effects of imitation were evident only in HC for TD subjects and only in RC for ASD subjects.

Studies on imitation are very useful to test the hypothesis that cognitive unconscious [Lakoff & Johnson, 1999] of autisc subjects process robot actions and human actions differently. This kind of studies should not be very difficult to realize, but they need to be studied, with rigorous systems of measurement and larger number of subjects both the compatibility effect and the facilitation effect.

As we have seen in §4.1, these studies are very interesting to examine autism from a theoretical point of view, but if we want to finalize studies exclusively on the optimization of the therapy, maybe we will need to test the capacity of social robots to elicit imitation of facial expressions or emotion. In our cross section, there are not studies that test this specific ability with quantitative analysis. An ideal experiment that tests facial expression could use FACE or Zeno because they have the most expressive faces; if experimenters want to test the ability of robot to elicit the imitation of emotion even Nao could be useful because its body is the most expressive in the sample of robots used in autism treatment.

Language: Q9

Very interesting results derive from Q9. The studies that have explicitly considered and measured the improvement of language with a robot are just four, only three of these give an answer to our question, but we have a total of 38 participants with ASD. Kim et al. [2013] (24 ASD) showed that robot seems to improve the language abilities in triadic interaction better than both a human agent and a computer. Puyon et Giannopulu [2013] (11 ASD) showed that robot seems to improve language more than a simple motionless toy, the improvement is very big (see Supporting Information). Despite the small number of articles that treat this theme, data from social robotics and improvement of language in autism therapy are the most clear. It is plausible that the improvement of language is bigger if children are younger, but we cannot demonstrate this assumption with our data. So, future studies could study the relation between age of children and improvement of language. This ideal experiment could compare, as well as groups of different ages, different robots, to find out if some characteristics are more stimulating than others, as for example, the presence of language in the robot.

Stereotyped behaviors: Q10

Probably, a very promising field of investigation is about the reduction of repetitive and stereotyped behaviors during treatment with social robots. In our cross section there are only 4 articles that test this parameter, all of them give positive results but in all of them there is a very small number of participants and none of them has an automatic instrument of measurement.

It could be useful to carry out some studies that permit a reliable comparison, using an automated system of measurements (such as wearable sensors for example), between the quantity of stereotyped movements during a therapy session that involves robot as a support tool and the quantity of stereotyped movements during a standard therapy session. Possibly with different kinds of robots.

Another important test in this direction could be a longitudinal study that using a wearable sensor, may be able to test the long term effectiveness of a treatment that involves a robot in reducing stereotyped movement in everyday life. This ideal experiment should have a control group of ASD children treated without robot.

Does the Use of Robot in Therapy Work Better for Boys Than for Girls?

Only two out of the 27 studies took into account differences between males and females. Anzalone et al. [2014] showed that pitch variance (that in this task was an index of oscillation of attention) was significantly lower in TD children than in children with ASD and in girls than in boys. Thus, in general, according to this study, females appeared more focused on robot than males.

The other study that focused on sex difference is Peca et al. [2014], that revealed a similar categorization pattern for girls and boys in TD children, but differences for four out of the six robots in ASD. For boys, Pleo, Nao, Keepon and Romibo had a stronger association with machines than they had for girls; moreover, Kaspar was associated to human by boys and to a toy by girls.

However none of the two articles had large samples of subjects, thus the data were not widely generalizable. The question is still waiting for new experiments.

Does the Use of Robot Therapy Work Better with People Who Have a Higher IQ?

Many studies included the IQ among the parameters to be measured in the participants, but only few of them took it into account. A few studies considered this parameter between covariates [Cook et al., 2014]; in Pioggia et al. [2007], however, the participants who got less benefit in robotic therapy, as well as being the ones with a more severe form of autism, were also the ones with the lowest IQ.

Two studies, however, analyzed this parameter in relation to the improvement in autistic symptoms during robotic therapy. In 2012, Shamsuddin et al. showed that children with a moderately impaired IQ (from 40 to 54) were receptive to robot-based intervention. Shamsuddin et al. [2013] distinguished three IQ profiles: moderate, mild and borderline, but the comparison between the different levels of lower IQ groups showed that there was no specific pattern to describe and distinguish between the three IQ levels. But because of the relatively small sample size, results may not be considered to be conclusive, thus experimenters require other investigation in this sense.

Is There An Ideal Age for Using Robot in Therapy?

In our cross section, younger children who received robotic therapy were 3.46 years old [Warren et al. in press/Zheng et al., 2013], older participants were adults aged 41.7 years [Cook et al., 2014]. There were no studies specifically aimed at determining whether the robotic therapy had better outcomes when administered at an age rather than another age.

Both in the studies that find advantages in robotic therapy, and in those failing to find this positive outcome, the age of the participants was heterogeneous, but it was not possible, on the basis of the data we collected, to establish a correlation between age of the participants and outcomes of robotic therapy.

Studies that move in this direction would be desirable.

Are the Advantages of the Use of Robot in Therapy Long-Lasting?

A key question is whether the advantages of robotic therapy last beyond the temporal boundaries of the session with the therapist, or, in other words, was the reduction of autistic symptoms during the therapy session still observed when the subject went back home?

In our sample of articles, only one study refers to this topic: Wainer et al. [2010] involved participants in lessons dealing with how to make a robot. The children were organized into groups of two and three and they gradually spoke more and more often about their project, both with playmates and outside the experimental context. The experiment involved 7 children with ASD. Although the outcome of this experiment's benefits of robotic therapy appeared likely to still be observable outside the clinical and experimental context, studies in this regard are still very few.

In Grandin et Panek [2013], the authors emphasized the need of looking for the strengths of the brain of each person with autism to improve their life expectancy. To do this, the autistic subject has to make his/her experience of the world looking for his/her own attitudes. In the same book, the authors argued that most of the autistic brains may have a cognitive style that is predominantly visual and others may have a cognitive style mainly for pattern. In both cases, engineering might be a good path to follow for the specific abilities of ASD subjects because engineering is concrete and is favored mainly by visual thinking styles. It is plausible to assume that early exposure to robots could arise the interest of the autistic subjects in something practical and provide an interest that one day may be used at a professional level. Wainer et al. [2010] positively highlighted this particular aspect.

Can a Robot Replace Human Therapist?

In one of the most important studies for the number of subjects and for the type of measurements, Chaminade et al. [2012], authors maintain in the conclusions that their result "supports the use of artificial agents as interactive partners in replacement of human therapists." If this was possible there would be a great advantage: the lower cost of therapy. But from our point of view, this hypothesis is probably wrong for a lot of reasons: first of all, at the state of the art, a robot that can be used without a therapist does not exist. Robots are frail and a human agent is needed to guide the robot in performing the procedure to avoid damages. It is likely that the presence of the robot alone during therapy increases the difficulty to generalize the learned skills for the children.

In line with our thesis, Coeckelbergh, Pop, Simut, Peca, Pintea, David, and Vanderborght [in press] asked 416 participants if the use of social robots that replace therapists was ethically acceptable: 44% of subjects strongly disagree or disagree; 29% nor agree and nor disagree, 18.8% agree or strongly agree.

Limitations

This review has some limitations: some of them are linked to the quality of studies included and others to its structure.

Although, through the PRISMA checklist we tried to make the review as objective as possible, some studies were difficult to classify within the parameters of eligibility that we set.

Being a relatively new field of study [the first robot for the treatment of autism was used in 1976 by Weir & Emanuel], although in literature there are a large number of articles (initial sample 998), longitudinal experimental trials are few, thus the quality of our final results has negative outcome and therefore many of the questions that arose this review were left without an answer.

Another limitation is that most of the studies taken into account do not have a control group. This is a limitation in understanding whether the robots are useful in treating autistic subjects more than they could be in the treatment of other diseases or in general with TD children; however, for the type of question that we discussed ("does the use of robot give advantages for the autistic therapy?"), experiments without a control group could also be useful.

Although we excluded studies that had less than four participants, many of the studies we have taken into account did not involve large cohorts of participants. Finally, the variability of intervention techniques does not allow a statistical generalization and this could be considered a further limitation.

Conclusions

At the current state of the art, it seems that robotic therapy has brought so far positive results. The robots were used as attractors or as mediators, or simply as measurement tools; in all fields, however, investigators have declared their enthusiasm for this new promising aid for research and therapy. Saying that robotic therapy works, obviously does not mean that it solves autism, but it provides therapists and researchers a means to connect with the autistic subject in a easier way. To date, the most enthusiastic reports were related to the use of the robot in free or semistructured interactions, approaches that according to our research seem currently the most effective when using robots in a clinical setting. In experimental research too, however, robots are precise instruments able to attract the participants' attention, therefore experimenters have also benefitted of them in well-structured procedures.

It most clearly emerges from this review that the studies conducted so far in this area are still insufficient. It is necessary to clarify whether the sex, IQ and age of participants affect the outcome of the therapy or the experiment and whether any of the beneficial effects brings benefits that are only observable during the robotic session or if they can still be observed outside the clinical/experimental context. Other studies should be focused on what is the best kind of robot to use in relation to a specific ability that is being studied.

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