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

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Abstract

Socially assistive robots have the potential to become a powerful therapeutic tool for individuals affected by the autism-spectrum condition (ASC). However, to date, only a few studies investigated the efficacy of robot-assisted training in structured protocols. The current study aimed at investigating the beneficial effects of a robot-assisted training embedded in the treatment plan provided by an Italian healthcare institution. 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 ASC. Twenty-four ASC kids (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 showed that the combination of robot-assisted training and the 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 ASC seem to improve their abilities to generate and respond to behavioral requests and in their tendency to initiate and maintain social interaction with the adult. 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 condition, 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 with neurodevelopmental disorders and, in particular, with Autism-Spectrum Condition (ASC). This spectrum is characterized by persistent impairment of social interaction, social communication, and imagination (Baron-Cohen, Tager-Flusberg, & Cohen, 2000), flanked by stereotypes 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 ASC 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 ASC 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 (sensory) cues would lead to the difficulty in processing properly social information, causing a subsequent overload of the individual's social and cognitive resources (Hill & Frith, 2003). The severity, precociousness, and specificity of social deficits in individuals with ASC have attracted the attention of clinicians and researchers, encouraging the design of different therapeutic approaches (for reviews, Yates, Couteur, 2016; Fernández, Mollinedo-Gajate, Peñagarikano, 2017).

Applied Behavior Analysis (ABA) is one of the most commonly used interventions for children with ASC (for details, see Axelrod, McElrath & Wine, 2012). This therapeutic approach aims at identifying maladaptive behaviors and to provide the individual with new strategies to encourage appropriate behaviors. In particular, through the interaction with a clinician, children with ASC can simulate interactive scenarios and learn some of the social skills needed to interact with the social world. Behavioral therapy is often combined with neuro-psychomotricity, which is aimed at teaching children with ASC how to integrate somatic experience with cognitive and emotional representations (Picq & Vayer, 1968). Considering the typical impairments in ASC individuals, another common intervention is “Verbal therapy”. This approach aims at teaching children how to communicate purposefully, not only by enriching their vocabulary but also encouraging non-verbal communication (such as gestures and vocalizations) (Goldstein, 2002). The combination of ABA, neuro-psychomotricity and verbal therapy can be considered the basis of a “standard” treatment plan, following the guidelines of the Italian National Health System (Caputo et al., 2018).

In combination with the standard treatment plan, a large variety of technological tools has been implemented recently in the context of ASC therapy, to promote social interaction (Rogers, 2000). The use of tools, that can act as mediators of the communication between the child and the therapist, seems to stimulate the interest of ASC individuals and improves the clinical outcome (Goldsmith & LeBlanc, 2004). New technologies, and, in particular, toy-like robots, have been efficiently used as clinical tools to extend and enhance social competences in children with ASC (for reviews on the topic, see Begum, Serna & Yanco, 2016; Cabibihan, et al., 2013; Diehl, Schmitt, Villano et al., 2012; Scassellati, Admoni, Matarić, 2012). Assistive robotics allowed clinicians and researchers to experiment with a new mediation platform for designing training protocols aimed at the rehabilitation of social skills in ASC individuals. Several authors demonstrated that imitative behaviors emerged spontaneously after involving ASC children in tasks that require to observe and mimic movements (dance moves) of a robot (Greczek et al., 2014; Duquette Michaud, & Mercier, 2008; Robins, Dautenhahn, Te Boekhorst et al., 2005). In 2013, Zhend et al., demonstrated that after only four sessions of a generic neuro-cognitive robot-assisted training, children with ASC improved in joint attention (Zheng et al., 2013). Robot-assisted activities that are focused on joint attention have proven to be useful also for the improvement of other behaviors, such as the tendency to share objects, turn-taking and reciprocal behaviors (Kozima, Nakagawa, Yasuda, 2006; Ricks & Colton, 2010; Kim et al., 2004).

The main advantage of robotic tools consists in their physical embodiment and in the extensive control that the experimenter/clinician can exert on their behaviors (Pennisi et al., 2016; Liu, Conn, Sarkar et al., 2008). Despite being featured with human-like traits, robots employed in socially assistive robotics should be able to display only simplified versions of human behavior (Walters et al., 2008). Such minimally

expressive design should prevent the sensory overload perceived by children with ASC during the interaction (Dautenhahn et al., 2008). Therefore, from a psychological point of view, for ASC individuals, a robot represents a safe, predictable and coherent environment to experience a simulation of social interaction (Dautenhahn & Werry, 2004). Importantly, the improvement in social skills acquired during the activities with the robot can be spontaneously extended to social interaction with other humans (François, Powell & Dautenhahn, 2009; Robins, Dautenhahn, Te Boekhorst et al., 2005).

The adoption of robot-assisted protocols in clinical contexts is fairly recent, but a consistent amount of results suggests the efficacy of such an approach (Aresti-Bartolome & Garcia-Zapirain, 2014; Coeckelbergh, Pop, Simut et al., 2016). So far, socially assistive robotics has been studied with a huge variety of methods, attracting attention of several communities, from social scientists to human-robot interaction researchers (Pennisi et al., 2016; Chevalier et al., 2019). However, to date, no studies assessed the incremental efficacy of robot-assisted training in conjunction with the standard treatment plan. Furthermore, applicability of such technologies in the healthcare environment, might require development of solutions allowing healthcare professionals to run the activities with the robot autonomously, without the assistance of technical and research staff. This is of the utmost importance when the activities are tailored to individuals with ASC, who might feel uncomfortable in the presence of a stranger during therapy sessions (Robins, Dautenhahn, & Dubowski, 2004). Indeed, autism research is extremely challenging, not only because of the difficulty with recruiting participants but also, and foremost, because of the vulnerability of children with ASC. New research needs to be optimized to ease the integration between novel paradigms and standard interventions (Shirley, 2005).

Based on these considerations, the current study aimed at exploring whether structured robot-assisted training could affect the social skills of ASC children when integrated into the standard treatment plan. In particular, our goal was to disentangle the effect of the standard behavioral therapy alone from the effect due to the combination of the standard therapy with structured robot-assisted training. To meet this aim, we designed a cross-over study in which children with ASC were exposed to the activities with the robot in the context of the standard behavioral therapy, during which the healthcare professionals were able to operate the robot-assisted activities autonomously and independently. For a duration of ten-weeks, healthcare professionals of Piccolo Cottolengo Genovese di Don Orione combined the robot-assisted training we designed with their regular therapy sessions.

Methods

Participants

The recruitment process was supported by healthcare professionals of the Piccolo Cottolengo Genovese di Don Orione. Relatives of children diagnosed with ASC 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 interested families. 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). 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.

Design

Considering the heterogeneity of ASC clinical manifestations, and to grant all the children 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. In other words, 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 the 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 – Crossover design adopted in the current study

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 reverse order. This allowed us to mitigate the potential effects due to the order of the treatments. Thus, before the beginning of the study, children were pseudo-randomly assigned to two groups, taking into account their scores at the Autism Diagnostic Observation Schedule (ADOS, Lord, Rutter, Di Lavore, 1999) and their chronological age (see Table 1 for details).

Table 1. Grouping based on the ADOS levels and the child's age (n = 36)

ADOS 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	

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). At the same time, children's social abilities were assessed using the Early Social Communication Scale (ESCS, Seibert, Hogan, & Mundy, 1982). The ESCS is often used by healthcare professionals to assess the social skills of individuals with ASC. 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.

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 kids 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).

During the second robot-assisted training period, two kids 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 kids (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 displayed by ADOS levels and age (n = 24)

ADOS 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	
<i>Level 1</i>	1	1	1	1	1	2	2	2	11
<i>Level 2</i>	0	0	0	1	1	2	1	1	6
<i>Level 3</i>	1	0	2	1	1	1	1	0	7
Total	2	1	3	3	3	5	4	3	

Training procedure

The training activities were carried out using Cozmo (Anki Robotics, San Francisco, CA, USA), a 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. Healthcare professionals were able to control the robot across the entire duration of the experiment, through an easy-to-use application that we developed ad hoc (for a screenshot of the interface provided to the therapists, cf. Fig. 2, right).

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. 2, left)

Figure 2 – On the left: experimental setup. 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 the 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).

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). After Cozmo's feedback, the turn ended and a new turn started. All Cozmo's actions and feedback were controlled by the healthcare professional in a Wizard-of-Oz technique (that is the healthcare professional controlled the robot remotely from a computer with custom-made interface, cf. Figure 2)

Data Analysis

To mitigate the effect of confounding factors due to the heterogeneity of ASC manifestation between Group 1 and Group 2, chi-square analysis was applied to the frequencies of ADOS 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 ($T1 - T0$; $T2 - T1$). 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) taking into account the 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. 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 along with the β 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

Initiating Social Interaction

The mixed model revealed that 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 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)(Fig. 3, left).

Responding to Social Interaction

The mixed model revealed 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 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)(Fig. 3, centered).

Maintaining Social Interaction

The mixed model revealed a marginal 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 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)(Fig. 3, right)

Figure 3 – Violin plot summarizing the fixed effect on social interaction dimensions due to the robot-assisted intervention. Red dots indicate mean values. Red bars indicate +/- 1 standard error. The asterisk denotes a significant difference (** $p < .01$; * $p < .05$). The black dot denotes marginally significant difference ($.05 < p < .055$).

Behavioral Requests

Initiating Behavioral Requests

The mixed model revealed that 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. 4, left).

Responding to Behavioral Requests

The mixed model revealed a marginal difference between the combination of the standard therapy with the robot-assisted training and the standard therapy alone with respect to 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. 4, right).

Figure 4 – 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 ($.05 < p < .055$).

Joint Attention

Initiating Joint Attention

The mixed model revealed no significant difference between the combination of the standard therapy with the robot-assisted training 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: $M = 1.32$, $SE = 0.84$)(Fig. 5, left).

Responding to Joint Attention

The mixed model revealed no significant difference between the combination of the standard therapy with the robot-assisted training and the standard therapy alone with respect to the improvement of children's tendency to 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: $M = 2.09$, $SE = 0.91$) (Fig. 5, centered).

Maintaining Joint Attention

The mixed model revealed no significant difference between the combination of the standard therapy with the robot-assisted training and the standard therapy alone with respect to the improvement of children's 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: $M = 1.35$, $SE = 0.85$) (Fig. 5, right).

Figure 5 – Violin plot summarizing the fixed effect on joint attention dimensions due to the robot-assisted intervention. Red dots indicate mean values. Red bars indicate +/- 1 standard error. Asterisks denote significant comparisons (** $p < .01$; * $p < .05$). Black dots denote marginally significant comparisons ($.05 < p < .055$).

Discussion

The current study aimed at investigating whether a robot-assistive training of social skills in children with ASC can boost the effects of standard therapy. We exposed children participating in this study to repetitive interaction with a toy robot, embedded in a standard therapy session across several weeks. During the interaction, children were asked to observe and respond to the behavior of the robot, which was performing a simple movement toward an object. Despite its simplicity, the behavior we implemented into the robot can be interpreted as a representation of common social behaviors, composed of behavioral requests and turn-taking. While interacting with other humans, neurotypical adults tend to spontaneously 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 or pointing at it, which is a form of non-verbal behavioral request. The interaction partner needs to compute the non-verbal request, sharing his attention on the requested object. Then, the partner needs to understand the right moment to provide a solution for the request, respecting turn-taking dynamics. Eventually, if such behavioral request is understood by the interaction partner, a reinforcing behavior happens (e.g., positive emotional feedback). This simple kind of social interaction requires the understanding of 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). In our study, these aspects were taken into consideration in the development of the behavior of the robot.

Our results converged in showing that the prolonged and systematic interaction with a toy-robot during therapy sessions enhances the improvement of social skills. Specifically, the robot-assisted training we designed seems to have boosted children's ability to make and respond to behavioral requests using non-verbal communication. Children seem to improve 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. We found no effect of the training on joint attention abilities. Taken together, our results indicate that the simple interaction with the robot we developed was able to teach the children how to initiate social interaction and make a behavioral request in an interactive scenario with an adult, thereby, importantly transferring the skills trained with a robot to an interaction with a human partner. 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 underage patients 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 sub-scale 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 sub-scale 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 of communication. Asking the child to express what color was the cube the robot was turning towards 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 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. Therefore, the lack of a significant effect on the children's joint attention is coherent with the training design. 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 ASC 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 toy-robots can play the role of enhancers of therapeutic communication (Michaud & Théberge-Turmel, 2002). Our results showed that robot-mediated activities can help children with ASC 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. As showed in our study, robots can be used as “simplified” social agents to simulate social interaction (Cabibihan et al., 2013). However, it is of utmost importance to evaluate the specific areas of social cognition that can be enhanced using robot-assisted and robot-mediated activities. In our case, the training we developed was effective to improve the ability of children of using non-verbal gestures to communicate their intentions and requests to the adult. Thus, children who would benefit more from our robot-assisted training are the ones with deficiencies in this domain. A deeper assessment of the individual’s abilities, combined with a tailored robot-assisted intervention can improve clinical outcome. For this reason, we suggest the adoption of assessment tools that are already being used in the clinical domain, along with a broader evaluation of the social skills that can be affected by robot-assisted training.

Despite promising results, it is important to point out some limitations of the current study. Indeed, the groups in which the original sample was divided into suffered from the high drop-out rate (1/3 of the initial sample dropped between T0 and T1). Initially, children were divided according to chronological age, Griffith's scores (evaluating the individual’s mental age) and the ADOS 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 own control.

Conclusion

Taken together, our results support the idea that the adoption of easy-to-use, low-cost technology, such as a toy robot, in a clinical environment positively affects therapy outcomes. In particular, children with ASC seem to learn prerequisites of social skills faster with the robot-assisted training rather than with standard therapy alone. Children involved in the current study improved in their ability to make non-verbal requests to a human partner. Furthermore, they improved in the understanding behavioral requests of the clinician. Our results indicate that skills learned through the interaction with the robot are spontaneously extended to the interaction with other humans.

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