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Investigating the Feasibility of a Wizard-of-Oz Robotic Interface (R2C3) in a Social Skills Group for Children with Autism Spectrum Disorder

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Abstract

Socially assistive robots (SARs) have been shown to be promising tools to help children with Autism Spectrum Disorder (ASD) learn social skills but their effect within groups remains unclear. Here, we aimed to investigate the use of the QTrobot with the Rehabilitation Robotic Companion for Children and Caregivers (R2C3) robotic platform in the context of a social skills group (SSG) for children with ASD. Six children with ASD between 6 and 11 years old were included in this exploratory study, and were randomly exposed to two conditions, active and inactive robotic interface, over ten weeks. We monitored the Autism Diagnostic Observation Schedule-2 (ADOS-2) communication and social scores and the number of engagement initiations and responses to social requests after each session. We also qualitatively explored the feasibility and usability of the Wizard of Oz R2C3 in the SSG setting and evaluated the interface design quality using the Design Information Communication Technology Inventory (DICTI). The robot did not hinder the effectiveness of the SSG, as evidenced by the participants' significant improvement in social skills. The use of R2C3 in active mode was successful and led to a marked increase in engagement based on children's social initiations, but did not show a significant increase in responses to social requests and ADOS-2 scores. Qualitatively, we observed that the robot promoted children's social initiations, notably during the early sessions. However, the design of the R2C3 interface posed some limitations. DICTI scores particularly emphasized the lack of personalization by the user and the inability to manage the complexity of the robot's behaviors, and of the time lag between the Wizard of Oz control and the behavior execution, making the robot's reactions challenging to integrate into the group's conversations. This exploratory study is promising as it suggests that the QTrobot with R2C3 interface promotes social initiations in children with ASD. Future studies should delve deeper into this use with a better-suited multi-party interface and more participants.

Trial Registration

IIQCASSGS, retrospectively registered on 07/03/2023.

Keywords Autism · Socially assistive robot · Wizard of Oz robotic interface · Social skills · Engagement

1 Introduction

The field of socially assistive robotics (SARs) has significantly expanded in recent years, particularly in therapeutic and educational interventions for children with Autism Spectrum Disorder (ASD) [1]. By influencing the affective state of its human interlocutor, SARs aim to enhance the development and generalization of social skills and communication [2], and potentially modify behaviors, making them a valuable tool in autism interventions. Furthermore, as the utilization of SARs in therapeutic interventions for children with ASD continues to grow, it becomes evident that these

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technological interventions hold considerable promise for promoting social skills development in children with ASD [1–3].

ASD is a complex neurodevelopmental disorder characterized by deficits in social skills and communication, restricted interests, and repetitive behavior [4]. Social skills training is a vital component of autism treatment, which focuses on minimizing maladaptive behaviors and facilitating the development of favorable social behaviors. Moreover, it can facilitate the acquisition of conversational skills (initiating, maintaining, and closing verbal exchanges), emotional skills (perceiving and understanding emotions) and social-cognitive skills, such as theory of mind [5]. This can be done by teaching interpersonal skills to patients and promoting their generalization and maintenance [6].

One of the most widely used approaches to improving social skills in youth with ASD is group-based psycho-social skills interventions [7–8]. However, despite their prevalent use, the effectiveness of these interventions remains inconclusive, primarily due to limited rigorous research. Additionally, there is no universal definition of social skills, nor the scales adapted to measure them. Variations in the intensity and duration of therapeutic implementations further contribute to this inconsistency [8–10]. Nevertheless, a recent meta-review provided suggestive evidence supporting the efficacy of the social skills group (SSG) in improving social communication deficits and reducing overall ASD symptoms in school-aged children and adolescents [11].

2 Related Work

2.1 Robotic Interventions for Children with ASD

There is rising evidence supporting that children with ASD have unique opportunities to use robots for therapeutic purposes [12]. Contrarily to human interactions, robots' predictability provides a highly structured and learning-driven environment to individuals with ASD. These types of interactions with SARs particularly, are likely to form consistent social situations in which certain social behaviors can occur [13–14]. This benefit has been linked to stimulation via repetition, simplified facial expressions resembling those of humans, and a progressive difficulty adaptation, all serving as crucial supports in skill acquisition [15].

Most robotic interventions for ASD focus on the development of communication and social skills. Given that children with ASD struggle understanding social cues and situations, the idea of employing robots as educators for such skills has gained significant attention [16–17]. Studies have suggested that SARs are effective in teaching, practicing, and eliciting desired social behaviors among individuals with ASD, such as social engagement, eye-contact, joint attention [18, 19], emotion recognition, and reduction in repetitive and stereotyped behaviors [20]. Other studies have focused on emotion regulation [21–22] and motor behaviors imitation [23–24].

Previous research indicates that robots as social mediators support children with ASD by encouraging social openings, or interactions between the child and another person [25–35]. Several SARs, such as NAO, Kaspar, Riby, QT Robot, KiliRo, and Kibo, facilitate social openings through social play scenarios, collaborative activities, and predictable actions [36–25] Additionally, many of these robots aim to promote emotional expression and recognition by modeling normative facial cues and helping children learn to interpret them [26–27]. Robots such as NAO, Kaspar, Charlie, Alice "Mina", QT Robot, IRobiQ, and CARO are designed with emotional cues to enhance imitation and emotional understanding [36–25, 28–29]. Furthermore, some robots like TEO4 and KiliRo focus on improving learning skills by helping children recognize numbers, alphabets, and social cues [12, 39]. In terms of clinical targets, structured robot-assisted interventions resulted in positive outcomes in areas like joint attention, emotional understanding, social interaction, and learning [18, 27].

One notable example is Kaspar, a humanoid robot designed to help children with ASD develop communication and social skills [30]. It has been used in safe and structured long-term studies in various play scenarios, promoting social behaviors like turn-taking, joint attention, and collaboration [30–32]. Kaspar's simplified human-like features allow children to explore social behaviors through tactile interaction, while its predictability makes social engagement less overwhelming. Kaspar's ability to provide feedback during interaction helps children with ASD learn appropriate social behaviors, while also assisting in basic learning activity like personal hygiene and emotional expression. Moreover, the authors highlighted the benefits of long-term interaction with robots, revealing how repeated exposure over several months encourages spontaneous social behaviors like imitation and turn-taking behaviors that might not surface in short-term studies.

However, it remains unclear whether these skills can be generalized to everyday life outside of the therapeutic setting. Long-term monitoring and further research are required to determine the full potential of robots in fostering lasting social and communication skills in children with ASD [33]. Results often depend on the participants' initial functioning levels and the study's design, making it challenging to generalize findings. While robotic interventions are viewed as a potential supplement to parental, educational, and therapeutic approaches, further high-quality research is needed to establish their long-term effectiveness [33]. Short-term interventions, typically around eight sessions of 30 min, have shown immediate improvements in social communication [15].

2.2 Robot Operations and Design

The literature has displayed a significant variability in both choice of robot and its design (autonomous vs. human remote controlled), as well as in their methodological implementation [15, 33]]. The robotic interfaces are predominantly controlled by the researchers through the *Wizard-of-Oz (WoZ)* technique; a paradigm that allows the use of such platforms in unstructured scenarios, so the therapist is continuously in control of the robot's behaviors through tele-operation via a tablet [40–41]. It is a common method in human-robot interactions [36], and it appears that only a minority of robots operate autonomously [32, 34, 39]. This likely due to the complexity of developing autonomous interfaces that can adapt in real time to the developmental needs of children with ASD [37, 33]. The WoZ approach compensates for robot's current inability to operate autonomously in socially appropriate or physically safe ways [42]. By allowing human control, WoZ enables participants to envision what future autonomous human-robot interactions could look like. Additionally, it provides an opportunity to test early design features during the development process. However, there are concerns about the authenticity of these interactions and their ethical implications. For instance, when participants are unaware if they are interacting with a machine or a human disguised as a machine, a concept referred to by Miller as "Turing deceptions" [43].

Robots' design characteristics and functionalities can play a significant role in the efficacy of the therapeutic intervention [37, 33, 44]. Design features including positive feedback (including personalized messages) and rewards (applause, dance or emotional expressivity) are now well established as they have been linked to promoting learning in children with Neurodevelopmental Disorders (NDD) [33]. Although most articles emphasize the potential of preprogramming, they often highlight design weaknesses, such as limited adaptability to children's special needs, restricted motions and verbal capabilities, and reliance on technical assistance [33, 44]. These findings provide practical guidance for improving robotic interfaces to better suit the needs of children with ASD in social group interventions [44].

2.3 Single vs. Multi Party Setting

Furthermore, there is currently a noticeable absence of multiparty or multiuser systems in interactions between children and robots [45]. While humans often engage in group settings where various social cues are exchanged through multiple channels (verbal and non verbal communication), the current focus on listening behavior in human-robot interaction primarily revolves around one-on-one interactions [45]. It's crucial to integrate multi-modal cues, such as gaze, to accurately assess listener engagement during conversations [45]. To date, only a few studies have explored multi-party systems in children/robot interactions [45–49]. Such systems should facilitate natural interaction, particularly important for child users in educational and entertainment contexts. By developing adaptive robotic systems with multitasking capabilities and a broad range of perceptual and actuation skills, users can create interactive applications that maintain interest and engagement [45]. While previous literature has predominantly focused on one-on-one or on pairs of children [28, 18], our study investigates the impact of a SAR in a multi-party setting.

2.4 Methodological Quality and Set-Up of Robotic Studies

From a study design perspective, the literature points out that the methodological quality of robotic studies is generally poor, particularly in terms of small sample sizes and duration, except for random control trials, which include larger samples [13, 38–26]. One noteworthy study by Scassellati et al. [37], in which they implemented an autonomous robot in the participants' home, had only included 12 participants and did not make use of a control group, a relatively small sample size in the context of high standards for evidence-based requirements. The interventions may also vary in intensity and duration, ranging from a couple of minutes single interaction [13, 30], to extended expositions ranging from eight to 30 sessions, each lasting approximately 30 min [13–14, 23–24, 18]. Additionally, only few studies have incorporated longitudinal follow-up [18, 50], which are essential for evaluating the user's motivation.

The studies' settings also differ from one study to another, with the most common location being ASD centers and clinics [15, 19, 30–35, 39, 42, 45, 51–52]. Other settings include laboratories [18, 22, 43, 44, 46–50, 51, 52, 53], school environments [19, 54], and homes [23, 39, 55, 61]. Interestingly, Kouroupa et al. [15], found in their meta-analysis that the effects of the robotic interventions are larger in clinical settings, compared to home or school environments.

Throughout the interventions, robots take on the role of social interfaces, employing strategies like emotive facial expressions (e.g., QT robot [32]), verbal interactions, storytelling and play engagement. In most of the studies, the robot became a mediator between the child and the play partner [15].

Despite the recent growth in research on SARs for ASD interventions, their use in the context of group interventions for children with ASD is still underdeveloped. Based on this observation, it seemed interesting to expand on the field by exploring the feasibility of using a robotic interface in a group setting previously developed by our team for children with dysgraphia [56]. To this end, the present study involves the SAR ‘QT’ and the *Rehabilitation Robotic Companion for Children and Caregiver* (R2C3) interface [57], controlled through the Wizard of Oz, within a SSG for children with ASD.

3 Objectives and Primary Contributions

The purpose of this exploratory study is to qualitatively explore the feasibility and usability of the Wizard of Oz robotic R2C3 interface [57] in a SSG and measure its effect on the engagement of six children with ASD over 10 sessions, based on two conditions: an active interface and an inactive interface.

The concept of engagement holds great significance in human–machine interaction as it not only aids in the design and implementation of interfaces but also facilitates the development of advanced interfaces that can adapt to users’ needs [58]. The most frequently used definition in studies investigating engagement is found in Sidner et al. [59] who describe engagement as “the process by which interactors start, maintain and end their perceived connection to each other during an interaction. It combines verbal communication and nonverbal behaviors, all of which support the perception of connectedness between interactors” [60]. Gaining insight into how humans employ nonverbal cues within a multi-party listening setting not only enhances our comprehension of human-to-human communication but also contributes to fostering effective human-robot interactions and group engagement [61].

3.1 The Main Contributions of this Paper

- To the best of our knowledge, this is one of the first studies implementing a SAR in a social skills group setting. We explored the feasibility of the SAR with children with ASD and comorbid Intellectual Disabilities (ID).
- We employed the first Information Communication Technologies Design Inventory (DICTI) to assess the robotic interface, which provided valuable feedback, which provided us with insights on areas to improve in the design for a future version tailored to the needs of children with ASD in a social skills group intervention [44].

3.2 Research Questions and Hypothesis

As predicted by the literature [7], we expect that SSG will improve children’s social skills as well their engagement within the group. Our exploratory hypotheses are as follows: (1) it is feasible to implement the R2C3 robotic interface in an SSG for children with ASD, (2) the presence of the QT robot will positively impact children’s engagement and will (3) improve children’s social skills and decrease their maladaptive behaviors during the SSG sessions.

4 Methods

4.1 Study Design

This is an exploratory feasibility study that implements the SAR QT with the Wizard of Oz R2C3 interface [57]. The experiment corresponds to an intra-participant design where each participant is exposed to both conditions (active and inactive R2C3 interface). The proposed activities are tailored to the abilities of each group of children. The primary variable of this study is children’s engagement in the group. The study was approved by the local university ethics committee (IIQCASSGS).

4.2 Participants

Six participants were recruited from the children’s outpatient unit of the Child and Adolescent Psychiatry Department at the Pitié-Salpêtrière Hospital. Our sample consisted of four girls and two boys, in contrast to most studies that include more males than females, with percentage of males ranging from 67 to 100% [14]. The inclusion criteria included an ASD diagnosis validated by the Autism Diagnostic Interview (ADI-R) [62] or the Autism Diagnostic Observational Scale (ADOS-2) [63], age 6 to 11 years, absence of SSG intervention in therapeutic care and consent of at least one of two legal representatives.

The exclusion criteria ruled out severe intellectual disability (ID), multiple disabilities, major behavioral disorders, degenerative disease or other disease that could interfere with the evaluations planned during this study (e.g., known epilepsy and/or history of seizures).

We recruited six participants and formed two social skills groups, taking into account the age of each participant. Group A included children from 9 years 6 months to 10 years 4 months, while Group B included children from 6 years 4 months to 8 years 7 months. The sample consisted of 4 girls and 2 boys. See Table 1 for the participants’ characteristics.

Table 1 Participants characteristics

Participants	*n*°1	*n*°2	*n*°3	*n*°4	*n*°5	*n*°6
Group	A	A	A	B	B	B
Age (y/o)	10 years 4 months	9 years and 6 months	9 years and 9 months	8 years and 7 months	8 years and 1 months	6 years and 4 months
Gender	F	F	F	M	M	F
ASD Diagnosis validated by ADI-R or ADOS-2	ADI-R com = 15 ADIR soc = 24 ADI-R rep = 7	ADI-R com = 11 ADIR soc = 28 ADI-R rep = 7	ADOS-2 = 14	ADI-R com = 4 ADIR soc = 16 ADI-R rep = 5	ADI-R com = 7 ADIR soc = 11 ADI-R rep = 5	ADI-R com = 13 ADIR soc = 17 ADI-R rep = 6
Comorbid disorders	Communication and oral language disorder	Communication and oral language disorder	ADHD	Speech, writing, communication and oral disorder	Communication and oral language disorder	Communication and oral language disorder
Additional clinical information	Delayed language acquisition; good nonverbal skills (imitation, pointing); uses pictograms.	Needs support for comprehension; can express her own emotions but needs support to better understand other people's reactions and emotional states.	Good communication skills but difficulty processing information; needs pictograms and support for comprehension.	Pictograms are essential to comprehension; needs adult' support; sensitive to failure and to positive reinforcement.	Delayed language acquisition; memory difficulties; behavioral problems; can express emotions; some emotional instability; stereotypical behaviors; restricted interests due to atypical sensory processing.	Deficient language skills; echolalia; reduced verbal comprehension; needs pictograms for comprehension; difficulties interacting with others, with transitions and joint attention; stereotypical behaviors.
SSG therapeutic goals	Support and develop verbal demands, practice turn taking, develop social skills, practice emotional regulation.	Support and develop verbal demands, practice theory of mind and identify other's emotional states.	Practice sharing and honing conversational skills, practice emotional regulation, turn taking and imitation skills.	Support and develop verbal demands, practice emotion recognition and theory of mind, practice sharing, conversational skills and turn taking.	Support and develop verbal demands, practice emotion regulation and hone conversational skills.	Support and develop verbal demands, practice imitation, joint attention, sharing and turn taking.

ADI-R Com = ADI-R score for language and communication (cut off 7); ADI-R Soc = ADI-R score for reciprocal social interaction (cut off 10); ADI-R Com = ADI-R score for restricted, repetitive and stereotyped behaviors and interests (cut off 3); ADOS-2 = ADOS-2 scores for autism spectrum (cut off based on age > 8); VCI = Verbal comprehension index; VSI = Visual spatial index; FRI = Fluid reasoning index; WMI = Working memory index; PSI = Processing speed index; N/A = not available

4.3 Materials

4.3.1 The Socially Assistive Robot QT

The SAR used during this study was QT, a humanoid robot developed by LuxAI[1], with 14 degrees of freedom for upper-body gestures. QTrobot has been suggested help children with autism practice social and engagement skills [9]. Two studies have highlighted the effectiveness of using this robot to decrease stereotypic behaviors and improve social skills in patients with autism [21, 64, 65] (See Image 1).

4.4 The R2C3 Interface

The Wizard of Oz R2C3 interface [57] was created as part of the iRecheck[2] project, which combines a robot and a serious game-based approach to handwriting rehabilitation for children with dysgraphia [56]. The interface contains 120 different behaviors classified into 33 menus according to their use. In the interface layout, there is a login page as well as a control page. The login page collects the name of one participant, which can be included in some pre-programmed behaviors, facilitating the personalization of the robot-child interaction. The control page includes the 33 menus in two tabs: the scenario and game tab and the reaction tab (see supplementary material).

To investigate the feasibility of the R2C3 interface features on the engagement and social behaviors of children during the SSG, QT is present in each session but is used in two different ways. During half of the sessions, the R2C3 interface is inactive and does not display verbal and non-verbal social behaviors other than eye blinking. During the other half of the sessions, the interface is actively used. The choice behind exposing the participants to both active and inactive conditions was to examine the differential impact of the robot's presence and behaviors on the children's engagement during group.

[1] LuxAI: https://luxai.com/.

[2] https://irecheck.github.io/.

Image 1 QTrobot

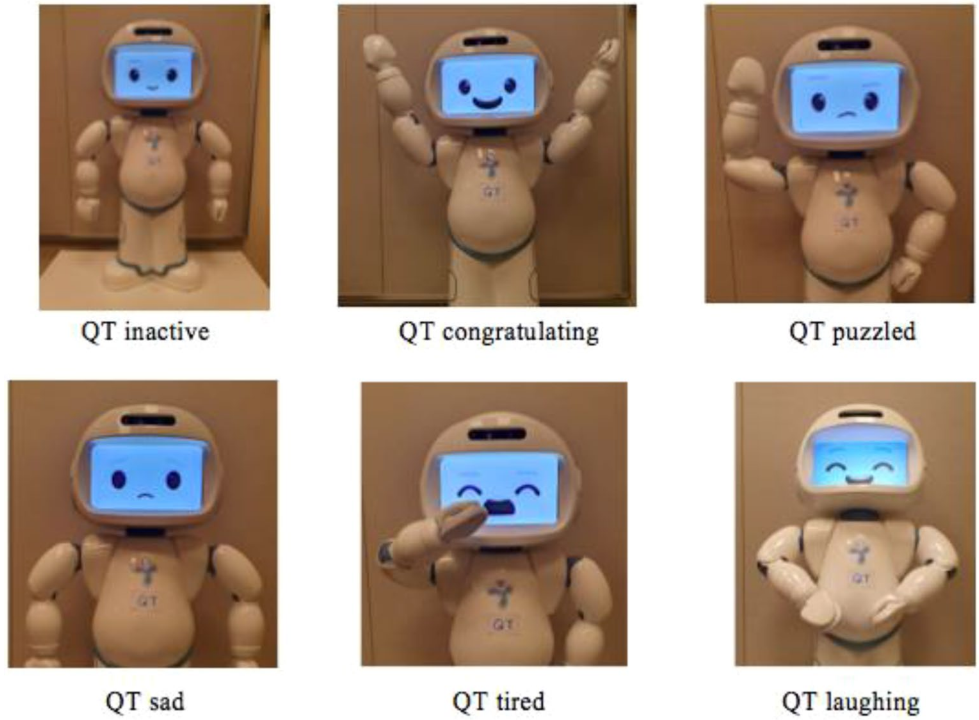


Table 2 R2C3 interface behaviors examples [57]

Category	Description	Examples
Positive reinforcement	The robot congratulates the participant.	“Bravo”, “Well done”, “So nice”, “Congratulations”
Encouragement when facing difficulties	The robot comments on the participant’s productions and encourages the participant to try again.	“Do your best”, “Breathe”, “I see you’re trying”, “Try again, you can do it”
Emotion-based feedback	The robot draws the participant’s attention to his or her emotions.	“You look happy”, “You feel bad?”, “You look angry”, “You look tired”
Interactions based on QT’s opinion	The robot expresses a personal opinion and questions the participant.	“Hello, my name is QT, what is your name?”, “Hello”, “Goodbye”, “Yes”, “No”, “Can you repeat”, “I don’t know, how about you?”, “Why?”, “It’s hard, can you explain?”

We used the Wizard of Oz paradigm, a human remote control of the robot, a popular design paradigm in human-robot interaction research [66], which allowed the therapist to display specific wanted verbal behaviors. The order in which the active or inactive conditions were implemented was randomized. Among the set of behaviors proposed by the interface, we used only the categories adapted to the context of the group (Table 2). We decided to expose the participants to both conditions because we were particularly intrigued by the lasting impact of the novelty effect of the robot throughout the ten sessions. Prior research suggested that the robot could influence children’s engagement [58, 59], but we were interested in exploring whether this engagement would persist over time (See Image 2).

4.5 Procedure

4.5.1 Experimental Setup

The study took place in the research laboratory located at the child psychiatry department of The Pitié Salpêtrière Hospital. All sessions were filmed with three cameras from three different points of view (front, right, left) to obtain a good angle for each participant. Parental consent for video recordings was collected before the study. The experimentation room was set up in the same way for both groups (see image 3). It included a children’s table in the center of the room, a chair for each participant and two chairs for the experimenters in charge of leading the group (only the children’s table and chairs are visible on image 3). The third experimenter was located in the back of the room and was in charge of controlling the robot with a tablet through the Wizard of Oz paradigm.

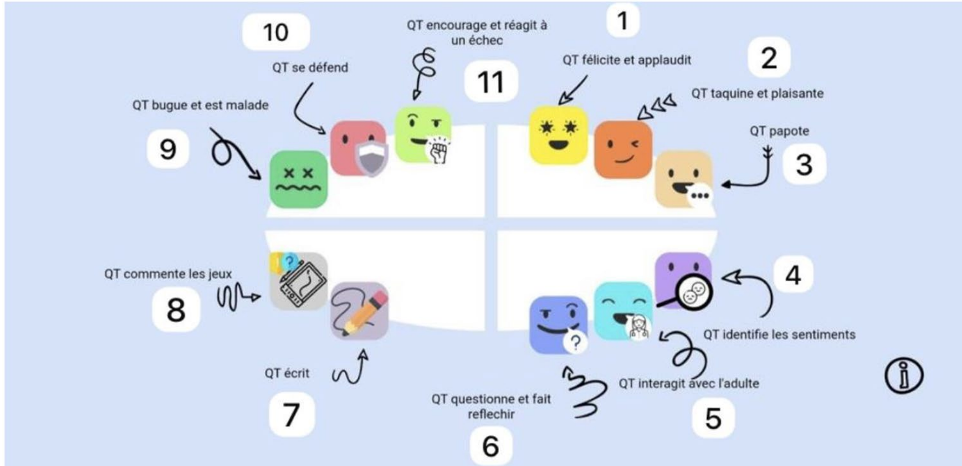
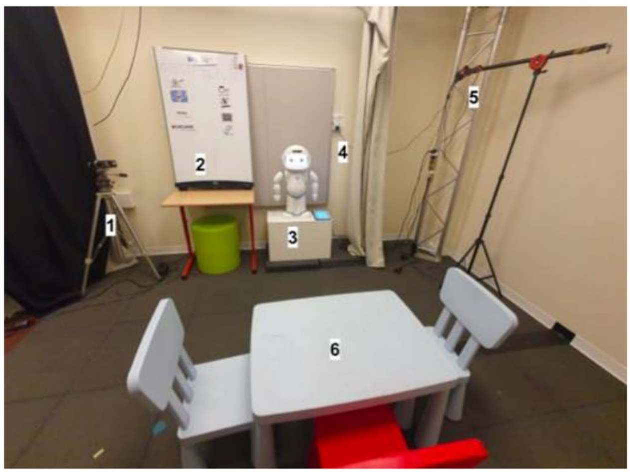


Image 2 R2C3 Interface [57]. (1) QT congratulates and applauds; (2) QT teases and jokes around; (3) QT chats casually; (4) QT identifies emotions; (5) QT interacts with adults; (6) QT asks questions and encourages reflection; (7) QT writes; (8) QT comments on games; (9) QT bugs and is feeling unwell; (10) QT defends itself; 11. QT encourages and responds to failure



1: Camera #1

2: Board used to present the activities and take attendance

3: QT robot & R2C3 interface

4: Camera #2

5: Camera #3

6: Table and chairs

Image 3 Experimental Set-Up 1: Camera #1 2: Board used to present the activities and take attendance 3: QT robot & R2C3 interface 4: Camera #2 5: Camera #3 6: Table and chairs

A whiteboard was used to present the visual schedule and take attendance (name labels and photographs of the children and experimenters and two photos of QT, one awake and one asleep, to illustrate the two robotic conditions). The robot was placed facing the participants next to the board.

4.5.2 Structure of the Sessions

The sessions' curriculum followed Ozonoff and Konstantareas' recommendations for social skills groups [6], and took place once a week in the early afternoon and lasted 30 min. First, the groups were organized around a structured and predictable framework, and the sessions always took place in the same way (Table 3). A timetable in the form of pictograms was presented to the children at the beginning of each session and remained posted so that the experimenters could refer to it throughout the session. Moreover, the proposed activities were adapted to the age and verbal level of the children. Thus, the difficulty levels of the games were not the same in the two groups. Similarly, the use of visual aids (pictograms, drawings, photographs) was systematic to support the children's understanding. Finally, the objectives for each session were progressive.

Prior to begin our study, we performed an introductory session so that the children could become acquainted with the experimenters and the robot, and familiarize themselves with the experimental room. This welcome session also aimed to gauge the level of each group in terms of comprehension, expression, behavior and social skills. Sessions were then spread out over 10 weeks.

According to previous research, effective social skills intervention strategies used for teaching social skills to children with ASD include behavioral modeling, coaching, behavioral rehearsal, and performance feedback, conducted in a small-group setting [67]. Our program activities provided opportunities to model, elicit and practice specific social skills, such as imitation and joint attention, but also initiating and maintaining conversations by creating reciprocal interactions with the children. Additionally, we practiced appropriate use of humor, which included teaching our participants to pay attention to humor feedback from others [68].

Table 3 Framework of the sessions, therapeutic objectives and robot's purpose

Activities		Objectives	QT's purpose
#1	Introductory ritual: Presentation of the schedule Who is present?: each participant gives his or her first name and puts his or her picture on the board How does QT feel today?: the children ask QT to determine whether he is feeling "sleepy" or is active	Facilitate transition to group Structure the session Practice turn taking Joint attention	Say hello Introduce himself Share how he feels at that moment.
#2	Physical or musical activity: Imitate a rhythm or sound, imitate a gesture	Imitation Practice turn taking	Encourage Congratulate
#3	Psycho-emotional activity: Identify different emotions from the images in social stories, make sense of an emotion by imitating a facial expression, evoke situations related to a specific emotion	Recognition of emotions Imitation Joint attention	Encourage Congratulate Label emotions Ask for children's explanations
#4	Activity around preferences: Based on different themes, such as sports, foods, and animals, the children use pictograms to discuss their preferences and ask others	Sharing something personal Practice turn taking Joint attention Practice conversational skills	Encourage Congratulate Ask for explanations Answer questions about his own preferences

Following a consistent session framework, we initiated each session with an engaging introductory ritual, incorporating participant photos and nametags to take attendance. This ritual not only facilitated the children's transition from their outpatient unit to our lab in the basement but also served as a mean to determine whether the QTrobot would be active or "asleep" during the session.

Our second activity involved physical or musical engagement, providing an enjoyable activity with musical instruments while simultaneously practicing social skills such as joint attention, imitation, turn-taking, and musical reciprocity.

The third activity was centered on psycho-emotional exploration, specifically focusing on emotion recognition and problem-solving skills. We employed various strategies, including presenting social stories through pictures, and pretend play utilizing puppets, and role-playing scenarios. Notably, during puppet play or role-playing, one therapist would introduce a social problem (e.g., sibling rivalry or jealousy) and prompt the children to assist the character in navigating the scenario through pretend play. The second therapist supported the children in helping them come up with adapted solutions.

Finally, our fourth activity revolved around sharing preferences on a wide range of topics (e.g., food, instruments, sports). This encouraged children to express themselves while providing an opportunity to inquire about the preferences of fellow participants and the robot.

During the sessions where QT was active, it was primarily a positive reinforcer for the children; he praised and encouraged them. He could also interact with them by greeting them at the beginning of the session and saying goodbye as well as questioning them ("What about you?", "Why?") and answering closed-ended questions ("Yes", "No", "I do not know"). During the sessions when QT was inactive, the experimenters explained to the children that the robot was tired and would only watch the session. To make it easier for the children to accept this idea, the experimenters had QT say, "I'm sorry, I'm tired" at the beginning of the session. As therapists, our primary role revolved around demonstrating social behaviors, actively engaging children in interactions, all while providing positive reinforcement for their efforts. All activities proposed during the 10 sessions are detailed in the supplementary material.

4.6 Outcome Measures

4.6.1 Clinical Measures

Social and communicative skills, as well as adapted and maladaptive behaviors, were measured directly after each session using the Autism Diagnostic Observation Scale (ADOS-2) module 1 [63]. The ADOS scores are organized into five domains: "A. Language and Communication", "B. Reciprocal Social Interaction", "C. Play", "D. Stereotypical Behaviors and Restricted Interests" and "E. Other Abnormal Behaviors". For this study, the domain "C. Play" was not included because the games included in the ADOS were not used in the groups. While acknowledging that the ADOS-2 is primarily a diagnostic tool, its validity and comprehensive assessment of various ASD dimensions on standardized video recording led us to consider it appropriate for monitoring clinical differences between active robotic sessions and inactive ones based on recordings of social skill sessions.

There is currently no scale available to measure the rate of children's engagement in a group setting. Studies on engagement have thus far focused on engagement in a dual situation (a child towards a robot), notably via metric measures (e.g., movement tracking) [58]. The rate of engagement was therefore measured by the number of times the child initiated a social interaction and the number of times the child responded to a social interaction. These social initiations and responses to social interaction requests could be verbal or nonverbal (phrases, single words, gestures, joint attention, etc.) and could be directed to QT, the adult, or another child. These data were counted for the same preference activity (described later) performed in each session. To limit bias, this activity was always presented in the same way and lasted the same amount of time (10 min).

Both outcome measures were annotated at the end of each session, based on the video recordings. The three trained researchers, one Ph.D. and two Master's students, were randomly assigned every week to two participants each and completed the ADOS-2 scoring system based on the presence of absence of symptoms and behaviors, and quantified engagement by tracking the number of times that children initiated interactions with either the robot or group members, as well as their responsiveness to social requests. Qualitative observations were also included at the end of each session in the form of clinical observational summaries.

4.7 Design Assessment of the Robotic Interface Using the Design Information Communication Technologies Inventory (DICTI)

The design of the R2C3 interface combined with the SAR QT was evaluated by the three experimenters using the ***Design Information Communication Technologies Inventory*** (DICTI) [44]. DICTI provides an easy tool to assess the design of ICTs, including robots, serious games (SG) and apps, augmentative alternative communication devices (AAC), and video modeling (VM). The endorsement of the trans-technology inventory was carried out through a Delphi study [69] involving a panel of 12 experts in ICT. Consensus and agreement were achieved after two rounds of feedback for each of the 13 items of the inventory: customization; feedback; rewards; contextualized learning; enhanced motivation; managing difficulty; increasing accessibility; clarity of instruction and content; attention capacity; clear goals; minimalistic graphics and audio; human interaction; and trustworthiness. Each item was rated using a Likert scale: 0 (absence), 1 (partially considered) and 2 (fully considered) [69].

5 Statistical Methods

The statistical analyses were conducted using R 4.2.2 software using bilateral tests with a 5% level of significance. First, we described the sample of participants. The distribution of the quantitative variables was summarized using the mean and standard deviation. The distribution of the qualitative variables was reported as a number and percentage of occurrence for each level. Next, we sought to assess whether the activation of R2C3 had an average effect on the QT SAR and engagement scores. A Poisson mixed effects regression model was run for each score (package "lme4"). The model formula was "Score ~ QT + (1|Subject)". The subject was specified as ordered at random origin, and the absence of overdispersion was checked by the "performance" package. The independence between the session number and the presence of QT was controlled by the experimental design. Finally, the average evolution of scores across sessions was modelled using the same method. The formula of the models was as follows: "Score ~ Session number + (1|Subject)".

6 Results

6.1 Impact of the Social Skills Group

Our initial hypothesis, which suggested the effectiveness of the social skills group based on the literature, has been validated [7–11]. The presence of the QT robot did not prevent or disrupt the social skills group according to plan. All predicted sessions could be performed with the corresponding duration. The clinicians conducted all the sessions on their own without an expert technician present, and no technical malfunctions were experienced during the entire study period. The control of QT's behaviors by the Wizard of Oz R2C3 interface was fluent enough to allow adequate group dynamics. The presence of QT did not affect the impact of SSG on participants, who showed a significant improvement in social skills after the ten group sessions on ADOS-2 scores for modules A (Language and Communication) and B (Reciprocal Social Interactions) of the ADOS-2 scale (Fig. 1a). Scores on modules A and B both decreased significantly by a factor of 0.959 ($p = 0.028$ *) and 0.936 ($p < 0.001$ *), respectively, with each new session. The SSG also increased children's engagement in the group. The number of responses to social interaction requests increased significantly ($p < 0.001$*) by a factor of 1.061 with each new session. In contrast, the number of social engagement initiations did not increase significantly across sessions ($p = 0.06$) (Table 4; Fig. 1b).

6.2 Impact of QT and R2C3 during the Sessions

The presence of the QT robot had a positive impact on children's engagement in the SSG. We coded children's number of social engagement initiations and responses to social interaction requests during the same activity and time frame of the sessions according to whether R2C3 was active

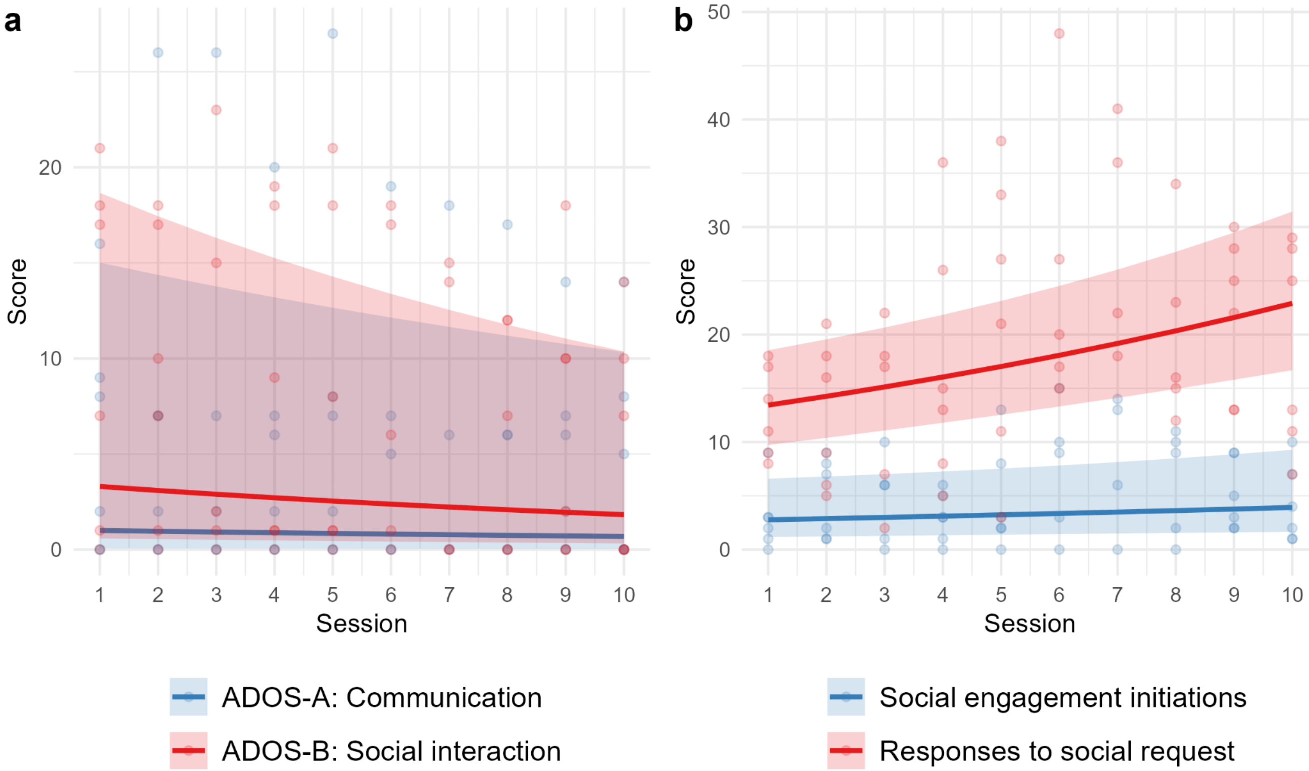


Fig. 1 Average evolution of ADOS-2 scores for modules A (language and communication) and B (reciprocal social interaction) (**a**) and average change in engagement initiation scores and number of responses to social requests (**b**) across the sessions

Table 4 Results of the effect of the sessions on the ADOS module scores and engagement rates

Sessions effect					
Score	Estimate	exp (Estimate)	Stf. Error	z value	Pr (>|z|)
ADOS_A communication	-0.042	**0.959**	0.019	-2.195	**0.028**
ADOS_B social interaction	-0.066	**0.036**	0.017	-3.937	**<0.001**
ADOS_D restricted interests	-0.215	**0.806**	0.057	-3.776	**<0.001**
ADOS_E abnormal behaviors	-0.047	0.954	0.032	-1.498	0.134
Responses to social requests	0.059	**1.061**	0.011	5.606	**<0.001**
Social engagement initiations	0.038	**1.039**	0.021	1.851	0.064

Table 5 Impact of the robot's active condition on ADOS-2 scores and engagement rates

QT effect					
Variable	Estimate	exp (Estimate)	Std. Error	z value	Pr (>|z|)
ADOS_A communication	0.01	1.01	0.11	0.09	0.93
ADOS_B social interaction	-0.08	0.92	0.1	-0.87	0.39
ADOS_D restricted interests	-0.25	0.78	0.3	-0.85	0.40
ADOS_E abnormal behaviors	-0.14	0.87	0.18	-0.76	0.45
Responses to social requests	-0.03	0.97	0.06	-0.50	0.62
Social engagement initiations	0.27	**1.31**	0.12	2.24	**0.03**

(Table 5). The number of responses to social interaction requests was not significantly different ($p=0.62$), but the number of engagement initiations was significantly different by a factor of 1.31 ($p=0.03$) when the R2C3 interface was active. We also noted that the number of social initiations when the robot was active ver (Fig. 2). For instance, for child n°4, the difference was more important when QT was active (delta = 6.75), whereas for child n°3, the social initiations were more important when QT was inactive (delta = -2). For the other four participants, the number of social initiations was higher when QT was active, but the difference was smaller than that for child n°4.

The activation of R2C3 with the QT social robot also did not improve children's social skills during each session group as measured by ADOS-2 scores on modules A (Language and Communication) and B (Reciprocal Social Interactions) for each session. Similarly, the activation of R2C3 did not improve children's negative behaviors as measured by ADOS-2 scores on modules D (Stereotypic Behaviors and Restricted Interests) and E (Other Abnormal Behaviors)

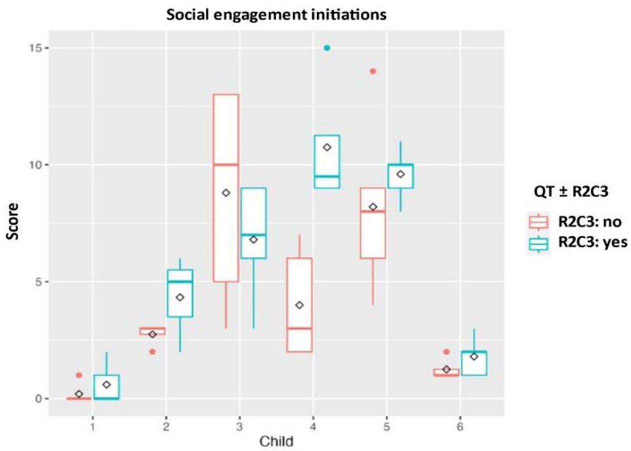


Fig. 2 Distribution of engagement initiation scores according to the active or inactive condition of R2C3. The diamonds correspond to the means of the initiation scores. The red boxes correspond to the sessions where QT is "tired", and the blue boxes correspond to the sessions where it is active

Table 6 R2C3 interface and QT robot design score according to the "design ICT inventory" [68]

Item	Rating
1) possible customization by the user	**0**: no personalization
2) feedback	**1**: feedback that is clearly related to a goal
3) rewards	**2**: rewards like objects, video, songs
4) contextualized learning	**2**: clear link between scenario and user
5) enhance motivation	**2**: fully considered
6) manage difficulty or complexity	**0**: no difference between levels
7) increasing accessibility: simplicity of use and autonomy	**2**: easy to use and usually accessible
8) clarity of the instructions and content	**2**: visually and language adapted
9) attention capacity	**1**: adaptation of duration or stimuli to keep the user engaged
10) clear steps or goals for short and long term	**0**: none
11) easy to process and modify graphics and audio	**0**: none
12) human interaction	**1**: exchange with one person
13) trustworthy	**2**: fully considered

(Table 5). Finally, in line with current research, we observed the fading effect of the robot's novelty effect over the course of the ten sessions [70]. Initially, the children showed high levels of enthusiasm and engagement with the robot, but this interest progressively decreased. By the later sessions, their interactions with the robot became less frequent and more passive, suggesting that the initial excitement had worn off.

6.3 Assessing the Design of R2C3

The design of R2C3 (combined with QT) was evaluated post intervention using the DICTI [57]. As shown in Table 6, the total score was 15, for a maximum of 26. We observed several positive points: The interface proved to be highly user-friendly, even for individuals with limited technical expertise; the positive reinforcements were varied and adapted, and the appearance and reactions of QT made it attractive and engaging. However, there was no possibility of customizing the interface to adapt to different profiles or of managing complexity (e.g., by adapting scaffolding according to the scenario and user capacities—i.e., the robot can first initiate the interaction, then just support it—or by modifying the speed of displaying the stimuli). Additional qualitative comments will be presented in the discussion.

7 Discussion

7.1 Social Skills

As expected, the social skills group demonstrated its effectiveness in enhancing children's social skills [7, 11], attributed to the structured and predictable framework of the sessions, activities tailored to individual developmental profiles, and the therapists' adaptive support to meet the children's needs [6].

In the context of the QTrobot/R2C3 active condition, there was a notable increase in social engagement initiations, while no significant difference was observed in responses to social requests. Interestingly, over time, children's initial enthusiasm for interacting with the robot decreased, indicative of the fading novelty effect. However, this shift did not imply disengagement; rather, it indicated a shift in children's focus towards both their peers and clinicians. The robot, in this context, assumed the role of a social reinforcer, complementing the clinicians' efforts and contributing to the multifaceted social dynamics within the group.

Qualitatively, we were able to observe a real benefit of the sessions on the social skills of the children within the group. These observations are consistent with the literature on SSG for children with ASD [5, 71]. As the sessions progressed, the children produced more social initiations for adults and other participants, whereas in the first few sessions, there was no interaction between the children and few responses to the adults' social interaction requests. We also observed an improvement in role-taking skills. We believe that the recommendations for SSG [6] in this study help explain the improvements observed, as well as the researchers' progressive adaptation of activities to the participants' cognitive and language levels. This was the case for the psycho-emotional activity. At first, we asked the children to describe and interpret images, which was difficult for a certain number of the children and not playful enough to truly involve them in the activity. We then transitioned to a symbolic game using puppets, where the adults simulated problematic social situations (e.g., jealousy, frustration, sickness). This allowed all children to participate and to interact with each other through the puppets ("Are you okay, Grandpa?", "Are you sick, Mickey?", "Can we share?", "It's ok to feel hurt"). Finally, beyond the improvement of social skills, this group was reported to be a real moment of pleasure for the children. All participants came to the sessions enthusiastically, and the hospital care team told us on several occasions of the participants' fondness for the group and QTrobot. Additionally, the educators from the outpatient unit reported that the participants would share with their peers and staff about the session and the robot, demonstrating generalization of conversational skills. Overall, this positive outcome is in line with studies that reported positive therapeutic outcomes with SAR in children with ASD by promoting social skills [39, 72, 73].

In contrast to other studies using robots to assist children with ASD, the robot in these sessions did not have a central role. Even when active, the experimenters led the activities and interactions, while in other studies, the robot is often positioned as the main facilitator, leading interactions, explaining tasks, or guiding the children, sometimes even remotely controlled. Here the robot played a complimentary role acting as a social reinforcer and motivator rather than primary agent in the session.

7.2 R2C3 and SAR QT Exploratory Feasibility and Usability Hypothesis

Our first main experimental objective was to investigate the feasibility and usability of the R2C3 robotic interface within a SSG with children with ASD. Our observations revealed that the feasibility and usability of the R2C3 interface and SAR QT within an SSG for children with ASD was good overall. inclusion of the robot in the group elicited positive reactions and engagement towards the intervention from the children, which facilitated their social interactions and communication skills [2]. Additionally, the robot's attractive humanoid allure provided a nonthreatening and consistent presence that led to increased motivation and participation in the SSG sessions [74]. We primarily used the positive reinforcement behaviors of R2C3. By doing so, we were able to position QT as a positive reinforcer that complemented the role of the therapists during the sessions [75].

From a usability standpoint, the interface was straightforward and easy to use, even for individuals with limited technological experience. The clinicians conducted all the sessions on their own after prior training on how to use the Wizard of Oz R2C3 platform, which consisted of learning how to connect the interface to the robot through shared Wi-Fi, exploring the platform and the different menus and finally experimenting with launching the robotic behaviors during made-up scenarios. This confirmed the usefulness of the Wizard of Oz paradigm for human machine interaction [34–35].

7.3 R2C3 Exploratory Hypothesis on Children's Engagement

The second main experimental objective was to explore whether the active condition of the QT robot using R2C3 had an impact on children's engagement during SSG. Social interaction initiations were significantly higher when QT was active, meaning that using the robot with the R2C3 interface promoted social initiations in children with ASD. This result can be explained in part by the novelty effect and strong interest that QT aroused in the children during the first sessions [43]. At the beginning of the study, the patients were very receptive to QT's positive reinforcement and reacted positively to each new intervention (looks, smiles, laughter). It is likely that this enthusiasm for QT motivated the children to invest in the group from the beginning and to continue to enjoy the sessions throughout the study. At the beginning of each session, they wanted QT to be "awake" (in response to the question, "How is QT today?", the children answered "Good!"; during the session, some children asked him, "QT, you are awake?") and could express their disappointment if the robot was inactive. In addition, according to the hospital caregivers, the children talked about QT outside the group by specifying his state during the session, either tired or awake. This attraction to QT persisted even after the children understood that it was controlled by the adult via a tablet ("You told QT to say that"). Until the end of the experiment, the patients enthusiastically mentioned QT before going to the group. However, in view of the heterogeneous results obtained and the small sample size, it seems difficult to generalize to all children an improvement of social initiations when QT was active (Fig. 2).

Despite a strong initial interest in QT, no significant increase in the number of responses when the robot was active. Over time, the children's sensitivity to QT's positive reinforcement decreased, often requiring redirecting the children's attention towards the robot. The experimenters often had to point out when QT had intervened ("Did you hear QT? He said he is proud of you!"). In addition, adult interventions seemed to have a greater impact on the children's behavior than the robot's behavior did. For example, when a child lost interest in the group, it was the adult's prompting that allowed the child to re-engage in the activity.

Although some children sometimes called out to QT, the participants primarily solicited the adults and sought their attention. It is also important to note that the scoring of engagement (the number of responses to social interaction requests and the number of interaction initiations) was conducted during a single activity rather than the entire session, and this activity was particularly conducive to placing QT in the interlocutor position.

Based on the literature on social robots [3, 20], we also hypothesized that the presence of QT would allow for a decrease in negative behaviors and an increase in positive behaviors of the children within the group. We found a positive effect on maladaptive behaviors during SSG, but it was not specific to sessions when QT was active as there were no significant differences in children's behaviors as a function of QT's status. The improvement in the children's behaviors seemed to be related to the establishment of a therapeutic framework within the group and to the progressive adaptation of the activities to the patients' cognitive and language level [7–8].

Further supporting these findings from previous studies [76, 77], our results suggest that QT's use as a simple reinforcer led to increased social initiations, emphasizing the potential of SARs to spark interest and engagement in children with ASD. This interest creates a valuable opportunity to teach social skills. When SARs are integrated into social skills sessions using appropriate and evidence-based therapeutic frameworks [7] and activities tailored the children's developmental needs, they may have the potential to enhance social sills more effectively than sessions without robots.

7.4 R2C3 Interface Design Improvement

Beyond these observations, we believe that the score of initiations significantly increased in contrast to the responses because of the limited capacities of the interface used, which seemed to favor the children's initiations. Indeed, QT was able to answer the children's questions but had difficulty engaging them in interactions (very few questions were available, and there was no possibility to rebound on a child's initiation). During the last activity, the participants showed real pleasure in questioning QT and learning more about him; they asked him questions spontaneously, were happy when he shared his tastes and expressed pleasure in giving him the pictogram corresponding to what they liked ("Do you like the fox, QT?", "Do you want some chocolate?"). However, the interactions were often limited to one response from QT without the possibility of rebounding on the response. The participants tended to respond more to the adults' prompts than to the robot's.

Other aspects of the R2C3 interface could be improved when implementing it in an SSG. These limitations explain its moderate scoring of the DICTI [44]. Due to the group scenario, the interface did not allow the robot to initiate interactions with more than one participant at a time. Nevertheless, the therapists were able to rebound on single child-robot interactions and generalize them to the rest of the group. They did so by involving the other participants in the child-robot interaction and creating a group dynamic between all participants based on the robot's interaction.

Similarly, R2C3 lacked the ability to adapt the robot's behaviors to the specific needs of each patient by proposing, for example, different levels of complexity in the robot's responses. Globally, exchanges with QT were very limited by the lack of customization of its interventions. QT's comments were predefined, and therapists could neither modify nor add to them. For example, when a participant asked QT a question, the adult had to almost systematically rephrase it as QT could answer only closed-ended questions.

The R2C3 robot's intonation/prosody also lacked modulation and expressiveness, accentuating the artificial impression of its answers [78]. Similarly, the range of emotions offered by the interface was quite limited. R2C3 did not have the option to share his emotional state but only to comment on others' emotional states ("You look sad", "You look angry"). Furthermore, he could not express his agreement or disagreement to create reciprocal social interactions (e.g., "Me too", "Me neither").

Finally, the time lag between the Wizard of Oz control and the behavior execution made the reactions less spontaneous or even unsuitable for some activities. The computation of adaptive algorithms should improve QT's turn taking [79]. Moreover, unlike other social robots such as SAR NAO [80], QT was limited in its movements (it could only move its arms), which restricted its use for certain physical activities.

7.5 Study Implications and Future Considerations

Our study findings shed light on the impact of implementing a SAR in SSG for children with ASD, and most notably on children's engagement, specifically in responses to social requests. To enhance the robotic integration, it is essential to customize the interface to cater to the requirements of children with ASD and the unique dynamics of the SSG [33]. Potential enhancements include multi-party systems, personalizing the interface and incorporating specific social behaviors for enriched interactions. Perhaps including an AI language model into the interface to facilitate more fluid and extensive vocal interactions with the robot. Although, this raises concerns across clinical, engineering, and ethical domains, that must be addressed prior to exploration.

Clinically, the challenge revolves around how clinicians can regulate interactions between the robot and children if an autonomous language model is in charge of the interactions. From an engineering standpoint, language models lack training to interact with children, particularly those with special needs. Ethically, these considerations require thorough attention before advancing the development and deployment of AI language models. Moreover, our study highlighted the novelty effect, whereby children's initial enthusiasm towards the robot diminished over time, with their social interest gradually shifting towards their peers and clinicians. This observation reinforces our understanding of the robot's role as an engagement facilitator and positive reinforcer. However, it raises critical questions about the long-term therapeutic potential of social robots: Are they truly designed as therapeutic tools, educational companions, or simply subjects of trends, with limited evidence to support their lasting efficacy? In light of these insights, our proposed next step involves conducting a new usability study with an adapted and enriched robotic interface, followed by a rigorous clinical efficacy Randomized Controlled Trial (RCT).

8 Limitations

This study presents obvious limitations due to its exploratory design. A control group was not included, and the number of participants and duration of the study were limited. In addition, there is currently no scale that can effectively measure social skills in their entirety [81]. The ADOS-2 module was used to assess specific ASD domains, such as social skills, communication and maladaptive behaviors, based on the sessions' video recordings, but it may not be sensitive enough to detect changes in skills over time. Additionally, our study did not include a follow-up, and our evaluations focused on the children's behaviors within the group and not on the transfer of their skills to everyday life. The R2C3 interface displayed several limitations, primarily related to its design, which was not specifically intended for use in an SSG for children with ASD. Because it was originally developed for the iReCheck project to rehabilitate writing skills in children with dysgraphia [56], certain features should be redesigned to be better suited for an SSG. The lack of customization/personalization of R2C3 appeared to be one of the main barriers in child-robot interactions during SSG. Personalizing the interface could enhance the user experience, increase the efficiency of the interaction, and ultimately facilitate the naturalness of the social exchange [82]. We believe the interface could be improved to fit the needs for an SSG based on the overall promising results of the current study.

9 Conclusion

We investigated the feasibility and usability of the R2C3 robotic interface and the impact of the SAR QT in an SSG for children with ASD. Our observations confirmed our exploratory hypothesis, demonstrating the feasibility of incorporating the R2C3 Wizard of Oz interface alongside the Socially Assistive Robot (SAR) QT within a Social Skills Group (SSG) setting.

The robot's social reinforcement complemented the clinicians' effectiveness during the sessions. From a usability standpoint, the interface is suited for non-technological participants. Quantitatively, our results suggest that the use of QT in active mode leads to a significant increase in social interaction initiations but does not show a significant improvement in responses to social interaction requests and ADOS scores. Both the active and inactive conditions demonstrated a significant improvement in the participants' social skills after the ten group sessions. Considerations for potential enhancements include the inclusion of a personalized interface with specific social behaviors for enriched interactions and the incorporation of the NAO Robot's motions to augment the overall user experience. A proposed next step involves conducting a new usability study with an adaptive interface, followed by a rigorous clinical efficacy Randomized Controlled Trial (RCT).

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Declarations

Ethical Approval This Study Was Performed in Line with the Principles of the Declaration of Helsinki. Approval Was Obtained from the Ethics Committee of Sorbonne University (CER-2023_BETTENCOURT-IIQCASSGS). The Procedures Used in this Study Adhere To the Tenets of the Declaration of Helsinki.

Consent to Participate and Publish Data Informed Consent Was Obtained from Legal Guardians.

Competing Interests The authors have no relevant financial or non-financial interests to disclose.

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