Follow the white robot: efficacy of robot-assistive training for children with autism-spectrum disorder

Davide Ghiglino[1-2, *], Pauline Chevalier[1], Federica Floris[3], Tiziana Priolo[3], Agnieszka Wykowska[1]

[1]Social Cognition in Human-Robot Interaction, Istituto Italiano di Tecnologia, Via Enrico Melen 83, 16040, Genova, Italy

[2] DIBRIS, Università degli Studi di Genova, Via Opera Pia 13, 16145, Genova, Italy

[3]Piccolo Cottolengo Genovese di Don Orione, Via Benvenuto Cellini 22, 16143, Genova, Italy

**Corresponding author*:

Agnieszka Wykowska
Istituto Italiano di Tecnologia
Via Enrico Melen 83,
16152 Genova, Italy
Email: agnieszka.wykowska@iit.it
Tel.: +39 010 8172242

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Abstract

Background: Socially assistive robots have the potential to become a powerful therapeutic tool for individuals affected by Autism-Spectrum Disorder (ASD). However, to date, only a few studies explored the efficacy of robot-assisted training embedded in structured clinical protocols. The current study aimed at investigating the beneficial effects of introducing a toy-robot, as a new tool for clinicians, in the treatment plan carried out by an Italian healthcare institution.

Method: In collaboration with the healthcare professionals of Piccolo Cottolengo Genovese di Don Orione, we designed a robot-mediated activity aimed at improving social skills in children with ASD. Twenty-four ASD children (Age = 5.79 ± 1.02, 5 females) completed the activities with the robot in a cross-over design, during a period of ten weeks. Their social skills were assessed before and after the robot intervention activities, using the Early Social Communication Scale (ESCS).

Results: Results showed that the combination of robot-assisted training with standard therapy was more effective than the standard therapy alone, in terms of improvement of social skills. Specifically, after the robot-assisted training, children with ASD improved in their ability to generate and respond to behavioral requests, and in their tendency to initiate and maintain social interaction with the adult.

Conclusions: Our results support the idea that robot-assisted interventions can be combined with the standard treatment plan to improve clinical outcomes.

Keywords: robot-assisted intervention, autism spectrum disorder, social skills, human-robot interaction, rehabilitation

Introduction

The learning and consolidation of social abilities occur spontaneously in neurotypical individuals. This natural process is reinforced by the constant interchange between the individual and the surrounding social environment (Hala, 2013). On the contrary, such abilities are heavily compromised in individuals affected by neurodevelopmental disorders and, in particular, with Autism-Spectrum Disorder (ASD). This spectrum is characterized by persistent impairment of social interaction and social communication (Baron-Cohen, Tager-Flusberg, & Cohen, 2000), as well as behavioral stereotypies and repetitive/limited interests (for details, see the Diagnostic and Statistical Manual of Mental Disorders, DSM-5, American Psychiatric Association, 2013). Already Kanner, in his first conceptualization of autism (Kanner, 1943) identified the lack of social and emotional reciprocity of autistic individuals as unique, when compared with other psychiatric conditions. Compared with their peers, children diagnosed with ASD show a notably lower amount of behaviors aimed at initiating, responding, or maintaining social interaction, such as vocalizations, manifestations of interest, sharing of emotion, use of gesture, imitative behavior, gaze following, and joint attention (Vivanti, Nuske, 2017). One explanation of such lack of social behaviors relies on the hypothesis that individuals with ASD experience extreme difficulty in filtering sensory input, which is fundamental to discriminate relevant and irrelevant information during the interaction with the social environment (Singletary, 2015). As a cascade effect, this hyper-sensitivity to social cues would lead to difficulty in processing properly social information, causing a subsequent overload of the individual's social and cognitive resources (Hill & Frith, 2003). The severity, precocity, and specificity of social deficits in individuals with ASD have attracted the attention of clinicians and researchers, encouraging the design of different and novel therapeutic approaches (for reviews, Yates, Couteur, 2016; Fernández, Mollinedo-Gajate, Peñagarikano, 2017).

In the last decades, a large variety of technological devices has been implemented in the context of ASD therapy, to promote social interaction (Rogers, 2000). The use of technological tools that can act as mediators of the communication between the child and the therapist, seems to stimulate the engagement of ASD individuals and improves the clinical outcome (Soares et al., 2021). In particular, toy robots have been efficiently used as clinical tools to extend and enhance social competencies in children with ASD, as they are usually relatively cheap and easy-to-use (for reviews on the topic, see Begum, Serna & Yanco, 2016; Cabibihan, Javed, Ang, & Aljunied, 2013; Diehl, Schmitt, Villano, & Crowell, 2012; Scassellati, Admoni, Matarić, 2012). Some of the main advantages of robotic tools consist of their physical embodiment and in the extensive control that the experimenter/clinician can exert on their behaviors (Cabibihan et al., 2013; Liu, Conn, Sarkar, & Stone, 2008), which allows for featuring them with simplified and repetitive versions of human-like behaviors (Walters, Syrdal, Dautenhahn, Te Boekhorst, & Koay, 2008). Their minimally expressive design seems to prevent also the sensory overload perceived by ASD children during interactions with other humans (Dautenhahn et al., 2009). Additionally, their attractiveness for children makes them a useful tool to engage individuals and their families in rehabilitation activities (Pennisi et al., 2016; van Otterdijk et al., 2020). From a psychological point of view, for ASD individuals, robots represent safe, predictable, and coherent environments to experience prototypes of social interactions (Dautenhahn & Werry, 2004).

Research on the topic is rapidly growing, as it is becoming more and more relevant to understand the most effective use clinicians can make with robot-assisted intervention in the context of ASD rehabilitation. In particular, it is important to understand how well such tools can be adapted to existing therapeutical approaches, and whether they can be used by therapists during daily clinical practice. In this context, Huskens et al. (2013) piloted a robot-assisted training based on Applied Behavioral Analysis (ABA, see Axelrod, McElrath & Wine, 2012) to promote question-asking in a small group of children with ASD. ABA is one of the most commonly used interventions for children with ASD and aims at identifying maladaptive behaviors to provide the individual with new strategies and to teach appropriate behavioral responses. Based on such aim, in the training proposed by Huskens et al., a NAO robot (SoftBank Robotics, Tokyo, Japan) prompted children with impairments in social communication skills to initiate and respond to verbal requests across four subsequent sessions of 10 minutes, encouraging them to interact proactively. The authors found that the training administered by the robot was well accepted by the children, and comparable to a similar training administered by a human therapist, in terms of efficacy. In another exploratory study, Huskens et al. (2015) explored the effectiveness of a different robot-assisted intervention on improving collaborative behaviors between ASD individuals and their siblings. In this study, the NAO robot was used as an interaction partner and assisted children during collaborative Lego play (see LeGoff, 2004; Owens, Granader, Humphrey, & Baron-Cohen, 2008), for a duration of three to five sessions of 30 minutes each. Although the obtained results were not statistically significant, presumably due to the small sample, the authors reported qualitative improvements in the children's tendency to play with their siblings, attributable to the activities carried out with the robot. In another more recent study, Cotescu, Vanderborght, and David (2017) designed and tested the efficacy of a robot-assisted intervention based on cognitive behavioral therapy protocols (CBT, see Wood & Schwartzman, 2013) which aims at reducing emotional dysregulation in ASD individuals. In their study, the authors used the feedbacks provided by the robot Keepon (Cao et al., 2014) to reinforce therapists' teaching during group sessions in which ASD children learned adaptive cognitive strategies to deal with negative emotions. Their findings highlighted that toy-like robots can successfully mediate the interaction between children and therapists, boosting individuals' learnings in group training scenarios. Recently, in a series of studies conducted in The Netherlands at the Karakter Child and Adolescent Psychiatry, several authors tested the efficacy and acceptability of robot-assisted intervention for ASD children embedded within Pivotal Response Treatment protocols (PRT, see Koegel, Ashbaugh, & Koegel, 2016). PRT aims at improving generic social competencies of ASD individuals by targeting key abilities such as social motivation and behavioral initiative, which might be enhanced by embedding a robotic-mediator in the standard treatment plan. In this context, De Korte et al. (2020) demonstrated that a 20-week robot-assisted intervention with NAO strongly improved functional self-initiation of the interaction of ASD children when combined with the standard PRT. In their study, the authors trained a therapist to autonomously use the robot with the children, to carry out a series of different games during therapy sessions. The authors assessed the incremental value of their training over standard PRT alone, as well as the perceived attractiveness exerted by the robot on the children, which seemed to positively affect also individuals' social motivation and engagement (Berk-Smeekens et al., 2020). Furthermore, in another follow-up study on the same sample, Otterdijk et al. (2020) showed that the prolonged exposure to different activities with NAO during rehabilitation sessions does not decrease the engagement that ASD children and their parents display during therapy, which was high even after the 20th week. In another recent study, also Zheng et al. (2020) deployed a NAO robot to improve prerequisites of social communication skills in a group of young children with ASD. In their training, the authors used a dynamically adapting robot to direct the attention of children towards objects (i.e. lateral screens) by using social gestures (i.e. pointing, gazing) and verbal prompts. The authors reported a significant improvement in joint attention of one sub-group of ASD individuals. However, when they considered their entire sample, they did not find statistically significant effects of their training. This may indicate that ASD individuals have an inhomogeneous response to robot-assisted interventions that target joint attention, possibly depending on the individual's level of impairment and the specificity of the training. Indeed, a previous study of the same authors (Warren et al., 2015), reported that after only four sessions of a generic neuro-cognitive robot-assisted training, children with ASD improved in joint attention. Other authors also demonstrated that robot-assisted activities that are aimed at training joint attention positively affect collateral social competencies, such as sharing objects, turn-taking, and reciprocal behaviors (Kozima, Nakagawa, & Yasuda, 2007; Ricks & Colton, 2010; Kim et al., 2013). Importantly, all the improvement in social skills learned during robot-assisted interventions seems to extend to social interaction with other humans (François, Robins, Dautenhahn, Te Boekhorst, & Billard, 2005; Powell & Dautenhahn, 2009; David et al., 2018; Marino et al., 2020).

The adoption of robot-assisted protocols in clinical contexts is fairly recent, but a consistent amount of results supports their efficacy (Aresti-Bartolome & Garcia-Zapirain, 2014; Coeckelbergh, et al., 2016). So far, socially assistive robotics has been studied with a huge variety of methods, attracting the attention of several communities, from social scientists to human-robot interaction researchers (Pennisi et al., 2016; Chevalier, Kompatsiari, Ciardo, & Wykowska, 2019).

Most of the above-mentioned authors converged in claiming that the use of robots in clinical practice may have positive effects on the clinical outcome of ASD children, even if, sometimes, the effects were not statistically significant and only qualitative. Still, additional studies are needed to build confidence in the strength and generalizability of such results and to clarify the feasibility of embedding prolonged robot-assisted training within the clinical environment. Indeed, it is fundamental to demonstrate that robots can be useful tools for clinicians to be used during daily rehabilitation sessions, as an additional resource to train the social skills of ASD individuals. However, most of the studies to date rely on the presence of an experimenter controlling the robot and seem to treat the robot as a method of therapy delivery instead of a tool at the service of healthcare professionals (Robinson, Cottier, & Kavanagh, 2019). Only a few studies so far have attempted to effectively embed a robot-assisted training in the standard treatment plan as one of the tools that healthcare professionals can autonomously use during one-to-one rehabilitation sessions. It is fundamental to clarify whether toy-like robots can be used effectively by therapists as an aid to engage patients and to stimulate specific competencies. Indeed, the applicability of such technologies in the clinical environment requires the development of solutions allowing healthcare professionals to run the activities with the robot autonomously, without the need for constant technical support. Exploring solutions that could ease the adoption of such technologies in the clinical environment is of the utmost importance, especially when the activities are tailored to young individuals with ASD, who might feel uncomfortable in the presence of a stranger (i.e. the experimenter) during therapy sessions (Robins, Dautenhahn, & Dubowski, 2004).

Based on these considerations, the current study aimed at exploring whether robot-assisted training, carried out by healthcare professionals alone during one-to-one rehabilitation sessions across several weeks, could affect the social skills of ASD children. To meet this aim, we designed a cross-over study in which children with ASD were exposed to activities with a toy-like robot in the context of the ABA treatment plan recommended by the Local Health Authority (Azienda Sanitaria Locale – ASL). During the activities, healthcare professionals were able to operate the robot autonomously and independently. For a duration of ten weeks, healthcare professionals of the Piccolo Cottolengo Genovese di Don Orione combined the robot-assisted training we designed with their regular therapy sessions. Importantly, we decided to be as inclusive as possible with ASD individuals who took part in the study, not limiting our sample to high-functioning children. This choice was made in accordance with the healthcare professionals, as we wanted to evaluate the versatility of the protocol in real-life scenarios, avoiding a selection bias. Therefore, the novelty of our study relies also upon the ecological approach that we applied, by taking into account the practical needs of healthcare professionals, who assist a heterogeneous panorama of patients daily. It is important to point out that our aim was to highlight the role of toy-robots as an addition to a standard therapy conducted by a human therapist; this should not, by any means, promote any approach of replacing with a robot a therapy conducted by a human therapist.

Methods

Participants

All children included in the study met the criteria for ASD according to the DSM-5 (American Psychiatric Association, 2013). Diagnoses were provided by the Local Health Authority (Azienda Sanitaria Locale – ASL) through the administration of diagnostic tools (i.e. Autism Diagnostic Observation Schedule – ADOS, Lord, Rutter, Di Lavore, 1999; Autism Diagnostic Interview-Revised - ADI-R, Rutter, Le Couteur, Lord, 2003) and endorsed by the healthcare professionals of the Piccolo Cottolengo Genovese di Don Orione. The recruitment process was supported by healthcare professionals of the Piccolo Cottolengo Genovese di Don Orione. Relatives of children diagnosed with ASD relating to this healthcare institution were informed about the possibility of taking part in the study. Before the beginning of the study, we presented the design, the procedure, and the rationale of the project to the families that were interested in participating. At the same time, we informed all families about the aims of the study and we provided them with a copy of the informed consent form they would be asked to sign in case of participation. Few weeks after the presentation of the study, we collected the informed consent to participate from the families of thirty-six children (age = 5.69 ± 1.06, 5 females). Eventually, twenty-four children completed the entire training and were included in the final sample (age = 5.79 ± 1.02, 5 females). Our experimental protocols followed the ethical standards laid down in the Declaration of Helsinki and were approved by the local Ethics Committee (Comitato Etico Regione Liguria). For each child taking part in the study, the written informed consent signed by his/her parents/legal tutors was collected and stored by healthcare professionals of the Piccolo

Cottolengo Genovese di Don Orione. We included in the sample each child whose parents provided informed consent.

Study Design

To grant all the children involved in the study the possibility of interacting with the robot, we opted for a two-period crossover design. This repeated-measure design consists of exposing participants to a sequence of two different treatments, during two different periods, and minimizes confounding effects on results due to the order of administration of the treatments. In such design, each participant crosses over from one treatment to another, and the improvements due to each of the treatments are eventually compared. In our case, participants were exposed to robot-assisted training and the standard therapy, and the efficacy of both pieces of training on the individual's social skills was compared (Figure 1).

- Figure 1 -

Considering the relatively small sample, we divided participants into two groups: one group (Group 1) received the robot-assisted training during the first period of the study and the standard therapy during the second period, the other group (Group 2) received the treatments in the reverse order. Children were assigned to the two groups, taking into account the information gathered from the Local Health Authority. More specifically, based on clinical observations and the results of ADOS and ADI-R, individuals with ASD are usually clustered in three functional levels, according to criteria outlined in the DSM-5 (for details, see the Diagnostic and Statistical Manual of Mental Disorders, DSM-5, American Psychiatric Association, 2013). According to the DSM-5 guidelines, the Level 1 of ASD comprises individuals who require support due to their difficulties in initiating social interaction and in organization and planning. On the other hand, Level 2 includes individuals who require substantial support, as their social interactions are usually limited to narrow special interests and accompanied by restricted and/or repetitive behaviors. Level 3 refers to individuals who require very substantial support, due to severe deficits in social communication and their great distress can be caused by changing actions or focusing on activities. Even though dividing individuals with autism purely on DSM-5 functional levels may be considered an over-simplification of ASD clinical manifestation, we wanted to maximize, as much as possible, the homogeneity between the study arms, in terms of functional profiles. Therefore, we considered DSM-5 functional levels to pseudo-randomly assign children to the two experimental groups. Additionally, we balanced children's chronological age across the groups (see Table 1 for details).

Table 1

Initial sample

DSM-5 Levels	4 years old		5 years old		6 years old		7 years old		Total
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2	
Level 1	2	3	2	2	1	1	2	1	14
Level 2	1	1	1	2	2	2	0	1	10
Level 3	2	1	2	2	2	1	1	1	12
Total	5	5	5	6	5	4	3	3	

Grouping based on the DSM-5 functional levels and chronological age.

Before the beginning of the activities with the robot, children's intelligence/mental age was assessed with the Italian versions of Griffiths' Developmental Scales (see Green et al., 2015).

Study Intervention

The training activities were carried out using Cozmo (Anki Robotics, San Francisco, CA, USA), a small commercial toy-robot. All the activities were carried out autonomously by a healthcare professional (in our case, either a logopedist, a psychomotricist, or a psychotherapist), during regular therapy sessions. Before the beginning of the activities, all the healthcare professionals that were involved in the study (n = 19, mean age: 35.74 ± 7.51, 1 male) underwent a two-day training with the authors of the study. During the training, they received all the instructions needed to control the robot autonomously and practiced with the protocol. Eventually, healthcare professionals were able to control the robot across the entire duration of the study, through an easy-to-use application that we developed ad hoc (for a screenshot of the interface provided to the therapists, cf. Fig. 2a). Thus, all Cozmo's actions and feedback described below were controlled by the healthcare professional during regular therapy sessions.

Each training session consisted of twelve turns of a game with the robot, lasting approximately ten minutes in total. During each turn, the robot and the child were facing each other. Two electronic cubes were positioned between the robot and the child (Fig. 2b)

- Figure 2 -

At the beginning of each turn, the two cubes lit up in two different colors. The robot turned towards one of the two cubes, "looked" at it for a few seconds, and came back to the original position, "gazing" at the child. Then, the child was asked by the healthcare professional which one of the cubes Cozmo looked at. The child was allowed to respond either verbally or manually (pointing to the cube, touching it, or touching the corresponding color on a piece of paper). Based on the correctness of the child's answer, the robot reacted with a smile (positive feedback) or a sad face (negative feedback). Besides, the therapist was allowed to avoid providing any feedback in case it was evaluated as not necessary or counterproductive. After Cozmo's feedback, the turn ended and a new turn started. The relatively short duration of each training session was determined to minimize the conflict with other therapeutical activities that were carried out by clinicians. Additionally, to grant to the healthcare professionals the possibility to run activities in parallel, and to avoid coordination issues, a total of five Cozmo robots were disposed of for the study. Furthermore, the custom-made interface developed to control the robot was installed on each healthcare professionals' computer so that everyone in the facility could access it in case of substitutions.

Study Outcomes

The main outcome of the study was the clinical improvement measured using the Early Social Communication Scale (ESCS, Seibert, Hogan, & Mundy, 1982). The scale was used to assess children's social and communicative abilities before the beginning of the activities and after each phase of the study.

The scale consists of a structured observation that evaluates the child's social skills across several semi-structured situations. In particular, the scale evaluates three dimensions: Social Interaction, Joint Attention, and Behavioral Requests. These three components are evaluated in parallel, and they are interdependent. The dimension of Social Interaction refers to the tendency of the child to engage in playful turn-taking interactions with others. The dimension of Joint Attention refers to the individual's skill in using non-verbal behavior to share the experience of objects with others. The dimension Behavioral Requests refers to the child's skills in using non-verbal skills to request aid in obtaining objects. The ESCS is often used by healthcare professionals to assess the nonverbal social skills of individuals with ASD. In the case of neurotypical individuals, the scale is administered to children with a mental age between 8 and 30 months of age. However, the Italian version of the scale is vastly used by healthcare professionals to assess the social skills of older children in case of proven communication deficits (Molina et al., 2016). Thus, for the current study, we adopted the ESCS, taking into account the heterogeneity of communication skills between ASD individuals of our sample, and the presence of non-communicative individuals. This choice allowed avoiding the exclusion of participants solely based on their communication skills and allowed also assessing the efficacy of our robot-assisted training with a clinically valid, uniform measure. Our choice may be considered a methodological weakness, as some of the older children may be at the ceiling level for the scale already at the first time point of evaluation. To minimize such bias, we considered the difference between two subsequent assessment time points as an indicator of the clinical progress (see section "Data Analysis" for details), instead of raw scores. In other words, the improvement of children who reached the ceiling level at the first evaluation was considered null. This approach was inclusive but extremely conservative, as a “null improvement” was against our a-priori hypotheses. Additionally, it is important to point out that our first aim was to harmonize robot-assisted training with healthcare professionals’ routines. Therefore, we chose to compromise the methodological rigor with the competencies and resources that healthcare professionals had when we introduced the robot within their standard treatment plans.

After the first assessment using the ESCS (T0), all children underwent an initial familiarization phase with the robot, consisting of a prototype of the proper training. This phase was necessary to assess whether the children were able to understand the instructions and engaged in the activities with the robot. After the familiarization phase, ten children were excluded from the study, as they were either unable to understand the instructions of the game or were uncomfortable/uninterested in the activities with the robot. Immediately after the familiarization phase, Group 1 started the robot-assisted training period while Group 2 continued the standard therapy for the subsequent five weeks. After Group 1 completed the robot-assisted training period, both groups were evaluated (T1) using the ESCS. Then, Group 2 started the robot-assisted training period, while Group 1 received the standard therapy, for a total of five weeks. Eventually, both groups were assessed a third time using the ESCS (T2). As a result of our design, both groups underwent robot-assisted training, twice a week, for five weeks. The duration of the training was between 10 and 15 minutes per session. The healthcare professional assessing children's improvements with the ESCS was blinded to the order of administration of the treatment.

During the second robot-assisted training period, two children were retreated from the study by their families due to personal reasons and were consequently excluded from the final sample. A total of twenty-four children (Age = 5.79 ± 1.02, 5 females, IQ(Griffith) = 58.08 ± 19.39) completed both the training and control phases (see Table 2 for details).

Table 2

Final sample

DSM-5 Levels	**4 years old**		**5 years old**		**6 years old**		**7 years old**		**Total**
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2	
Level 1	1	1	1	1	1	2	2	2	11
Level 2	0	0	0	1	1	2	1	1	6
Level 3	1	0	2	1	1	1	1	0	7
Total	2	1	3	3	3	5	4	3	

Grouping based on the DSM-5 functional levels and chronological age.

Data Analysis

To mitigate the effect of confounding factors due to the heterogeneity of ASD manifestation between Group 1 and Group 2, chi-square analysis was applied to the frequencies of DSM-5 functional levels across Group 1 and Group 2. Additionally, a Wilcoxon signed-rank test on the children's Griffith scores was applied to verify that there was no difference between the groups in terms of mental age. Detailed results of these analyses can be found in the Supplementary Materials.

Considering the unbalanced distributions of our ESCS scores, the dependent variable of the analyses related to the improvement on each ESCS subscale was the difference calculated between two subsequent assessments (T1 – T0; T2 – T1; Table 3 reports average ESCS scores at each time point by group).

Table 3

ESCS scores

Group	*Dimension*	*Sub-dimension*	*T0*	*T1*	*T2*
Group 1	**Social Interaction (SI)**	**Initiating SI**	4.43±5.63	14.72±8.44	14.80±8.47
		Responding to SI	10.52±10.77	14.65±9.96	16.21±9.54
		Maintaining SI	5.73±9.18	10.73±10.64	10.73±10.64
	Behavioral Requests (BR)	**Initiating BR**	8.96±8.36	12.71±8.69	15.00±7.23
		Responding to BR	8.02±8.86	10.15±8.10	10.33±7.94
	Joint Attention (JA)	**Initiating JA**	2.58±5.63	4.04±5.95	4.18±5.87

		Responding to JA	9.48±9.00	14.45±8.24	14.95±8.14
		Maintaining JA	5.24±6.44	9.17±7.60	9.98±8.01
Group 2	**Social Interaction (SI)**	**Initiating SI**	12.86±10.80	15.36±8.80	16.93±7.83
		Responding to SI	12.44±10.22	16.10±9.74	18.75±8.34
		Maintaining SI	8.51±10.43	10.83±10.59	15.74±10.15
	Behavioral Requests (BR)	**Initiating BR**	11.35±10.08	10.10±7.47	17.64±6.84
		Responding to BR	9.63±7.69	10.88±7.20	15.08±5.62
	Joint Attention (JA)	**Initiating JA**	2.13±2.70	4.63±5.85	7.44±6.97
		Responding to JA	11.73±9.15	15.40±9.16	18.53±6.15
		Maintaining JA	9.52±6.93	11.41±8.59	14.89±7.52

Average scores of social skills assessed with the ESCS in Group 1 and Group 2 across the periods of the study

For data analysis, a series of mixed-effect models were applied to investigate the overall effect of the robot-assisted training (treated as the fixed factor) net of potential individual differences (treated as the random factor), regardless of the order of administration of the treatment. Analyses were conducted using the lme4 package (Bates, Maechler, Bolker, & Walker, 2014) in R Studio (R Studio Team, 2015). Parameter estimates (β) and their associated t-tests (t, p), were calculated using the Satterthwaite approximation for degrees of freedom (Kuznetsova, Brockhoff, & Christensen, 2015) and presented to show the magnitude of the effects, with bootstrapped 95% confidence intervals (Efron & Tibshirani, 1994).

Between- and within- groups effects of the training on the children's social skills were further assessed using separate Wilcoxon signed-rank tests. Results related to the Wilcoxon signed-rank tests can be found in the Supplementary Materials.

Results

Social Interaction

The combination between the standard therapy and the robot-assisted training turned out to be more effective than the standard therapy alone in the improvement of children's tendency to initiate social interaction [$\beta = 4.64$, $t_{23} = 2.39$, $p = .026$, 95% CI = (0.83, 8.45)](Combined treatments: M = 5.93, SE = 1.38; Standard therapy: M = 1.29, SE = 1.38). However, no significant difference between the treatments was found with respect to the improvement of children's tendency to respond to social interaction [$\beta = 0.77$, $t_{23} = 0.51$, $p > .05$, 95% CI = (-2.17, 3.72)](Combined treatments: M = 3.39, SE = 1.06; Standard therapy: M = 2.61, SE = 1.06). Furthermore, only a marginal difference between the treatments was found on the tendency to maintain social interaction [$\beta = 3.79$, $t_{23} = 2.06$, $p = .051$, 95% CI = (0.18, 7.41)](Combined treatments: M = 4.95, SE = 1.30; Standard therapy: M = 1.16, SE = 1.30).

Behavioral Requests

The combination between the standard therapy and the robot-assisted training was more effective than the standard therapy alone in the improvement of children's tendency to initiate behavioral requests [$\beta = 5.12$, $t_{23} = 2.95$, $p = .007$, 95% CI = (1.73, 8.52)](Combined treatments: M = 5.64, SE = 1.23; Standard therapy: M = 0.52, SE = 1.23)(Fig. 3a). Furthermore, we found a marginal difference between the treatments on the improvement of children's tendency to respond to behavioral requests [$\beta = 2.45$, $t_{23} = 2.07$, $p = .050$, 95% CI = (0.14, 4.76)](Combined treatments: M = 3.17, SE = 0.84; Standard therapy: M = 0.72, SE = 0.84)(Fig. 3b).

- Figure 3 -

Joint Attention

We found no significant difference between the combination of the standard therapy with the robot-assisted training and and the standard therapy alone with respect to the improvement of children's tendency to initiate joint attention behaviors [$\beta = 0.81$, $t_{23} = 0.69$, $p > .05$, 95% CI = (-1.51, 3.13)](Combined treatments: M = 2.13, SE = 0.84; Standard therapy: M = 1.32, SE = 0.84), respond to joint attention behaviors [$\beta = 1.96$, $t_{23} = 1.53$, $p > .05$, 95% CI = (-0.54, 4.47)](Combined treatments: M = 4.05, SE = 0.91; Standard therapy: M = 2.09, SE = 0.91), or tendency to maintain joint attention [$\beta = 2.35$, $t_{23} = 1.96$, $p > .05$, 95% CI = (0.01, 4.69)](Combined treatments: M = 3.70, SE = 0.85; Standard therapy: M = 1.35, SE = 0.85).

Discussion

The current study aimed at investigating whether a toy robot can be a useful tool for clinicians to train the social skills of children with ASD during one-to-one rehabilitation sessions. We exposed a group of ASD children to repetitive interactions with a commercial toy robot Cozmo, which was included in their standard therapy plan for several weeks. During each session of the training, children were asked to observe and respond to the behavior of the robot, which was performing a simple movement toward an object.

Our results converged in showing that the prolonged and systematic interaction with a toy-robot, that makes repetitive non-verbal requests during therapy sessions enhances the improvement of social skills. Specifically, the robot-assisted training we designed boosted children's ability to make and respond to behavioral requests using non-verbal communication. Children improved mainly in the ability to initiate behavioral requests, using pointing and gazing to communicate their needs. These results are paralleled by the improvement we found in social interaction abilities: after the robot-assisted training, children tended to initiate and maintain social interaction more than after standard therapy alone.

The behavior we implemented in the robot was designed to be a simplification of common social behavior, composed of behavioral requests and turn-taking. Indeed, while interacting with other humans, neurotypical adults tend to express intentions through a complex series of non-verbal behaviors (Argyle, 1972). For example, one can express the need for an object or an intention towards an object, just by gazing at it, which is a form of non-verbal behavioral request (Shepherd, 2010). For neurotypical adults, the gaze is an extremely important signal for social interaction and communication (Csibra and Gergely, 2006). A review by Senju and Johnson (2009) pointed out that perceived direct gaze can even modulate subsequent cognitive processes and behavioral responses. Autonomic arousal in response to gaze cues has been associated with some of the social deficits displayed by ASD individuals (i.e. emotion identification, affect sharing, attentional orienting; for a review, see Cuve, Gao, & Fuse, 2018). Such atypical responses to gaze cues might preclude the correct development of higher-level social skills, such as pragmatic competencies (Loukusa, Moilanen, 2009) and theory of mind (Von Dem Hagen, Stoyanova, Rowe, Baron-Cohen, & Calder 2014), which require the exploitation of non-verbal, behavioral cues displayed by the social partner. In our study, the behavior of the robot was aimed at prompting repetitively the attention of the child towards one of the cubes, not only through the robot's "gaze", but also orienting its entire body towards the object. The inclusion of such non-verbal, behavioral cues was designed to maximize children's understanding of the robot's "requests". Indeed, when an individual makes a non-verbal request, by gazing at or pointing to an object, the interaction partner needs to first compute the behavioral cues and, subsequently, engage their attention on the requested object (Huang, Andrist, Sauppé, & Mutlu, 2015); then, if the interaction partner succeeds in the correct understanding of the behavioral cues, the solution for the request may be provided, accordingly to circumstances and with a timing that respects turn-taking dynamics. We designed our training based on this relatively simple kind of social interaction, taking into account that providing an answer to behavioral requests requires an understanding of several social signals and norms, ranging from the ability of understanding non-verbal cues of communication to the understanding of social dynamics (Knapp, Hall, Horgan, 2013).

Our results indicate that this relatively simple and predictable interaction with a commercial toy-robot was useful to encourage children to initiate social interaction and make non-verbal requests while interacting with an adult. In general, the repetitive exposure to the behavior of the robot translated into the enhancement of fundamental social competencies, which are crucial for an individual with limited communicative skills. For a more in-depth understanding of the meaning of our results, they need to be interpreted along with the scale we used for the assessment of social skills.

The ESCS is vastly used in the clinical environment during the assessment procedure of children with neurodevelopmental disorders. One of the key features evaluated with this scale is the ability of the child to understand and behave according to the rules of turn-taking and communication during playful scenarios (for details, see Seibert, Hogan, & Mundy, 1982). Indeed, the ESCS evaluates the ability of the child to communicate efficiently, making requests, and responding to the activities proposed by the adult. In particular, the subscale related to Behavioral Request focuses on the non-verbal strategies that the child uses to communicate a desire to the adult or to respond to the adult's requests. The subscale related to Social Interaction refers to the spontaneous tendency of the child to take part in playful activities with a positive attitude. The subscale related to joint attention behaviors refers to the child's tendency of using non-verbal behaviors to share the experience of objects or events with others. Given the design of our training, we speculate that children included in our study explored mainly the ability to communicate requests and respect turns during the interaction. The task required the child to respond to what color was the cube that the robot was turning towards. This required the child to read the robot's behavior as a non-verbal request, similar to pointing or gazing. We speculate that the repetitive exposure to the robot's non-verbal requests, during a turn-taking game, promoted the children's tendency to display similar non-verbal gestures during the spontaneous interaction with the adult. The lack of effect of training on joint attention score in ESCS might be because the ESCS considers joint attention as the tendency to share experiences of objects or events with others, without an instrumental or imperative purpose. The training we designed was not aimed to cover this aspect of the interaction, as the non-verbal communication of the robot had always an instrumental connotation. Additionally, the robot was not presented as a social partner during the activities. This may have downgraded the social motivation and engagement children felt towards the toy. Thus, the lack of a significant effect on the children's joint attention is coherent with the design of the training. Interestingly, the toy robot we used for this study was extremely simple, and the improvement of social skills did not require exposing the children to a humanoid robot, that would have been able to display a more accurate pointing or gazing behavior. This suggests that ASD children might be able to abstract the behavior displayed by a robot and to adapt it to their behavioral repertoire. In our study, this translated into a significant improvement in the ability of the children to initiate social interactions and behavioral requests by adopting non-verbal strategies of communication.

The improvement in the social skills of children involved in our robot-assisted training is in line with previous studies, supporting the idea that robots can play the role of enhancers of clinical outcomes (Ismail, Verhoeven, Dambre, & Wyffels, 2019). In line with previous research, our results showed that robot-mediated activities can help children with ASD understanding some of the fundamental features of social interaction (Matarić & Scassellati, 2016). In this sense, robot-assisted and robot-mediated activities can be beneficial considering the repetitiveness and the simplicity of the behavior that the robots can display. More importantly, our study showed the even low-cost, commercial toy robots can be adopted by healthcare professionals as useful tools in clinical practice. Indeed, most of the robots used in ASD research may not be reasonable for clinical applications due to their high cost, and the level of skills required to operate them (Saleh, Hanapiah, & Hashim, 2020). The training we developed took into account the practical aspects related to the adoption of such technologies, from the cost of the devices to the easiness of controlling them. We recognize that using toy robots instead of complex humanoids implies several constraints, first and foremost the limited behavioral repertoire that the robots can display. However, one of the final aims of assistive robotics should be providing healthcare professionals with affordable tools that they can use in their everyday practice. Therefore, all the methodological choices made while designing the current study were taken following healthcare professionals' needs and requirements.

We also acknowledge some limitations of the current study, that should be considered for future research. First, the use of the ESCS might have reduced the strength of our results. Due to the relatively small sample size, it was not possible to run further reliable analyses stratifying by DSM-5 functional levels of ASD. We speculate that individuals with higher communication impairments benefited the most from the training, but it was not possible to test such a hypothesis. However, it is important to point out that the adoption of assessment tools that are already being used in the clinical domain to evaluate the efficacy of assistive robotics gives further ecological validity to this research. Nevertheless, future research should include a broader and deeper assessment of the participants' social skills that can be affected by robot-assisted training, minimize the risk of type-II errors.

Another limitation of the current study was due to the drop-out rate we faced from the beginning of the activities. Indeed, the groups in which the original sample was divided suffered from the high drop-out rate (1/3 of the initial sample dropped out between T0 and T1). Initially, children were pseudo-randomly assigned to the two groups taking into account their chronological age, Griffith's scores (evaluating the individual's mental age), and the DSM-5 functional level (evaluating the severity of the diagnosis). After the drop-out, Group 1 ended up being slightly worse at T0 under most of the ESCS scales (see Supplementary Materials for details). However, the cross-over design, combined with the mixed effect models, should minimize the confounding effect due to the unbalancing between groups, as each individual could be treated as their control. Unfortunately, studying the effects of prolonged exposure to technologies in clinical populations entails the risk of drop-outs, that cannot be foreseen a-priori. To minimize such limitations, authors should be as inclusive and flexible as possible, especially when it comes to children and fragile individuals.

Conclusion

Taken together, our results support the idea that the adoption of an easy-to-use, low-cost toy-robot in a clinical environment positively affects therapy outcomes. Children with ASD received robot-assisted training in combination with the standard treatment plan, during their regular therapy sessions. Children undergoing the combined treatment improved better than the others in their ability to make non-verbal requests to a human partner, and in the understanding of behavioral requests of the adult. Our results also showed that skills learned through the interaction with the robot within the clinical environment are spontaneously extended to the interaction with other humans.

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Conflict of interest

The authors declare no conflict of interest.

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Figure Legends

Figure 1 – *Crossover design*. The figure depict the experimental design adopted in the current study

Figure 2 – *Experimental setup*. On the left: experimental setup showing the Cozmo robot and the cubes used for the training. The Cozmo robot is a palm-size robot, similar in size a shape to a remote control truck. It can move in every direction though tracked wheels. It is provided with a bucket that allows for some degrees of interaction with obects (tapping, moving, lifting) and can be used to enhance its emotional repertoire (lifting it genlty when it displays happiness or frantically when it displays agitation). Further details on its design and functioning can be found in the product description (available at: https://ankicozmorobot.com/). On the right: the control panel of the application provided to the therapists to run the training. Using the panel, the therapists were able to start the trial (section B), annotate the answer, and provide feedback through the robot (section D). Additionally, therapists were able to provide intra-trial encouragements using additional feedbacks (section A) and to make the robot move again toward the target cube (section C).

Figure 3 – *Improvements on Behavioral Requests*. Violin plot summarizing the fixed effect on behavioral requests dimensions due to the robot-assisted intervention. Red dots indicate mean values. Red bars indicate +/- 1 standard error. Asterisks denote significant differences (** $p < .01$; * $p < .05$). The black dot denotes marginally significant comparison ($.05 < p < .055$).