

# Socially Assistive Robotics in Autism Spectrum Disorder

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Autism spectrum disorder (ASD) is a neurodevelopmental disorders that is characterized by complex behavioral phenotype and deficits in both social and cognitive functions and has been gradually increasing for the past 20 years. However, practically there are some difficulties in diagnosis and treatment due to a limited number of specialist and considerable cost. Emerging technology, especially socially assistive robotics (SAR), has expanded into the evaluation and intervention for children with ASD. SAR refers to a robot that provides assistance to the user in a social interaction setting. SAR becomes a tool that can teach or demonstrate socially desirable behaviors to help children who have trouble expressing themselves to others owing to their underdeveloped communication and social skills as a result of ASD. This paper reviews the use of SAR to assist in the therapy of children with ASD and the extent to which the robots were successful in helping the children in their social, emotional and communication deficits was investigated. The study investigates the different roles that these robots were observed to play with children with ASD by categorizing and the outcome of studies that have been conducted in Korea. Despite the fact that SAR research is still in its formative stages, if rigorous research plans are developed based on clinical usefulness and effectiveness, and if a clinician with specialized knowledge of ASD participates in or evaluates the results of the research, there is the possibility to create a new paradigm for the treatment of ASD.

**Key Words:** Robotics; Autism Spectrum Disorder; Mental Health Services

## INTRODUCTION

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder characterized by persistent deficits in the ability to communicate and interact socially across multiple contexts, along with identifiable patterns of restricted and repetitive behaviors, interests and activities. The fundamental cause of ASD is a neurobiological impairment that obstructs the normal function of the brain, and its effects are found not in any specific area; rather it manifests with diverse symptoms that reach across the whole range of development. The Diagnostic Statistical Manual, 4th Edition, Text Revision (DSM-IV-TR) identified the condition called Pervasive Developmental Disorders (PDDs), along with the most common form, Autistic Disorder, as well as Asperger Disorder, and Rett's Disorder

as ASD disabilities presenting this type of symptoms, but more recently DSM-5, which was previously diagnosed as a subtype is now also categorized as a distinct type of ASD. The prevalence of ASD has been gradually increasing for the past 20 years. In epidemiological studies made following the publication of DSM-IV, the prevalence of ASD has been found to be 10-16 cases per 10,000 people [1] or, in the case of a study published by the Center for Disease Control and Prevention (CDC), 1 child in 68 [2]. According to the CDC report, the prevalence of ASD has increased from 1 case per 100 children in 2006 to 1 in 88 in 2008 and then to 1 in 68 by 2010 [2-4]. This means that early screening for ASD symptoms, which appear at an early age can increase the possibility of therapeutic intervention to minimize the increase of symptoms and reduce the burden that ASD puts on the family and society. However

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er, there are a limited number of professionals who are trained in the diagnosis and treatment of ASD, and because the treatment for the variety of forms in which ASD presents all require intensive individual educational and behavioral intervention, a large portion of the children with ASD are unable to receive appropriate treatment. Even for those who do have the opportunity to receive treatment, the costs are considerable due to the long treatment period required [5]. Recently, this has led to a variety of trials and research to explore the possibility of using robot systems in the diagnosis and treatment of ASD. Through simple robot systems, computer technology has the capacity to provide a variety of virtual reality environments and it is attracting further attention because of its ability to generate repetitive interceptive and counteractive actions tailored to the special situation of each child. This paper will introduce the most recent research regarding Socially Assistive Robotics (SAR) and will examine how SAR systems can be applied in the field of treating ASD. At the same time it will explore the possibilities of increasing the number of programs utilizing this kind of basic robotics and the problems and limitations related to these programs.

## SOCIALLY ASSISTIVE ROBOTICS

### 1. Definition and examples of Socially Assistive Robotics

The term SAR refers to a robot that provides assistance to the user in a social interaction setting [6]. What this means is that the robots have the possibility to perform a variety of interactions that can fulfill a clinical role without the need for a trained professional, or with a minimal contribution of the professional's time, and the SAR provides education and feedback to the user while fulfilling the role of coach and monitoring the progress of the treatment. Assistive Robotics (AR) are a similar concept to SARs, used primarily in rehabilitating patients suffering from physical impairments or disabilities, by interacting physically with the user, and by performing appropriate actions that assist the user's physical movement. Some examples of AR are wheelchair robots, mobility aides, companion robots, manipulator arms, and educational robots. Another type of conceptually similar robotics is Socially Interactive (or Intelligent) Robotics (SIR). A key feature of these robots is their ability to interact, and the interaction with the robot can help guide the user by simulating social interaction, but the robots are not specifically designed to provide people with assistance [7]. One example is robotic toys which are capable of produc-

ing a variety of facial expressions and gestures, and can imitate the user's face and movements. These robots are used to evaluate the differences in the fundamentals of other social interaction (language, gestures, etc) that are by the subjects when they interact with robots and with other people. The special feature of SARs is that they include social interaction components in order to provide assistance to the human users [8]. From the point of providing assistance to their human users, SARs are similar to IRs, but the type of assistance provided is in social interaction, rather than physical movement and while SIRs are designed to match their movements to the user's interactions with the robot, the purpose of SARs is to use familiar and effective interaction to assist the user with measurable development in rehabilitation, recovery and academic studies [6].

### 2. Socially Assistive Robotics in mental health care

SARs have already been utilized in post-stroke rehabilitation, recovery for cardiac patients, weight-loss and exercise programs, and patient education. Most recently, new applications for SARs are being explored in the field of mental health care. If we analyze the use of SARs in the field of mental health care, they can be described as companions. There has already been a lot of research regarding the effectiveness of the therapeutic effects of pets, and due to drawbacks with live pets such as the environment in hospitals, allergic reactions, the work involved in taking care of the animals and other related reasons, SARs look promising as a substitute for providing the same kind of assistance as live pets. Paro (a robot designed to look like a baby harp seal), shown in Fig. 1, is being used to provide a sense of safety to elderly people who were traumatized by the Fukushima Nuclear Plant accident, with the subjects feeling comforted when they stroke or hug Paro. Robots like this help to raise the spirits of elderly people who have dementia-related cognitive impairment or are at high risk for depressive disorders, and several studies have shown them effective in reducing stress and loneliness [9-12]. A second role that versatile SARs can fill is that of a therapeutic play partner. Another line of research on SAR applications to mental health care has focused on robots as play partners who help children in practicing or building clinically relevant skills, most often in children with ASD [13]. In addition, robots in a variety of designs are being utilized for improving concentration, facilitating joint attention and modeling appropriate social interactions. A third function they can take is that of coach/instructor, explaining the treatment program and monitor-

Companion	 <span data-bbox="1082 412 1114 455">A</span>	
Therapeutic play partner	 <span data-bbox="874 634 906 676">B</span>	 <span data-bbox="1327 634 1359 676">C</span>
Coach/Instructor	 <span data-bbox="820 1017 852 1059">D</span>	 <span data-bbox="1353 1017 1385 1059">E</span>

**Fig. 1.** Sample robots used in clinically relevant Socially Assistive Robotics research. (A) Paro (courtesy of Christine Hsu), (B) Keepon (courtesy of H. Kozima), (C) Pleo (courtesy of Innvo Labs Corporation), (D) Bandit (courtesy of M. Mataric, USC, USA), and (E) Dragonbot (courtesy of P. Guggenheim). SAR, socially assistive robotics.

ing or supervising the user's participation in the program. For example, with subjects who are elderly people suffering from dementia, the robots can demonstrate the rules for attention or memory tasks and indicate appropriate choices, and the robot can also be programmed to increase the degree of difficulty of the tasks when the user is repeatedly successful [14]. In this way the robot can serve as a coach/instructor not only at the health care facility, but also at the patient's home, making it possible to continue the treatment program at home, increasing the efficacy and compliance of the treatment program.

## SOCIALLY ASSISTIVE ROBOTICS AND AUTISM SPECTRUM DISORDER

A robot to be employed as a SAR faces significant demands; it must perceive its environment, interact with human users, display appropriate social cues, and effectively communicate with human users. Because of these special features, a SAR becomes a tool that

can teach or demonstrate socially desirable behaviors to help children who have trouble expressing themselves to others owing to their underdeveloped communication and social skills as a result of ASD.

### 1. Special features of Socially Assistive Robotics used in the field of Autism Spectrum Disorder

For effective use in the treatment of children with ASD, and important element of the SARs is giving the robot an appearance appropriate to children. A wide variety of robots with different appearances have been developed, including humanoid robots, animal-like robots and machine-like robots (nonbiomimetic), with the ability to imitate human facial expressions and gestures. Because a humanoid robot can provide the necessary social cues in a way that very closely imitate those of real people, they can be recognized more easily by children with ASD, and the robot can be programmed with applications that provide practice with the interpersonal skills that the children need [15]. On the other hand,

beyond standard applications for providing children with ASD the chance to learn social skills, sometimes it can be less difficult for the children to relate to the social cues if they are given by a robot designed as a simple animal or cartoon character, so such robots are also being developed [16]. If we investigate the functional-

ity of the SARs in (Fig. 2), we discover that in many cases things such as lights or a song are included to provide positive reinforcement to children with ASD, and in order to keep the attention of the children, the SARs may be programmed with a variety of movements and gestures. Because some children with ASD also have



**Fig. 2.** Robots used in autism therapy. (A) Kaspar (courtesy of the Adaptive Systems Research Group, University of Hertfordshire, UK), (B) Tito (courtesy of F. Michaud), (C) Roball (courtesy of F. Michaud), (D) Muu (courtesy of M. Okada, Toyohashi University of Technology, Japan), (E) Pleo (courtesy of Innvo Labs Corporation), (F) Bubble blower (courtesy of D. Feil-Seifer), (G) Nao (courtesy of Aldebaran), (H) Robota (courtesy of A. Billard), (I) Infanoid (courtesy of H. Kozima), (J) Bandit (courtesy of M. Mataric, USC, USA), and (K) RoboJang (courtesy of Robocare Co., Ltd.).

hyperactivity and impulsive behavior, it is important to avoid sharp elements on the robots, and it is important to consider the possibility that they may be knocked over or fall. It is also important that the SARs are programmed more for active interaction than passive engagement, and they need to be able to provide interaction autonomously even in the absence of the therapist [17]. Of course, it is never possible for a robot to completely replace the role played by a human therapist. For the time being, because robots are not as skilled as humans at evaluating how the child's activity needs to be reflected, human therapists remain an essential part of the treatment system [18].

## 2. The role of Socially Assistive Robotics in the field of Autism Spectrum Disorder

The most important role of SARs in the treatment program of children with ASD is in the area of eliciting target behavior to determine diagnosis and treatment. Compared to normal children, the skills of children with ASD to communicate emotionally with others is limited, including their ability to pay attention, make eye contact, their social smile, and including their emotional expressions, gestures and ability to imitate the social communication of others [19]. Using an SAR, it is possible to determine how much of a difference there is between a child with ASD and a normal child, in order to make a diagnosis, and during the treatment program, the robot can be programmed to help the child practice interactions and learn socially appropriate and desirable behavior, and also provide the child with simulated interactions with people.

### 1) Eliciting target behavior

Numerous studies have been conducted to explore the theory that robots are useful in eliciting the desired target behavior from children with ASD. They can be used to elicit the target repetitive and stereotypical behavior that characterize conditions like ASD, and also for increasing joint attention and prosocial behavior.

The former is used for diagnostic purpose, and the latter function is utilized for therapeutic purposes.

#### (1) *Eliciting target behavior for diagnosis*

Since the most typical symptoms of ASD are externalized actions, observation of these is an essential part of the process for a trained clinician when creating a developmental evaluation. Currently, there is no effective way to confirm a diagnosis for ASD using laboratory tests, imaging tests, or genetic tests. This means

that there remains the possibility that an ASD diagnoses can be linked to the subjective opinion of the clinician, and the result may vary depending on the viewpoint of the clinician. For this reason an objective quantitative evaluation of the patient's social functions is needed, and it is hoped that SARs can be utilized to fulfill this function. Not only can SARs be used for behavior evaluations in the diagnostic process for ASD, but they can be programmed to provide standardized stimuli to induce ASD's symptoms, leading to more reliable diagnoses. For example, while a child with ASD is playing a card game with a SAR, the child's tone of voice, eye movements, changes in expression, form of conversation, and degree of compliance with the robot's instructions can be influenced by the robot, and recorded for later evaluation and analysis by the research team. SARs can also be used to replace the Autism Diagnostic Observation Schedule (ADOS) currently in use, which uses tools such as a bubble gun to elicit interaction between the child and the test administrator. However, so far, research on the use of SARs as a diagnostic tool for ADS has been restricted. Up until now, research on SARs in the area of diagnosis has been focused on methods of eliciting target behaviors and on categorizing different types of behaviors. What makes it difficult to conduct sufficient studies is that methodologically, there are a large number of elements that must be included, and also it is not easy to gather a pool of subjects for study who cover all the required sectors of diagnosis, cognition, language and other elements that must be studied [20].

#### (2) *Eliciting target behavior for treatment*

The area where SARs are currently utilized in relation to ASD is in the area of treatment and special education programs. Many children with ASD are limited in their ability to comprehend the external world, and in their verbal and non-verbal communication skills. However, because it appears that robots providing interesting visual images and simple motions are more successful at eliciting response from children with ASD, they are used for therapeutic purposes, to develop prosocial behaviors in the children [21]. There is no doubt about the fact that the robots are successful in engaging the interest and participation of children with ASD.

The most prevalent research is that concerning imitation and joint attention. Imitation means learning new physical or verbal skills, very important in exploring the outside world and joint attention is crucial in creating interest and joy in relation to other people, and working toward developmental milestones in communication, learning and cooperation, both of which are not easy

to find in children with ASD [22]. Most SARs used in the treatment of children with ASD utilize imitation through simple imitation games that the children can engage in, and then providing positive reinforcement by rewarding the child with singing and dancing if the game is completed successfully [23-26].

When SARs are used, children with ASD naturally develop joint attention skills, sometimes with the robot as the subject of the joint attention, with the robot giving the child simple verbal instructions, "Look over there, what is that?" or by indicating where the child should look using head gestures [27]. A chair was placed in the middle of the research room, and images were installed in the area the child could see from the chair, and joint attention experiments were made by testing whether a robot could get the child to look at a particular image. At first, the robot had to combine a verbal instruction with a visual head gesture to get the child to look at the correct image, however as the number of successful repetitions increased, joint attention improved, and the robot was able to get the child to look at the image with a verbal instruction alone [28].

In addition, playing a game of catch with the robot, throwing a ball back and forth [29], and a 'chase-and-avoid game' [30] with the robot, gave the ASD children practice in waiting for their turn, thus improving their ability at turn-taking, a skill required for successful conversations with others. Another special feature of the SARs is that they have faces with clear open features that can express emotions, giving the children the chance to experience emotions in interpersonal interactions [31]. This means that the use of SARs is effective in contributing to the children's awareness of emotions and the ability to express them. Besides that, after the ASD children have experienced interaction with an SAR by talking or playing games, there is a greater likelihood that they can move on to three way interactions including the SAR and the therapist.

## 2) Modeling, teaching, or practicing skills

This role resembles that of "eliciting target behavior" that was mentioned earlier; however, the area where the capacity of the SARs to actively and directly teach is being utilized is the area of treatment, programming them to guide the children with ASD to acquire social skills by imitating the actions of the robots, and eventually leading them toward successful human interactions. The focus is on using the process of eliciting target behavior not once, but repeatedly, with rewards given to promote and strengthen the motivation to repeat and maintain the behavior. If we look at the social skills in this way, we see that what we are discussing is a very

complicated set of automatic mental skills, including facial expression, nuance, intonation, and other complicated elements. What this means is that the process of training people who have difficulties with social interaction, such as children with ASD, requires the inclusion of a very complicated set of elements, and it can be seen that the robots, which have the capability to make predictions, and provide simplified stimuli customized to the subject following a consistent pattern can serve a very useful role in teaching social skills. Since it has been observed that children with ASD show a preference for objects over the praise or interest given them by their therapist [32], the flashing lights, vibrations, sounds and simple movements provided by the SARs in response to appropriate responses from the children have proved to be useful in reinforcing the desired behavior.

## 3) Quantification of observed behavior

Much of the research up until now has been focused on the qualitative results of the interaction with the robots. The cited work of the most advance researchers now is taking a new focus, on the extent of the SARs' effectiveness in eliciting particular behaviors or effecting training in desired behaviors. However, from this kind of qualitative research alone, it is difficult to get a draw a generally applicable conclusion regarding the treatment of children with ASD using SARs. It is crucial to also gather quantitative data by observing children with ASD, and robots have a unique ability to do this more effectively than people. They are able to gather quantitative data regarding "time child looked at the robot", "time spent in a state of joint attention", and "frequency of attempted conversation with other participating children". This kind of trials can be found in any number of studies. For example, Jordon et al. videotaped children with ASD playing card games with robots, using a smart board and with a human opponent, and analyzed the recordings to gather data on "how much time the child watched his opponent," "how many times the child spoke to his opponent," "how many times the child demonstrated joint attention," and "how many times the child showed a happy expression." [33] In a similar study, Kim et al. also, videotaped the interaction of children with ASD with an SAR in the form of a dinosaur, and used a coding scheme to identify the actions of the children when they analyzed the video [34]. They rated the children's degree of compliance to the instructions of the therapist according to the Likert type scale to generate quantitative data. Research of this kind can provide concrete quantitative data about the effectiveness of SARs,

an important complement to the subjective qualitative data obtained in clinical trials.

### 3. Researches in Korea

Studies have already been conducted in Korea regarding visual, aural and tactile responses by children with ASD in interactions with robots [35], and starting in 2010, trials have also been made toward developing combined stimulus robots with the ability to choose the stimulus preferred by children with autism [36]. Following that, abundant data has been gathered regarding the use of robots in educational applications with children with autism and other emotional and behavioral problems in a variety of situations. In 2011, a robot that could be remotely controlled was installed in a child care center for children with disabilities, and the result of the interactions that the children had with the remotely controlled robot showed a higher frequency of child-initiated questions and a higher frequency of self expression than could be seen when the children interacted with a teacher; results which elicited high satisfaction ratings from professionals regarding the robot's capabilities [37]. In 2013, robotic programs developed at Daegu University were programmed into a robot developed at the Korean Institute of Science and Technology (KIST), and after the programs were tried out with students attending a special school for the disabled, and the results showed that the students' ability to concentrate in class showed improvement, along with their peer relationship abilities. Against the background of research like this, starting from 2014, research has been ongoing involving KIST, Daegu University, Hanyang Medical Center and other institutions, regarding "Development of diagnostic and training robot systems for students with autism and ADHD". The goal of this research is to develop

robotic systems with the capability of providing programs that can assist in the evaluation of therapeutic and educational work with children with ASD and ADHD and, while being remotely controlled, can monitor and mediate occurrences of atypical behaviors in students in special education classes for children with disabilities which Fig. 3 shows the outline of this robot system. Among the robots currently in development shown in Fig. 4, it is predicted that they will be able to identify eye movements, recognize facial expressions, be aware that a place has been vacated and identify hand and head movements, so that they will be able to not only identify the problem behaviors of children with ASD and ADHD, but also will show possibilities in being able to gather quantitative data for use in clinical work and educational programs.

### 4. Limitations and remaining issues

#### 1) Limitations to research on SARs

Even though the efficacy and effectiveness of research on this topic is in its infancy, the clinical use of interactive robots with individuals with ASD has received considerable media attention over the past decade. However, much of the published research is in journals that focus on robotics (e.g., *Autonomous Robots*, *Robotica*) rather than in prominent ASD journals or clinically focused journals. One reason for this is that much of the research up until now has produced insufficient concrete evidence, being constructed on anecdotal events or composed of educational programs without sufficient documentation [38]. In addition, the analyzable data obtained from SAR research has been limited due to the fact that the majority of research has been conducted for the purpose of developing robotic systems, rather than for evaluating the clinical effectiveness and usefulness of the robots. According to Diehl, et al.



Fig. 3. ROBOJJANG developed by Robocare Co., Ltd.

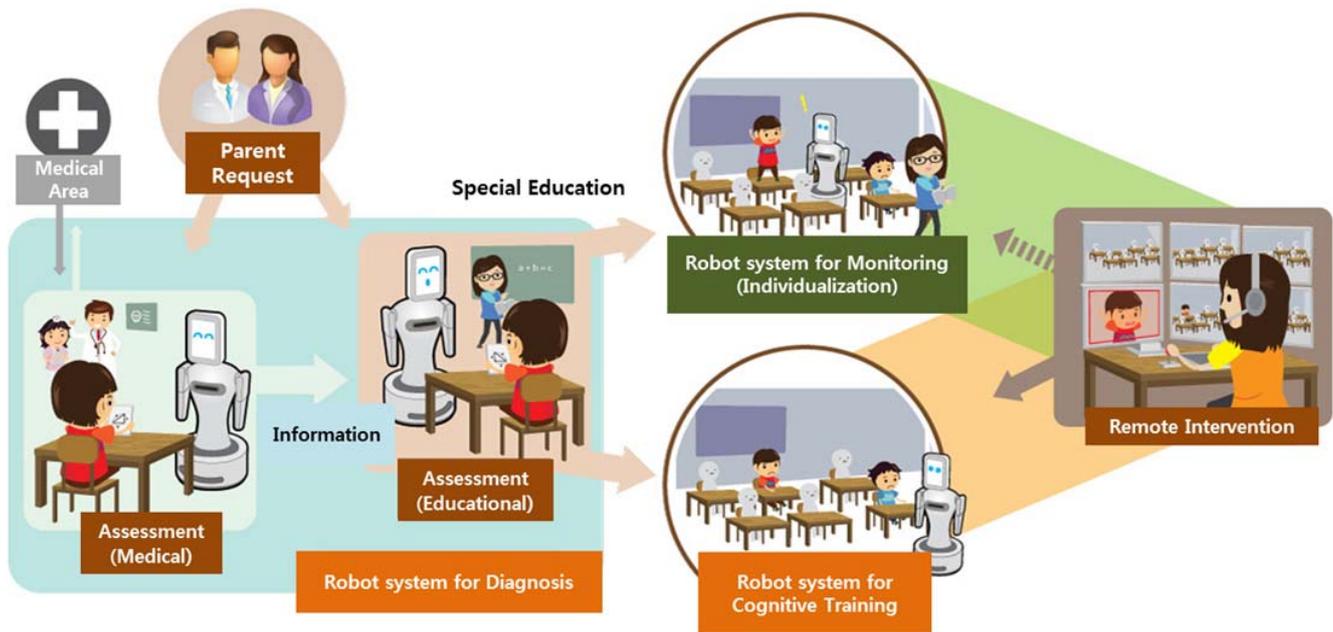


Fig. 4. Outline of robot system for the children with disabilities.

a bibliographic search of research reports revealed that among 15 academic papers published on the subject, only three concerned research with a subject pool of six or more children with ASD, and most of them were conducted with only three or four subjects [20]. In addition, only four of them utilized ASD's gold standard diagnostic tools (ADOS or ADI-R, for example), and only two of the research reports were published in clinical journals. In conclusion, there is very little research that is not limited either by the use of an insufficient sample size or because of their focus on results other than diagnosis-related data. Beyond that, most of the research case studies report only on the response of individual ASD children, omitting results on the evaluation of effectiveness within the group or between groups of children; and only a small number of the reports included results regarding a control group, which is required to allow for the possibility of conducting comparison analysis. Finally, taking a long-term look at the research, although the length of the training programs, the locations and the links between the situations do show promising results, there are restrictions. These restrictions may possibly be unavoidable because there is a wide variety of forms in the clinical presentation of children who are diagnosed with ASD, and not all of them show interest in robots, which makes it difficult to design accurate research parameters. Not only that; because this is a field of research that is in its early stages, while requiring very expensive robotic systems in order to be conducted, it is extremely difficult to conduct large-scale

research and it is also difficult to conduct research with patients' homes for extended periods of time, which puts a limit on the research possibilities [15].

## 2) Direction for future research

There is still a lot of background work that needs to be done in regards to SAR research. First of all, strict and accurate evaluations must be made of the children with ASD who are candidates for the research. Taking into consideration the wide range of characteristics connected with ASD, children being considered as part of a research group should be assessed not only with a standard diagnosis, but also the strengths and weakness in their perceptive and language abilities should also be evaluated, in order to assemble an appropriate group of research subjects. Secondly, in the majority of SAR systems currently in use, the robots are remotely controlled by people. Depending on the reaction of the children with ASD, the human who is controlling the robot from behind a curtain or by watching a video monitor from another location controls the actions that the robot makes in response. Even if the operator is quick in evaluating the reactions of the children with ASD; if that operator is not sufficiently proficient in the operation of the robot's actions in response to the children, the overall effectiveness of the process is compromised. Work is needed to sensitively evaluate the responses of the controller to the actions of the children and program the robot to make its own direct automatic responses,

and following that, the robots need further development in order to account for the frame of mind and preferences of the operator. Thirdly, further research is needed not only on what kinds of robots are most effective for therapeutic intervention for ASD, but also on which types of ASD children respond most effectively to therapeutic work with robots. If information can be gathered on how children with different levels of cognition, language, social impairment, stereotypical behavior, sensory abnormality and other characteristics are influenced by SAR therapeutic programs, it will be possible to make a much clearer evaluation of where SAR programs can be most effectively utilized. Finally, future research should also focus on increasing cognitive ability through the use of SARs. Although research up until now has been exclusively focused on changing the behavior of children with ASD, future research can provide a look at increasing the clinical effectiveness of ways interaction with the robots can contribute to improving the cognitive ability of the children with ASD, and at the differences of interactions between normally developed children and children with ASD.

## CONCLUSION

Because the most recent technological advances in SARs have been aimed at enabling the robots to imitate a variety of human behaviors or to help children with ASD to make progress in developing their social skills, the research regarding SARs can be described as being in the technical area, showing the innovations in the use of SARs in treating children with ASD. A variety of research has been conducted in the area of ASD, and despite differences in the research with regard to the nation where the research was conducted, the degree of disability of the children with ASD, the external design of the robots, the features of their interaction, and other factors, the results have been uniformly accepted across the board [39]. Even so, there is no uniform understanding of how the robots have been successful in helping children with ASD to improve their prosocial behavior and ability for social engagement. To start with, there is a hypothesis that the simple stimuli from the robots work to counteract the overstimulation that characterize children with ASD, and there is also a hypothesis that while it would be easy for small nuances to appear in the instructions of a human, who would adjust their requests or responses to match the situation, because a robot will make uniform, predictable responses, the robot is easier for the children to trust and respond to, which

means the SAR can prove to be more effective than a human clinician. Also, there is a hypothesis that it is easier for the children to approach and respond to the robots, because the interactions with the robots do not have the kind of recalled negative experiences that the children have from their relationships with people. Disregarding which of these hypotheses may be correct, there is no doubt that SARs have extensive possibilities in the diagnosis and treatment of children with ASD. Despite the fact that SAR research is still in its formative stages, if rigorous research plans are developed based on clinical usefulness and effectiveness, and if a clinician with specialized knowledge of ASD participates in or evaluates the results of the research, there is the possibility to create a new paradigm for the treatment of ASD.

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