Review of assistive technology in the training of children with autism spectrum disorders

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The use of socially assistive robotics (SARs) is a promising method for improving the social skills of children with autism spectrum disorder (ASD). Studies conducted in this field in recent years show that the use of robots as collaborators may have positive effects on the development of social skills in children with ASD, especially in those areas where they reveal great deficits.

In this literature review, we present, organize and evaluate the most important features and results of 13 relevant scientific articles. In analysis of the research findings we explored the documented effectiveness of robotics in enhancing the social skills of children with ASD in the areas of mutual attention, verbal communication and imitation skills, and also in the reduction of stereotypical behavior. Analysis of the results of the 13 studies confirmed that robots can have positive immediate effects on the communication skills of children with ASD, which holds promise for future intervention programs and relevant research.

KEYWORDS: Autism spectrum disorder, robotics, social robotics, social skills

Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder that presents in the form of severe difficulties in social communication and interaction, along with repetitive behaviors and stereotypical interests. The main cause of ASD is considered to be a neurobiological malfunction that has not been traced to a specific area of the brain, impeding its normal function (Cho and Ahn 2016).

In order for ASD to be diagnosed, the main symptoms must appear in the early developmental period and impair the child's everyday activities (DSM-5; APA 2013). Some of the most common symptoms are related to difficulties in attention and impairment in cognitive, sensory, motor and emotional functions. Children with ASD display difficulties in understanding the feelings, motives, and body language, etc., of other people and in managing their social relationships. As ASD is characterized by a spectrum of symptoms and a wide range of intelligence, it is possible for children with ASD to be low functioning or high functioning.

Both the verbal and non-verbal communication skills of children with ASD are generally quite low, and some never develop completely functional speech corresponding to their chronological age. Lack of awareness of the way of thinking, and even the presence, of other people, is a major feature of ASD, resulting in difficulties in social interaction (Quill 1995).

The diagnosis of ASD is becoming more common. Epidemiological studies have indicated an occurrence rate of ASD of 1:100 children in 2006, 1:88 in 2008 and 1:68 in 2010 (Cho and Ahn 2016). ASD can be diagnosed in early childhood (Ouss *et al.* 2014) and early intervention is considered necessary to minimize the occurrence of symptoms.

Children with ASD tend to adjust to schedules that include repetitive patterns and activities, and they respond negatively to change, in contrast to their peers of typical development (TD) who adjust relatively easily to new conditions. As every child with ASD has different abilities and needs, a personalized program must be designed for each child separately. In recent decades, various methods of therapeutic intervention have been developed for children with ASD, among the most common of which are Applied Behavioral Analysis, the TEACCH Autism Program, the Picture Exchange Communication System (PECS), the MAKATON language program, the SPELL framework, and Sensory Integration Therapy (Francis 2005).

Apart from these methods, there is progress in the utilization of information and communication technology

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(ICT) for children with ASD. Assistive technology refers to "an electronic item/equipment, application, or virtual network that is used to intentionally increase, maintain, and/or improve daily living, work/productivity, and recreation/leisure capabilities of adolescents with ASD" (CSESA Technology Group 2013). Improvement in several skills of children with ASD may be achieved with the use of assistive technology, mainly because the information is visualized. It also appears less intimidating, because a computer offers stability and does not exhibit emotional transitions in a way that a human partner would (Robins *et al.* 2005, Scassellati 2007).

Robotics is a field of technology that encompasses designing, developing and studying robotic tools. It combines elements from other scientific fields, including computer technology, electronics and engineering. Robotic science has made a giant step forward and has yielded many benefits in global industry, medical science and personal care. Robots can be described as automatic machines that incorporate programmed behavior, used for replacing the human component to complete a specific task. Robots can be categorized based on their form and capabilities in four categories (Amran *et al.* 2018), which are:

- Humanoid robots or androids, which come in a form that is similar to that of a human. A good example is "Nao" produced by Aldebaran Robotics.
- Industrial robots, which complete tasks and execute commands automatically and without human intervention.
- Telerobots, which refers to a specific type of semi-autonomous robots that are used for telecommunications.
- Autonomous robots, which are designed with a built-in artificial intelligence (AI) system, to complete tasks and to act without receiving commands from humans

Based on their functionality, robots can also be categorized as follows:

- Social robots, which can become engaged, to a certain extent, in social interaction with humans through speech and gestures.
- Assistive robots, which help people with special needs, and especially those with motor disabilities.
- Service robots, which can be designed to offer any kind of help a person may need.

A new field of robotic technology has emerged in recent years, called socially assistive robotics (SARs). Robots in this category provide help in establishing social interaction rather than offering other kinds of services. All SARs robots are designed to exhibit emotional cues and facial expressions. Many factors affect their efficacy, the most important of which are their form and characteristics (Scassellati *et al.*2012).

SARs technology is documented to be of help for people with health issues and also to be of use to teachers as an educational tool (Mataric, 2014). This type of robot can help people with strokes, Alzheimer's disease and intellectual disabilities, and also children with ASD, to enhance their social interactions (Feil-Seifer and Matariae 2009). In the case of ASD, through methodologically designed activities, SARs can aid in the amelioration of social and cognitive deficits (Cho and Ahn 2016).

Children with ASD exhibit a spectrum of characteristics, including lack of social skills (speech, mutual attention, play skills, etc.), stereotypical interests, repetitive behaviors, and others. The main aims of intervention programs for children with ASD is the enhancement of social skills and the reduction of stereotypical behaviors. Such programs traditionally make use of various materials, such as toys, or even people familiar with the child, to establish an environment for social behavior manifestation and modification. In this context, the superior effectiveness of SARs in modifying social behaviors in children with ASD has been demonstrated (Robins *et al.* 2005, Scassellati 2005).

The use of SARs began to overcome the obstacles inherent to human-to-human interaction, which tends to be unpredictable, as robots can establish a simplified, predictable form of communication for children with ASD. They feel safer and "in control" with a robot, and are more likely to engage in activities with a robot, designed by the teacher. Robotic tools, in contrast to humans, can focus on one task at a time, making learning more targeted and simpler for the child with ASD (Amran *et al.* 2018).

For teaching children with ASD, several types of robots have been found suitable, each of which has a distinct form and functions. Irrespective of the appearance of each robot, children perceive them as attractive toys, which increases the likelihood of engaging them in activities and interaction (Amran *et al.* 2018). It is reported that most children with ASD exhibit a clear preference for robots, rather than non-robotic toys, or even people, and they tend to respond faster to cues provided by a robotic partner than a human partner (Bekele *et al.* 2013, 2014).

SARs for use in ASD intervention programs are available in various forms, the most common categories of which are the humanoid, those in the form of an animal or the machine-like. As these categories are not always commercially available, some research groups have designed and developed their own robots, which has resulted in differences in the structure of interventions and in the results (Scassellati *et al.* 2012).

SARs are eligible for use in an ASD intervention program, and in research, when certain conditions are met; these include interaction with the environment and the people around, and using cues for social interaction. SARs can be used as a model that indicates social behavior, as a toy that serves as a "bridge" for communication with others, and as a mediator that facilitates the expression of feelings and behaviors that would not be expressed otherwise (Scassellati *et al.* 2012). When the robot is equipped with facial features similar to those of a human (mouth, eyes, nose, etc.) this may help in establishing mutual attention between the child with ASD and the robot.

Children with ASD have difficulty in establishing eye contact with other people, but according to a study conducted with the use of the robot "Kaspar", eye contact was increased. A human face appears more intimidating to a child with ASD than that of a robot, whose expressions and reactions are more limited and predictable (Amran *et al.* 2018).

Ricks and Colton (2010), comparing the effectiveness of humanoid and non-humanoid robots, found that children with ASD managed to maintain and generalize the acquired skills from an intervention program using a humanoid robot, but they participated more in activities using non-humanoid robots (Ricks and Colton 2010). One characteristic that a robot must have to be eligible for use in ASD intervention programs aimed at enhancing social skills in children is the ability to move or interact verbally with people (Amran *et al.* 2018).

Apart from humanoid robots, LEGO robotics has gained in popularity. The most popular LEGO model is "Mindstorms", which consists of an intelligent "brick" computer that controls the whole robot, modular sensors motors and LEGO parts that can be used for. Wainer and colleagues (2010) incorporated LEGO NXT robots in their study on 7 children with autism and report that the robotics generated specific social behaviors, such as increased collaboration among the participants. In addition, positive affect was engendered, which was also manifested later, in other settings (Wainer *et al.* 2010).

The integration of a robot in an intervention program requires it to be controlled by the teacher/researcher. A widely accepted way of controlling a robotic tool remotely is the "Wizard of Oz" technique which allows the teacher/researcher to control the robot from across the room, or even from another room, without being perceived by the child. This is achieved through a device such as a tablet or smartphone connected to the software of the robot, by which the robot's functions can be adapted to the needs of each specific intervention (Scassellati *et al.* 2012).

Our attempt was to conduct a literature review on the effects of SAR's to children with autism regarding their social skills enhancement. A notable review on this subject was made by Cabibihan *et al.* (2013), which included studies using different types of robots (Anthropomorphic, Non-Anthropomorphic or Non-biomimetic. After an analysis of the results, researchers sorted the robots according to their role (e.g. social mediator, behavior eliciting agent etc.). Ismail *et al.* (2019) discussed about the use of SAR's, and more specifically about their medical and engineering content, and their effectiveness in contributing towards the core deficits of autism, namely communication, social interaction and stereotypical behavior. Another significant literature review was presented by Grossard *et al.* (2018), who pointed out the benefits of using Serious Games and SAR's in enhancing the social skills of children with autism, after analyzing the results of two relevant projects.

Objectives

This review aims to present an evaluation of assistive technology in the training of children with ASD in social skills. The main object was to assess the effectiveness of several SARs devices in the development of social skills in children with ASD based on their features and characteristics, as reported in the current literature. We intended to address the current literature research gap by categorizing these results by the forms of social behavior that have been observed and discuss each one thoroughly and separately, as this hasn't been done on previous reviews. Furthermore, many reviews focus on the effects of assistive technology in enhancing communication skills of children with autism, without any references to other forms of social skills. Our attempt was to exhibit whether or not assistive technology is effective in reinforcing a wide variety of social skills (from eye contact to proximity and positive affect).

Our first task was to form the review's research questions based on the current bibliography. Since our main object was to investigate whether the social skills of children with ASD would develop with the use of SARs, most of our research questions covered this particular subject. We included research questions that were concerning eye contact and imitation skills separately, as these (along with false belief attribution, which is not discussed in the current review) are the main areas of social cognition. Atypical development of social cognition is thought to explain impairments of social behavior in ASD (Senju 2013).

The review was based on the following research questions:

1. Are eye contact and mutual attention increased in children with ASD when a robotic tool is used in the intervention?
2. Do children with ASD exhibit increased verbal skills towards a robot?
3. Is it possible to enhance the imitation skills of children with ASD through SARs interventions?
4. Do SARs provide a more effective tool for enhancing the social skills of children with ASD, compared to human interaction?
5. Do children with ASD exhibit social behaviors towards a robotic partner?
6. Can robots be an effective means of developing the social skills of children with ASD in their interaction with others?

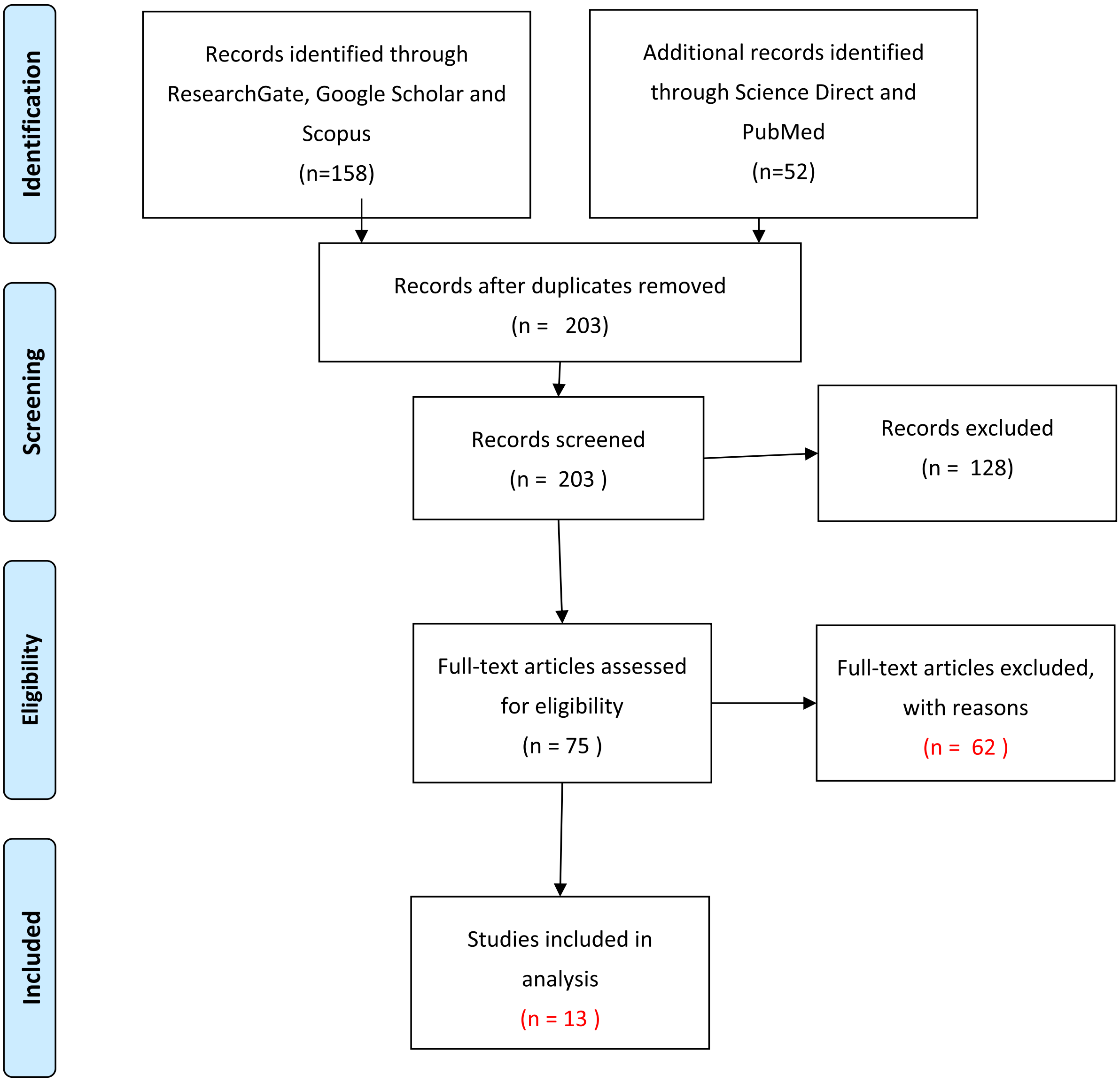

Figure 1 Choosing the analyzed research papers based on PRISMA flowchart.

Methods

The methodology of this study was based on Barbara Kitchenham's guide "Procedures for performing systematic reviews", specifically to present, evaluate and assess published studies related to the specific subject and research questions based on a reliable methodological system (Kitchenham 2004).

The first step was to search for articles on platforms including ResearchGate, Google Scholar, Scopus, PubMed and Science Direct. The keywords we used were "autism", "robot", "robotics", "asd" and we specifically combined "autism" AND "robot", "autism" AND "robotics", "asd" AND "robot", "asd" AND "robotics". We included studies that were conducted in the years 2008-2018, as most research papers on this subject have been published in the last decade.

Next we formed the eligibility criteria to assess the study quality of the research papers. Studies related to the effectiveness or non-effectiveness of robotics in enhancing the social skills of children with ASD should be included. Each should be a primary study and incorporate an intervention, experiment or case study, applied to children with ASD. It was required that each study provided a detailed presentation of the features of the robotic tool.

We excluded studies the primary objective of which was the construction of a robotic tool, with absence of reference to its effectiveness in enhancing social behaviors. Studies were excluded that did not present any data, detailed analysis or the exact ages of the participants, and studies that included only preschool children with ASD (under 6 years). Since the review was conducted by two researchers, in case of disagreement on whether or not to include a research paper, we discussed and searched if this paper reached all of the criteria listed above. Figure 1 shows a flowchart based on PRISMA, which is an evidence-based minimum set of items for reporting in systematic reviews and meta-analyses (Moher *et al.* 2010).

Ultimately, we summarized all available evidence from the final selection of studies. Evidence was

Table 1 Studies included in the review of the effectiveness of socially assistive robotics (SARs) in intervention programs for children with autism spectrum disorder (ASD): characteristics of the study populations (independent variables)

Number	Study	Participants (number)	Robot	Age (years)	IQ	Gender (boys:girls)
1	Severson et al. (2008)	11	AIBO	5–8	NS	10:1
2	Feil-Seifer and Mataric (2011)	8	Bandit	5–10	NS	NS
3	Hanafiah et al. (2012)	1	NAO	10	107	1:0
4	Kim et al. (2012)	18	Pleo	9–14	NS	15:3
5	Costa et al. (2013)	8	Kaspar	6–10	NS	8:0
6	Huskens et al. (2013)	6	NAO	8–14	85–111	6:0
7	Kim et al. (2013)	24	Pleo	4–12	≥70	21:3
8	Yussof et al. (2013)	2	NAO	6–9	NS	2:0
9	Pop et al. (2014)	11	Probo	4–7	NS	11:0
10	Wainer et al. (2014)	6	Kaspar	8–9	NS	5:1
11	Conti et al. (2015)	3	NAO	11–12	Mild ID/Severe ID	3:0
12	Costa et al. (2015)	8	Kaspar	6–9	NS	8:0
13	Scassellati et al. (2018)	12	Jibo	6–12	≥70	7:5

categorized to social behavior categories, such as eye contact, imitation, verbal communication etc. The analysis of results includes the measures of all behaviors that the researchers observed. We interpreted the findings, which is presented in the "Discussion and Conclusions" section. Results from each category are discussed in detail and there is reference to whether or not our initial research questions are answered.

Results

Our first search yielded 210 results and after merging 7 duplicates, 203 studies were left. Application of the rigid research criteria for this review, according to the research questions, resulted in a final selection of 13 studies.

In every study that uses a robotic tool as a means for achieving the goals of an intervention, the characteristics of the robot constitute an independent variable. In this review, the independent variable is the form of the robot (whether it is humanoid, non-humanoid, in animal form, etc.). Other independent variables are the age of the participants, their IQ, their gender and the type of intervention. The characteristics of the participants, all children with ASD, and the robots (i.e. the independent variables) in the 13 studies reviewed are shown in Table 1.

NS = not specified/ not answered.

Robots used in the studies reviewed

As seen in Table 1, 7 different robots were used in the intervention studies reviewed.

"Nao" is one of the most popular robots for autism therapy and was developed by Aldebaran Robotics (Kim *et al.* 2013). Nao is a humanoid robot in the size of a toddler and it has 25 Degrees of Freedom, which allows it to move freely and adapt to the environment. It can be programmed to fit to a child's needs and its height is 57 cm. Although it is a humanoid robot, its facial features are quite simple, making it less intimidating for children with autism (Huskens *et al.* 2013).

"Kaspar" is also a minimally expressive humanoid robot with a height of 60 cm. It has 6 DoF on its head and neck, 6 DoF on its hands and 2 DoF on its eyes. Kaspar's face is made of a silicone material, allowing it to display expressions and feelings in a simplified way. It can respond to touch and move its eyes, face and hands (Pennisi *et al.* 2016).

"Probo" is an animal-like robot that is 58 cm in height and has 20 DoF. It is designed in a way that it can provide a "natural" interaction with humans and it is controlled by a Robotic User Interface (Pennisi *et al.* 2016). It is made of a flexible and a furry material. The robot Probo is able to give the right cues to the users in order for them to develop social interaction. Its 20 DoF allow Probo to display facial expressions, making it easier for children to maintain eye contact (Pop *et al.* 2014). The robot can be controlled through a "Wizard of Oz" interface (Landauer 1986, Wilson and Rosenberg 1988).

"Pleo" is another animal-like robot that resembles a dinosaur toy. It has 16 DoF and it is equipped with a navigation and orientation system, a camera, microphones, touch, movement and orientation sensors, which allow it to move freely. This robot is also able to express feelings through its movements and sounds when a child touches it (Pennisi *et al.* 2016).

"Aibo" is an animal-like robot in the form of a dog which is equipped with 5 touch sensors in the head, chin and back area. These features allow it to interact with the environment and move freely. Aibo can also follow voice commands (Pennisi *et al.* 2016).

"Bandit" is a humanoid socially assistive robot that has been designed by the researcher Maja Mataric in the University of South California of Los Angeles in 2004. Bandit has been used as a partner in interventions for children with autism and for the rehabilitation of stroke patients. This robot is able to display various feelings and expressions and it is also able to move, as it is equipped with wheels. Bandit is 56 cm high and it is designed to move its hands in order to express social gesture (Moro *et al.* 2018, Bugnariu *et al.* 2013).

"Jibo" is a 12-inch socially assistive robot that is equipped with a touch screen and has 3 degrees of

Table 2 Studies included in the review of the effectiveness of socially assistive robotics (SARs) in intervention programs for children with autism spectrum disorder (ASD): Outcome measures (dependent variables)

Number	Eye contact	Verbal communication	Imitation	Proximity/ Touch	Play skills	Stereotypical behavior	Engagement/positive affect
1		*			*	*	
2							–
3	–					*	
4							*
5	*						
6		*					
7		*					
8						*	
9	*	*			*	*	
10	*	–			–		*
11	*		*	*			
12	*		*	*			
13	*	*			*		*

* = positive results.
- = ineffective results.

freedom. This robot can communicate verbally through its speakers and can also make eye contact with the user through its animated eyes. This robot can also exhibit expressive behaviors through its color-changing lights (Scassellati *et al.* 2018).

The outcome measures in intervention studies are the behaviors that are expected to change after the intervention, which are defined as dependent variables. The outcome measures (dependent variables) in the 13 studies that are discussed in this review are shown in Table 2.

SARs' effects on social behaviors

Eye contact

As shown in Table 2, most of the intervention studies in children with ASD investigated eye contact and/or mutual attention. Among the 13 studies reviewed, 9 studies recorded whether the use of a robotic tool increases the frequency of eye contact with the researcher.

In the case study of Hanafiah and colleagues (2012) the child with ASD maintained his eye contact with the robot Nao, but he did not direct his gaze towards his human partner during the period of observation (Hanafiah *et al.* 2012).

In the study of Pop and colleagues (2014), eye contact was defined as the gaze orientation of the child towards the play partner's upper body area, meaning the area surrounding the eyes, for more than two seconds. Two groups of children were formed, one of which participated in the experiment twice. Specifically, the first time all play activities were performed with a human partner, and the second time, for the intervention group only, with the robot Probo. Initially no significant difference in eye contact was detected between the two groups, later analysis made separately for each subject, showed an increase in eye contact with the robotic partner intervention, according to Cohen's d ($d = 3.59$) compared with the human partner part of the intervention ($d = 1.01$) (Pop *et al.* 2014).

Conti and colleagues (2015) implemented an intervention with 3 children with ASD, based on an imitation game of the moves and actions of the Nao robot. They observed that eye contact oriented towards the robot had a duration of 38% over the whole experiment for the first subject, 54% for the second and 84% for the third subject. Of particular interest was that the children directed their gaze for longer towards the researcher after being informed that he was operating the robot.

In a study conducted by Costa and colleagues (2013), eye contact with the robot Kaspar, and the researcher, and gaze in other directions, were measured in two groups of children with ASD, high functioning and low functioning. Two measurements were recorded, one for each phase of the experiment; the children's gaze towards Kaspar had a longer duration, 75.04% and 51.01% of the duration of the first and last phase, respectively. A decrease in eye contact with the robot was observed in the last phase, with a concomitant increase in eye contact with the researcher (4.29% and 16.01% in the first and last phases respectively. Significant differences were detected between the high-functioning and low functioning groups ($p = 0.048$) (Costa *et al.* 2013).

Costa and colleagues, in a later study (2015), observed that eye contact towards the robot Kaspar had a longer duration (>47.3% of the total duration of the experiment) than eye contact with the human partner or gaze in other directions (27.26%, 39.74%, respectively). Furthermore, eye contact with the human partner appeared to increase five-fold in the final phase of intervention compared with the initial duration (Costa *et al.* 2015).

Wainer and colleagues (2014) investigated social behaviors in children with ASD through collaborative play executed either dyadically (a group of two children) or triadically (two children and the robot Kaspar). They observed that the children directed their gaze more towards one another when Kaspar was acting as a partner in the game, and that this type of eye contact increased as the experiment went on. In the triadic interaction, the children made more changes in eye contact between the game and each other (Wainer *et al.* 2014).

Other researchers, such as Scassellati *et al.* (2018), also incorporated triadic interactions between a child with ASD, a caregiver and an autonomous social robot and investigated whether joint attention would be increased after 1 month of home-based intervention. After extracting data by 12 children with autism, researchers came to the conclusion that children with lower nonverbal ability exhibited greater joint attention skills.

David *et al.* (2018) followed a different approach and measured ASD children's response (eye contact) to joint attention after prompting. Results showed that eye contact was more frequent after pointing to the observed object combined with gaze orientation both for human and robot interactions. These observations suggest that pointing is really important for developing joint attention and eye contact in children with autism both for human-to-human and human-to-robot interactions. Yun *et al.* (2017) compared the frequency of eye contact for two groups of preschool ASD children. The first group interacted with a humanoid robot and the second had to interact with a human therapist. Results showed that eye contact had increased from baseline for both groups (77.92% in treatment group and 73.81% in control group, Z= −2.52 and −2.37, respectively, $p < 0.05$).

Verbal communication

Pop and colleagues (2014) measured the occurrence of verbal initiation made by 11 children with ASD. The number of spontaneous utterances during collaborative play with a human partner initially appeared no different from that with the robot Probo in the role of a partner ($U = 7.00$, Z = −1.47, $p = 0.14$). It was observed, however, that 73% of the participants in the group without the robot showed poorer performance in verbal initiation than those in the group that worked with the robot Probo. Analysis of each subject separately revealed no significant difference between baseline and intervention (Z = −0.36, $p = 0.715$ for the human partner intervention; Z = −0.67, $p = 0.5$ for the robot intervention) (Pop *et al.* 2014).

Huskens and colleagues (2013) conducted a study using the robot Nao with children with ASD, measuring the number of self-initiated questions, which are considered to be a specific form of verbal communication. The study was based on the principles of applied behavioral analysis, the effectiveness of which has been demonstrated). According to the analysis, intervention phases with and without the robot Nao were both successful in promoting self-initiated question asking. The researchers noted that the scores of the study children were high even before the intervention (Huskens *et al.* 2013).

Kim and colleagues (2013) investigated the manifestation of social skills, including verbal communication, in children with ASD, with and without the use of the robot Pleo. Specifically, the researchers compared human-to-human interaction with the use of Pleo and the use of a tablet application, concerning their effectiveness in evoking social behaviors. They found that the participants produced more speech during robot interactions ($M = 43.0 \pm 19.4$) than in human partner interactions ($M = 36.8 \pm 19.2$, t(23) = 1.97, $p < 0.05$). Both robot and human interaction resulted in more speech than the use of a tablet application ($M = 25.2 \pm 13.4$). It is of note that verbal communication with the human partner also increased when the robot was used.

Severson and colleagues (2008) compared the interaction of 11 children with ASD with the robot dog Aibo and a mechanical toy dog that was not robotic. The verbal communication of the children with the robot was greater ($M = 2.73 \pm 3.05$ words/minute) than with the mechanical toy dog ($M = 1.07 \pm 1.62$ words/minute, Z = −2.073, $p = 0.038$. Conversely, Wainer and colleagues (2014) predicted that children with ASD would communicate verbally more with the robot Kaspar, but their observations did not confirm their hypothesis, as verbal communication levels with were the same with and without the robot (Wainer *et al.* 2014).

Scassellati and colleagues (2018) reported that the participants made more attempts to initiate communication with their caregivers on the last day as compared to the first day of the intervention with the social robot ($M = 4.08$, SD = 1.00 and $M = 3.17$, SD = 0.39, respectively). Also, it was reported that they made more attempts to initiate communication with other people on the last day as compared to the first day of the intervention ($M = 3.91$, SD = 0.90 and $M = 3.00$, SD = 0.00, respectively) (Scassellati *et al.* 2018).

Imitation

Imitation skills enhancement of children ASD through robotic technology was investigated in two of the studies in this review. Conti and colleagues (2015) measured the number of imitations of, or responses to, movements of the robot Nao made by schoolchildren with ASD, following appropriate prompts. The first child, although usually avoiding new situations, showed an interest in the robot and managed to imitate some moves. The second child did not manage to mimic the robot's movements, but the third child was the most successful in mimicking and interacting with the robot Nao. It is of note here that the second child, after failing to imitate the robot, was diagnosed with severe intellectual disability and lacking of motivation (Conti *et al.* 2015).

In the study of Costa and colleagues (2015), children with ASD were expected to imitate a choreography game executed by the robot Kaspar. Although their initial responses were not encouraging at first, the children's imitation scores showed increase as the study progressed (Costa *et al.* 2015). Another study (So *et al.* 2018) showed that children with ASD managed to imitate gestures more accurately after robot intervention than their typically developing peers who didn't receive robot interventions.

Proximity/touch

Conti and colleagues (2015) observed the number of touches of the robot Nao by 3 schoolchildren with ASD, and reported that touch was less frequent than other forms of social interaction. For example, the first student touched the robot for 11% and the second and third students for 3% of the total amount of time observed (Conti *et al.* 2015).

Costa and colleagues (2015) presented more detailed results about the amount and quality of the children's touching of the robot and of the human partner. The robot Kaspar is equipped with touch sensors that allow measurement of the number and the quality of touches. Their study showed differences in the intensity of touches between Kaspar and the human partner (÷2 (6, $N = 1432$) = 18.34, $p < 0.05$, and ÷2 (6, $N = 394$) = 21.49, $p < 0.05$ respectively). The number of soft touches of Kaspar was 8.5 times that of rough touches, while for the human partner, the number of soft touches was 23.6 that of rough touches. Of interest is the observation that schoolchildren exhibited far more spontaneous touches in the presence of Kaspar (10.3 times more frequent than touches after prompt). After prompts were provided, touching of the robotic partner became softer, indicating that robotic technology can aid in directing children with ASD towards using touch as an appropriate way of communication (Costa *et al.* 2015).

Play skills

Many researchers use symbolic play to assess the skills of children with ASD, and some have integrated robotic technology in intervention programs to enhance their play skills. According to Pop and colleagues (2014), who conducted an intervention study with and without a robot, observed that children engaged in collaborative play more when the robotic partner was present than with the human partner ($U = 1.00$, Z = -2.55, $p = 0.011$ for the intervention phase with the robot). Engagement in functional play was not increased in the presence of the robot Probo, but the children directed their play more towards the robot than towards the human partner. They were more willing to interact with the robot and participate in activities that included the robot ($U = 4.00$, Z = -2.08, $p = 0.037$ for the intervention phase) (Pop *et al.* 2014).

Although the robot Aibo has similar features with the mechanical toy dog used by Severson and colleagues (2008), children with ASD engaged more in play when Aibo had the role of the play partner. They even exhibited more social skills, including unprompted speech, eye contact, etc. (Severson *et al.* 2008).

Wainer and colleagues (2014) were unable to confirm their hypothesis that children would engage more in collaborative play with triadic interaction (child-robot-child) than with dyadic interaction (child-to-child). No significant difference was demonstrated in engagement in play after intervention with the robot Kaspar. Although the children had difficulties in focusing their attention, taking turns and collaborating with others, they all managed to engage in collaborative play to a certain extent with the robot (Wainer *et al.* 2014).

Scassellati and colleagues (2018) used games as a means to enhance the social skills of children with autism. The difficulty of each game could be adapted by the robot Jibo, in order to match each child's needs. The researchers reported that 86% of the participants completed the emotion-understanding game by the last session, 58% and 100% of them completed the two perspective-taking games and 67% of them completed a sequencing and ordering game (Scassellati *et al.* 2018).

Stereotypical behavior

The number of instances of stereotypical behavior was measured Pop and colleagues (2014), who showed that when using the robot Probo, children with ASD exhibited less stereotypical behavior than in their play activities with the human partner ($U = 4.00$, Z = -2.05, $p = 0.040$) (Pop *et al.* 2014).

Hanafiah and colleagues (2012) compared the percentage of stereotypical behaviors exhibited by a schoolchild with ASD during intervention with the robot Nao, compared with when in the classroom. Stereotypical behaviors were observed for only 2.5% of the duration of the intervention with Nao, compared with 25% in the classroom, indicating a major difference (Hanafiah *et al.* 2012). Severson and colleagues (2008) recorded stereotypical behaviors at a rate of 0.75 per minute during play with the robot Aibo and 1.1 per minute with the mechanical toy dog (Z = -1.84, $p = 0.066$) (Severson *et al.* 2008).

The research hypothesis of Yussof and colleagues (2013) was that schoolchildren with ASD would exhibit less stereotypical behaviors in the presence of a robotic partner. The stereotypical behaviors were measured using a list called the Gilliam Autism Rating Scale (GARS-2). The first schoolchild exhibited only 6% of the GARS behaviors and the second 17%. The researchers found these results encouraging since the measurements were made the first time the children had contact with the robot Nao (Yussof *et al.* 2013).

Engagement and positive affect

Engagement was the outcome taken into account by Kim and colleagues (2012) when observing one group of children of typical development (TD) and one group of children with ASD. Each group was observed during activities with the robot Pleo, and the children's engagements with both the robot and other people were measured by two observers using a Likert scale and inter-rater reliability testing. The results indicated that the group of children with ASD exhibited no greater difficulty engaging in activities with the robot than those of TD (TD: $M = 4.36 \pm 0.50$, ASD: $M = 4.27 \pm 0.62$; t(27)=0.39). The children with ASD spent more free play time with Pleo than those of TD (TD: $M = 207 \pm 49$s, ASD: $M = 307 \pm$ SD = 137s; t(20.3)=2.7, $p = 0.02$, Cohen's $d = 0.97$). These findings support the researchers' initial hypothesis that children with ASD engage in play with a robotic partner as much as their peers of TD. They concluded that robotic tool integration in the classroom might be a pleasant way of teaching children with ASD, enhancing their motivation to learn new things and to interact with others (Kim *et al.* 2012).

The observations of Wainer and colleagues (2014) also supported their research hypothesis that children with ASD would interact more effectively with their human partner if the robot was also a partner (triadic interaction). Their results showed that during the study, children with ASD manifested higher rates of social interaction with the robot than in the regular classroom (Wainer *et al.* 2014).

Although most studies have indicated that children with ASD interact positively with robots, Feil-Seifer and Mataric (2011) reports converse findings. In a study of 8 children with ASD, each accompanied by a parent, the interaction was observed with a humanoid robot named Bandit. The study aimed to record the quality of interaction between the robot and the child in free play activity in the presence of a familiar face (the parent). Four of the children exhibited positive affect towards the robotic partner and tried to approach it with social behavior and the other 4 demonstrated negative interaction with it. The children were therefore categorized into two groups. In the first group (positive reaction) the children spent 78% of the session interacting with Bandit, 3% staying close to the parent and 11% hiding against the wall, with a robot avoidance rate of 0%. The second group (negative reaction) spent 36% of the session interacting with the robot, 2.6% close to the parent, 20% avoiding the robot and 38% hiding against the wall (Feil-Seifer and Mataric 2011).

Discussion and conclusions

In this review, we presented the possible benefits of using technology, and particularly SARs, in intervention programs aimed at enhancing the social interaction and communication skills of children with ASD. The literature search yielded 13 relevant studies, which were based on 6 types of SARs. Each robotic platform has unique features and abilities which research has shown that they can aid in developing and improving the social skills of children with ASD. In this review the skills were categorized in Table 1 to facilitate analysis of the outcome.

Most of the studies reported on small samples of children with ASD, or were case studies, and the most important information is derived from the studies using larger samples and systematic measurement of specific outcome variables.

Eye contact is a feature that is characteristically poor in children with ASD, and which was considered amenable to enhancement by a robotic tool. The initial studies have produced promising results, and eye contact was observed to be increased when Probo was used as a robotic partner (Pop *et al.* 2014). In a study on the quality of interaction of 35 children with ASD with Probo and a therapist separately, the only differences in interaction quality were in eye contact, which was increased in the presence of the robot (Simut *et al.* 2016).

The Nao robot has also been reported effective in eliciting eye contact (Conti *et al.* 2015), and it was observed that eye contact was directed to Nao, but not the therapist, possibly due to the flashing lights in the robot's eyes (Hanafiah *et al.* 2012). In another study, however, only 2/4 children exhibited increased eye contact with the Nao robot (Tapus *et al.* 2012).

The robot Kaspar has also been studied for its abilities in eliciting eye contact (Costa *et al.* 2013, Costa *et al.* 2015, Wainer *et al.* 2014). Although most researchers agree that eye contact is enhanced between the child and the therapist in the presence of the robot, others maintain that the robots have a negative effect, as they distract children from the current activity (Anzalone *et al.* 2014, Bekele *et al.* 2013, Warren *et al.* 2013).

The focusing of a child's gaze towards a robot does not generate social behavior, but its encouragement is a way of teaching children with ASD how to initiate and maintain eye contact. Once the child is able to maintain eye contact with the robot, then the robotic partner should be replaced gradually by a human partner for generalization of the acquired skill. A useful future study might be to compare the effectiveness in enhancing eye contact of different robotic platforms in several groups of children with ASD.

Verbal communication is another social skill that is deficient in many children with ASD. Positive results were derived from a study comparing speech towards the robot Aibo and a mechanical toy, in which verbal communication was increased in the former (Severson *et al.* 2008). No major improvement in verbal initiations were noted as sessions of children with Probo progressed (Pop *et al.* 2014). Some researchers hypothesize that the younger the age of the child with ASD, the better will be the effect of a robot on verbal communication (Pennisi *et al.* 2016). This has yet to be confirmed but it could be investigated in future research.

Imitation was explored in two studies in this review, and that using the robot Kaspar reported the more reliable results, specifically that imitation attempts increased as the study progressed (Costa *et al.* 2015). This study only measured the child's imitations of the robot's body movements. To claim that SARs are suitable for stimulating imitation skills, the studies should also focus on imitation of facial expressions in children with ASD. Some examples of robots that can be used for this purpose are the robot "Face" and the robot "Zeno". "Face" (Facial Automation for Conveying Emotions) is a life-like android robot that resembles a woman's face whereas "Zeno" is a facially expressive robot in the form of a child (Mazzei *et al.* 2010, Salvador *et al.* 2015).

Touch plays an important role in shaping social skills during a child's development. Tactile interaction allows the child to be more fully aware of its own existence and the presence of others. It has been observed that some children with ASD have a hypersensitivity to touch and tend to avoid tactile stimulation, or even exhibit signs of panic when someone or some specific material touches the child. Other children with ASD seek to touch specific materials. Some of the robots have been developed to elicit tactile interaction and measure the quality of the touch (frequency, intensity, etc.). For example, Kaspar is covered with a soft fabric which makes it look like a toy doll, while Nao a plastic cover.

Play is a fundamental activity in a child's life and absence of play might hinder healthy development. According to the World Health Organization (WHO, 2001) play is an integral part of a child's life when quality of life is evaluated. Children with ASD have difficulties engaging in collaborative play and symbolic game and often end up playing alone, without the involvement of peers. Results from the studies with the robot Probo and the robot Aibo have been positive (Severson *et al.* 2008, Pop *et al.* 2014). One study with the robot Kaspar was less successful, as the 6 children with ASD observed engaged more in collaborative play in dyadic than in triadic interactions with the robot (Wainer *et al.* 2014).

Patterns of repetitive and stereotypical behavior and adherence to routines are among most common characteristics of ASD. Reduction in stereotypical behavior in children with ASD was documented with the use of 3 of the robots, specifically Aibo (Severson *et al.* 2008), Nao Hanafiah *et al.* 2012, Yussof *et al.* 2013) and Probo (Pop *et al.* 2014). In future studies researchers could use devices such as motion sensors to detect and record the children's stereotypical movements. It would also be useful to compare the frequency of these behaviors during and after intervention in different contexts.

Engagement and positive affect were variables described in some of the studies. Both terms refer to the sense of contentment that the child is feeling when interacting with a robot. Positive affect is a factor that reinforces the probability of success of a robotic tool in modifying the behavior of a child with ASD. Especially where the development of social skills is concerned, children with ASD are more likely to engage in interaction with a robotic partner if the experience is enjoyable.

In the study of Kim and colleagues (2012), the researchers described engagement as "positive affect". Comparing a group of 18 children with ASD with a group of children of TD in free play in the presence of the robot Pleo, more time with the robot was spent by the children with ASD, which can be easily translated into positive affect. Wainer *et al.* (2014) employed a different approach, as they compared the engagement of ASD children in the classroom using the robot Kaspar in a triadic interaction, with positive results.

Although most of the SARs studies did not study specifically the engagement and positive affect of the children with ASD, Feil-Seifer and Mataric (2011) focused primarily on this aspect. Half of the study children with ASD showed positive affect when interacting with the humanoid robot Bandit, developed by the research group, while the other half exhibited signs of discomfort. It should be noted here that Bandit is a humanoid robot that has not yet been tested by many research groups and on different children with ASD. Kaspar and Pleo, on the other hand, are two popular robots that have been used extensively with children with ASD with no reports of discomfort or anxiety.

At this point, we are going to address our research questions, in the light of the studies reviewed here. The first question is whether eye contact and mutual attention are increased when a robotic tool is used in the intervention. The results show that robotic tools can stimulate initiation of eye contact in children with ASD, and may also help in maintaining it. Although the robotic platforms are different from each another, they are all capable of attracting the child's interest and encouraging them to maintain eye contact. This comes as no surprise, as a robot is perceived by the children as an attractive and interesting toy. Mutual attention is another aspect of social skills that is deficient in children with ASD, and the robotic partners appear to aid in its development, as most of them are designed to give prompts and attract the child's gaze.

The second question is whether social robots increase the verbal skills of children with ASD. The majority of studies showed that involvement of SARs may be associated with a greater increase in the verbal skills of children with ASD than interventions performed by a person only. Only one study showed no evidence of increase in verbal skills with the robot Kaspar, although other forms of social communication were increased after interaction with the robot.

The third research question is about imitation skills, and whether they can be developed through robot interaction. Only 2 small studies addressed this question, both restricted to observation of body moves, and with conflicting findings. One study with Kaspar showed positive results for development of imitation skills, but the other study, with Nao, failed to show imitation. No appropriate study was found on imitation of the robot's facial expressions corresponding to certain emotions, which is an area warranting future research.

The fourth and fifth questions can be answered together, as they are concern the manifestation of social behavior towards robotic partners and the effectiveness of interaction with robots as compared to human interaction. As noted above, most studies have demonstrated that robotic technology can help children with ASD develop their social skills through repeated exposure. In addition, the pleasure that the children derived from interaction with the robots appeared to enhance the learning process, which in most cases encourages the researcher or the teacher to make further use of this method of intervention.

Some researchers documented that children with ASD showed increased verbal communication with their human partner when a robot was present. During collaborative play involving two children with ASD and Kaspar, not only did the children show increased eye contact with the robot, but they also directed their gaze towards one another more often. So, the sixth research question is answered and our hypothesis that a robotic platform can work as a medium for social interaction is confirmed. Robots appear to children with ASD to be more predictable and stable in their reactions compared with humans, and they can help to bridge the communication gap between children with ASD and those around them.

Most studies based their conclusions on the success of the robot in enhancing social skills and communication in the research setting, and very few explored the maintenance of these abilities outside the study. It is important for researchers to investigate whether the newly acquired skills are being generalized to the child's everyday life as a robotic intervention should work not only in the clinical, research setting. Integration of social skills in the everyday routines of children with ASD is an important goal that should be set and evaluated by researchers and therapists.

In order to consider an intervention successful, useful information must be given to future researchers in such a way that they can reproduce it at a subsequent time. Usually, more weight is given to describing the goals, the characteristics of the participants and the results of the intervention, and less to a working description of the stages of the intervention.

In future studies, it would be of particular interest to explore the effectiveness of a robotic intervention for children with ASD of different age groups. The participants in the studies reviewed were between the ages of 4 and 14 years, meaning that most of them were schoolchildren. Some researchers maintain that robotics should be introduced in the education of children with ASD from an earlier age, in order to achieve better results in the development of verbal communication, but the optimal age has not been determined, and could be the subject of future research.

All activities that are designed by therapists, researchers or teachers for robotic intervention must be addressed at the specific group of children that are going to participate. This means that each program must be suitable for the age, intellectual level, abilities, etc., of the children. Heterogeneity between children with ASD is very and the unique characteristics of one child could either hinder or reinforce measurement of the success of an intervention program. If the intervention group is heterogeneous, inclusion of characteristics of the children should be set as variables when analyzing the results.

Robots can be used alongside with the therapist or the teacher of a child with ASD as a valuable partner in designing, implementing and evaluating intervention, but SARs cannot replace a teacher or a therapist for many reasons. Firstly, research has shown that most people prefer robotic platforms to have a supportive role in therapy, without replacing the therapist or the teacher. A robot's autonomy level affects its abilities and limitations, but the presence of a human operator is considered to be necessary by therapists and parents, especially when used for therapy or educational purposes (Coeckelbergh *et al.* 2016). In addition, without the presence of a human partner when learning from a robot, it is almost impossible for children to transfer their social skills to humans and there is a risk of failure of the intervention.

Another issue that must be taken into consideration by future researchers is how to evaluate the quality of interactions between humans and robots. Most researchers create their own questionnaires to do so, and no stable measures have been reported for such evaluations. Being able to measure the quality of such interactions in the future might help in creating more effective interventions.

The positive effects of assistive technology and specifically SARs, in enhancing the social skills of children with ASD has been demonstrated. Research carried out in different contexts, by different research teams, and using different robots, confirm that the attractive appearance, predictable reactions and simple cues of robots can modify social behaviors in these children. Many questions, however, remain unanswered and it is of great importance that research into the immediate and long-term effects of SARs intervention for children with ASD is continued.

Limitations and future directions

In this literature review, we attempted to answer some research questions about the effectiveness of SARs in enhancing the social skills of children with ASD. While most questions were answered positively, demonstrating the promise of this technique, other questions remain unanswered. According to the criteria set here, only 13 studies were included in this review, but future reviews could include more in order to produce more general conclusions. Also, future researchers can consult other guides when performing systematic reviews, such as APA's "Literature Review Guidelines", PRISMA's "Transparent Reporting of Systematic Reviews and Meta-analyses", "Literature review guidelines" by the American Psychological Association, "Five steps to conducting a systematic review" by Khan *et al.* (2003), etc. It is hoped that future studies on the use of SARs for intervention with children with ASD will use larger samples, with both qualitative and quantitative analysis, in a way that makes the results more valuable.

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Ethical approval

All procedures in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent

Informed consent was obtained from all individual participants included in the study

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