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Design and Evaluation of a Mobile Robotic Assistant for Emotional Learning in Individuals with ASD: Expert Evaluation Stage

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Abstract

This article introduces the design and assessment of a robotic assistant aimed at generating therapeutic interventions for individuals with ASD. A uniform oval-shaped structure was considered for the design, featuring two arms, leg-like wheels, and a facial screen for displaying facial expressions. Six basic emotional states were generated, enriched with facial expressions, colors, sounds, and movements, aiming to emulate human nonverbal language to the greatest extent possible. The construction process was executed using additive manufacturing technology, specifically 3D printing. Once the functional prototype was developed, its appearance, therapeutic usability, generation of emotional states, and social skill development were evaluated through structured surveys on a Likert Scale. The evaluation took place in two stages: (a) expert peer evaluation, involving 5 experts in ASD, with consensus levels determined using Kendall's Coefficient of Concordance (ω), that show a susbtantial agreement ($\omega = 0.709$) regarding the robot appearance and slight agreement ($\omega = 0.183$) in mood generation; (b) perception assessment with individuals who work daily with people with ASD, with 36 participants, and survey validation through Cronbach's Alpha ($\alpha = 0.94$), followed by results analysis using descriptive statistics, which indicates that the robot appearance is suitable for the majority of evaluators, but they differ in the robot dimensions. Outcomes highlighted the robotic assistant's specific characteristics that warrant adjustments before piloting with ASD individuals. This study presents a replicable protocol for the preliminary evaluation of any technological support geared towards therapeutic interventions, preceding experimental processes involving the target audience.

Keywords Robot assistant · Autism spectrum disorder · Social skills · Emotional learning · Experimental assessment · Therapeutic intervention

1 Introduction

Individuals with Autism Spectrum Disorder (hereinafter referred to as ASD) exhibit a set of conditions that compromise their personal capacity for interacting with their environment [1–3]. Presently, it is estimated that 1 in every 160 children worldwide is affected by ASD, and as diagnostic processes improve, this number continues to rise [4]. ASD remains a significant public health concern. Findings presented in [5] affirm that prevalence estimates for ASD are consistently on the rise across most communities, necessitating ongoing public health surveillance to quantify and comprehend these changes. As a result, more avenues for learning and research are required to assess the myriad factors influencing ASD prevalence over time [6].

Consequently, there exist multiple methods focused on addressing the acquisition and enhancement of social skills, enabling individuals with ASD to engage with peers in the most functional manner possible. Beyond traditional methodologies rooted in therapeutic criteria, Information and Communication Technologies (ICTs) have begun to play a pivotal role in screening, diagnosis, and therapeutic inter-

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vention processes. Currently, various technological supports have been developed to cater to individuals with ASD [7, 8].

One of the technologies that has garnered significant attention from developers in the creation of therapeutic supports is robotics [9]. Children with ASD often exhibit heightened interest in interacting with robots compared to their peers. For that reason, the use of robotic assistants within therapeutic processes is under extensive investigation [10]. These robot-based therapeutic interventions effectively target joint attention, imitation, verbal communication skills, and the enhancement of social interaction for individuals with autism [11–13]. Within this context, researchers conduct studies in the field of social robotics, as part of the Human-Robot Interaction (HRI) paradigm. For an HRI system, computational decision-making algorithms are imperative for recognizing individual emotions [14]. In this domain, understanding an individual's emotions holds significant importance for technological advancement.

As an innovative methodology, robotic assistants are employed as technological tools to enhance communication skills and social interaction for children with ASD. In their case study, Goodrich et al. [15] illustrate that social robots elicit positive social communication behavior in an autistic child. Similarly, Scassellati et al. [16] demonstrate that preschool and school-age children with ASD exhibited significant improvements in social communication with adults due to the intervention of a robotic assistant in their therapeutic sessions, compared to sessions exclusively involving adults. Additionally, Diehl et al. [10] posit that specific applications of intelligent robotic systems can be harnessed positively, paving the way for new therapeutic intervention options. This approach enables the customization of treatments, rendering them individualized, flexible, and adaptive for each individual with ASD, based on novel and highly relevant quantitative measurements of engagement and performance.

In this context, within the framework of the UNESCO Chair: Assistive Technologies for Educational Inclusion at Universidad Politécnica Salesiana - Ecuador, we have designed and constructed a mobile robotic assistant to support emotional learning for individuals with ASD. This robot is capable of generating six basic emotional states, grounded in the work of Ekman [17], along with an additional neutral or waiting state. These emotional states are based on nonverbal expressions encompassing facial expressions, colors associated with color psychology [18], sound emission, and articulation movement. Furthermore, we have deemed the use of open-source software and hardware pivotal, aiming to ensure that future researchers can readily replicate the proposed solution. It's worth emphasizing that accessibility to ICTs, and technological literacy is a universal right [19], guiding our commitment to inclusivity and equitable technological participation.

Our overall experimental proposal is structured around three crucial evaluation stages, all integral to ensuring the therapeutic utility of the robot. The first stage involves an evaluation of the robot by experts in the ASD field. Subsequently, the robot's assessment is extended to a group of neurotypical children, followed by the execution of a pilot evaluation with a group of children with ASD. In the scope of this present work, we focus solely on the first stage, which aims to assess the perception of autism experts regarding the emotional robotic assistant. Based on their observations, adaptations and corrections are made to the system, thereby facilitating progress into the subsequent stages of experimental process.

Subsequent sections of the document are organized as follows: In Sect. 2, a comprehensive overview of related works concerning the use of robotic assistants for individuals with ASD is provided. Section 3 elucidates the materials and methods employed in the robot's design, encompassing the generation of movements and emotional states. Following this, Sect. 4 delves into the experimental design employed for evaluating the robot through interactions with ASD experts. Section 5 showcases the results derived from the evaluation process, followed by ensuing discussions. Lastly, Sect. 6 encapsulates the study's conclusions and the prospective avenues for future research within the current investigation.

2 Related Works

Numerous technological supports based on robots have been developed to provide assistance during therapeutic interventions for ASD. Boccanfuso et al. [20] indicate that harnessing the unique qualities of simple yet powerful robots to deliver emotional stimuli objectively presents a potential opportunity to advance our understanding of distinctive differences between very young children and young adults with typical development and those with ASD. Alterations in the frequency of close and interactive robotic play and caregiver-guided emotional responses, particularly across states such as happiness, anger, and sadness, emerge as significant and recurring themes. Repetition was observed within both studied groups. Additionally, Kozima et al. [21] suggest that robotics as an Assistive Technology (AT) tool profoundly impacts the cognitive development of children with ASD. This aligns with other studies that have identified the potential of robots as tools to captivate and sustain the attention of children with ASD, ultimately fostering cognitive development [22].

In 2009, Dautenhahn et al. [23] pioneered the development of the KASPAR robot, a humanoid robot designed for Human-Robot Interaction with a particular focus on non-verbal communication. This robot, characterized by an infant-like appearance, employs gestures as the primary mode of communication, especially tailored for children with ASD. Despite its initial success in research endeavors [24, 25], developers acknowledge the challenge of refining facial expressions and increasing degrees of freedom in facial movement for enhanced communication. The continuous evolution of the robot underscores the importance of ongoing feedback and inclusive design in the realm of technological support for individuals with ASD [26].

A noteworthy instance of robot-based therapies is presented by Ali et al. [27]. They examined the effectiveness of a therapeutic intervention grounded in the use of two humanoid robots (NAO) within an interaction ecosystem. Their study addresses current social challenges faced by children with ASD by introducing an integrated intervention—a triadic human–human–human communication—initially derived from human–robot–robot triadic communication. Furthermore, through a preliminary comparison of participant performance between robots and human operators, the overall outcome revealed an enhancement in the child's skills and abilities. After participating in triadic interactions with the robot, all children exhibited improved social behavior and better engagement in mutually satisfying interactions.

Another robotic assistant is presented by Bharatharaj et al. [22]. Their non-humanoid robot design, named KiliRo mimics the morphology of a parrot and constitutes a semi-autonomous robot capable of moving its legs, wings, and head. Additionally, KiliRo can learn the alphabet, numbers, and recognize humans. Adaptive Rival Model Method (AMRM) employed by Bharatharaj et al. represents a novel teaching method that enhances the learning and social interaction skills of children with ASD. Results, assessed through emotion-centered facial recognition, indicate that autistic children tend to exhibit non-rejecting behavior towards the parrot-like morphology and display joyful behaviors within robot-involved environments.

Furthermore, Bekele et al. [28] proposed developing and applying a robotic system to support areas of need in children with autism, such as communication challenges, aiming to test the efficacy of an intelligent system capable of effectively managing cues and attention responses. Results revealed that children with ASD paid more attention to humanoid robots and spent less time observing human instructors, consequently reducing stereotyped behaviors during intervention phases. Evaluation outcomes indicate that robot-based intervention has a more pronounced impact on children's cognitive development compared to traditional teaching methods.

In parallel, researchers like Ghorbandaei et al. [29] developed robotic platforms specifically tailored for reciprocal interaction with children with ASD, consisting of structured and unstructured interaction modes. In the unstructured interactive mode, a vision system recognizes the user's facial expressions through fuzzy clustering. An interactive decision-making unit is combined with a fuzzy finite state machine to enhance the quality of human-robot interaction. In the structured interaction mode, a set of imitation scenarios was designed, featuring various facial behaviors akin to reciprocal imitation games, serving as an appropriate way to teach imitation skills. As a result, the platform's acceptability among autistic children aged 3 to 7 was observed, with a preliminary acceptance rate of 78% as measured through observation. The behavior of the children towards the robot was analyzed, with 11 out of 14 children showing willingness to interact.

Continuing this trajectory, Taheri et al. [30] proposed intervention scenarios designed to involve two humanoid robots, NAO and Alice, for three pairs of children with ASD, a parent, a therapist, and a robot operator. These scenarios aimed to engage participants in joint tasks and individual/group imitation. Over a span of approximately three months, each group attended 12 study sessions lasting 30 min. The study employed a Wizard of Oz-style robot controller with instructions executed by the robot and/or therapist. Various assessment tools facilitated the investigation of participants' behavioral changes. Overall, according to the Gilliam Autism Rating Scale (GARS) questionnaire, there was a decrease in the severity of autism symptoms across all participants. Additionally, results from The Autism Social Skills Profile (ASSP) questionnaire revealed improved total scores in social competence for participants with high activity levels, as well as enhancements in its subindices: social reciprocity, social participation/avoidance, and harmful social behaviors, all within a span of nearly 3 months of robot-assisted interventions.

Following these advancements, Melo et al. [31] describe the INSIDE project, a networked robotic system designed to enable the use of mobile robots as active agents in the treatment of children with ASD. The central concept of INSIDE research is that of symbiotic autonomy, aimed at developing an autonomous robotic platform capable of interacting with human agents in situations that neither the robot nor the human can achieve independently. The collaborative therapeutic activities consisted of social routines such as "Saying hello" and "Saying goodbye" as the initiation and conclusion of the interaction, respectively. Additionally, five games focused on training attention skills, following instructions, social reciprocity, empathy, and taking turns. As a result, a therapy more tailored to the interests and skills of the children was achieved, leading to enjoyable and encouraging interactions, constituting a positive shared experience for children with ASD.

Drawing from the previously conducted studies, it becomes evident that the development of therapeutic supports grounded in social robots has garnered significant interest over the years, yielding remarkable progress in enhancing intervention processes for individuals with ASD. However, a common

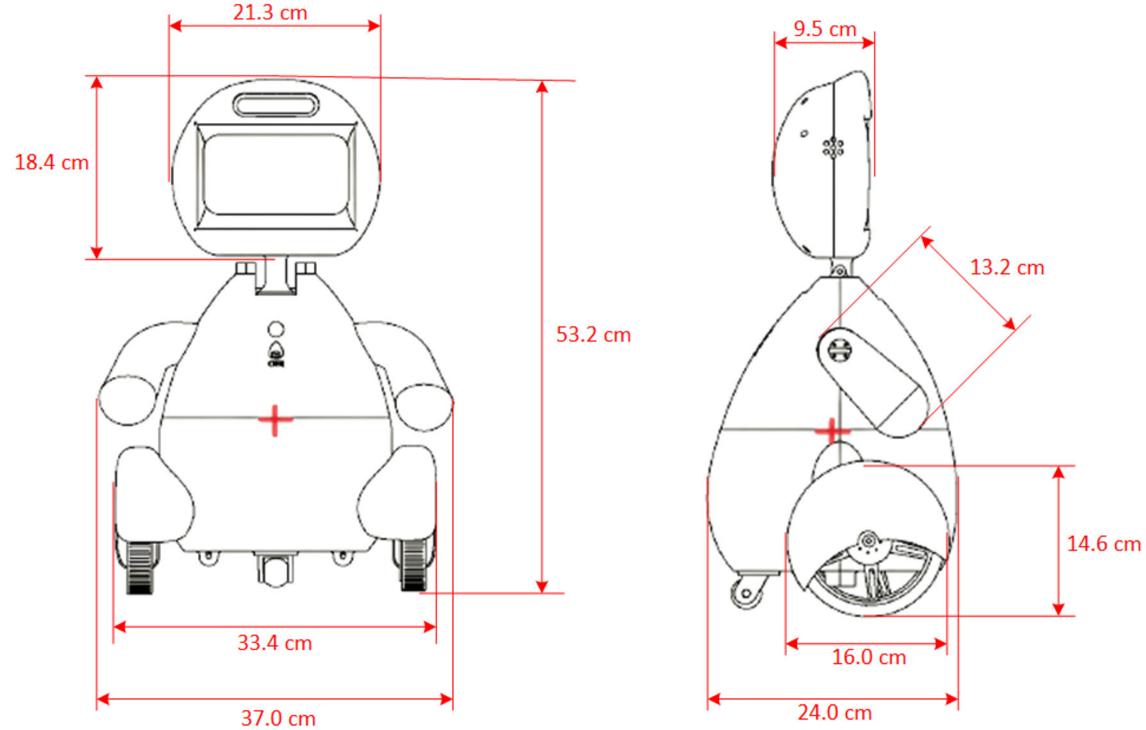

Fig. 1 Center of gravity and dimensions of the robotic assistant (front and side view)

aspect in the development of robotic assistants for individuals with ASD is the lack of a pre-interaction evaluation stage involving experimental subjects from the target groups of interest. Evaluation by expert peers and feedback from professionals represents a suitable resource for obtaining initial feedback to identify areas for improvement in robot development, emphasizing the importance of making a positive first impression on children with ASD. In this context, in the subsequent sections, we present our social robot proposal and an experimental protocol incorporating lessons learned from preceding researchers. Our objective, mirroring the majority of the cases analyzed, is to enhance the conditions of individuals with ASD and achieve meaningful advancements in their well-being.

3 Robot Design

In our prototype, the robotic assistant structure is defined by a uniform structural design capable of housing the devices and/or electronic components responsible for generating emotional states. Robot's form is inspired by other social robots (NAO and Cozmo [32, 33]) known for their oval-shaped designs and human-like features. The construction process was conducted using additive manufacturing technologies, specifically 3D printing. This process is relatively more cost-effective and suitable for the prototype construction phase compared to traditional or alternative manufacturing methods. Rather than melting or machining a piece, it allows for layer-by-layer creation and modifications that do not incur a significant economic impact [34].

Starting from an oval-shaped structure, the center of mass of the robotic assistant was determined. Based on generated trajectories and varying independent speeds of the differential wheels, the placement of a support wheel is required to prevent swaying and falls. It was determined that the robotic assistant should have a slight backward inclination of approximately 4° relative to the ground surface to maintain balance. The center of mass was established using CAD software, as depicted in Fig. 1, with a red cross-shaped marker in both frontal and lateral views. Additionally, the robot dimensions have been specified.

In Fig. 2, the final prototype design is shown. Tire covers were added, and all sharp edges were also removed in order to prevent any potential accidents or injuries to the users as much as possible. We also developed a set of animations with masculine features and another with feminine features, allowing users to choose which gender they feel most comfortable interacting with. Previous research has identified the significance of gender in interaction over other characteristics [35].

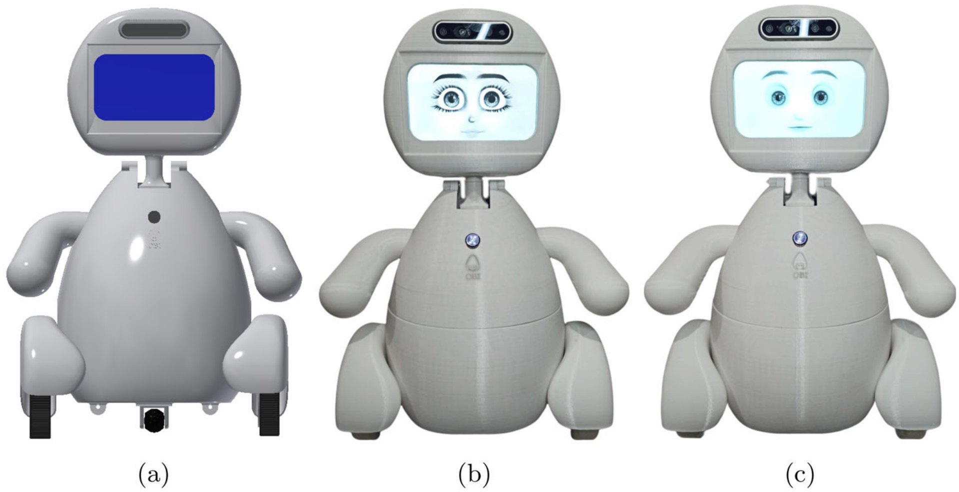

Fig. 2 Final prototype of the robotic assistant: **a** prototype extracted from design software, **b** actually constructed prototype with feminine facial features, **c** actually constructed prototype with masculine facial features

3.1 Movement Generation

In order to maintain a seamless interaction, it is imperative for the robotic assistant's joints to produce organic or natural movements [36, 37]. Movements generation involves the synchronized control of various actuators: neck (2 degrees of freedom), shoulders (1 degree of freedom), and the differential wheels. Schulz et al. [38] present a systematic review analyzing various animation techniques in Human-Robot Interaction, offering a comprehensive perspective on the possibility of achieving natural and realistic movements that foster interaction. In another work [39], the same author implements the Slow-in and Slow-out principle to animate a robot with motions familiar to elderly users. Both studies underscore the significance of pursuing natural movements in robotic assistants. To achieve this, our work involves mathematically modeling cubic polynomial curves and applying them to the degrees of freedom of the robotic assistant. This process generates specific trajectories through position-based control mechanisms.

$$q(t) = at^3 + bt^2 + ct + d \tag{1}$$

Input variables of time, initial position, and final position of the motor are represented in Eq. (1), generating the position interpolator curve visualized in Fig. 3. Furthermore, it's important to note that the velocity of this mathematical model, being the derivative of position, starts and ends at zero velocity.

Integration and control of the proposed technology for the robotic assistant were achieved through the use of Robot Operating System (ROS), which operates under the permissive open-source software license, Berkeley Software Distribution [40].

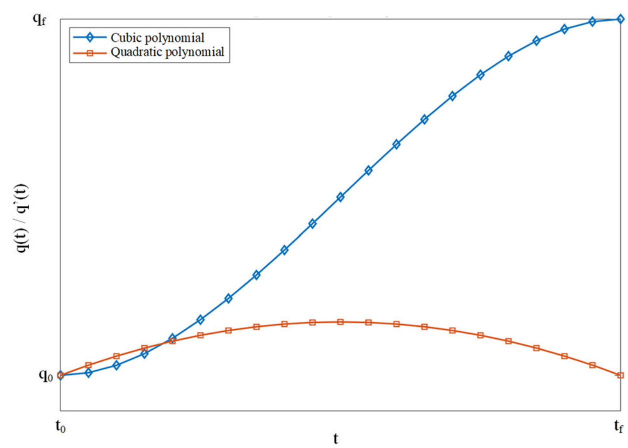

Fig. 3 Trajectory generation through a position and velocity interpolator

Despite not being an operating system in the traditional sense, ROS provides essential services for the remote control of the robotic assistant. These include hardware abstraction, low-level device control, common functionality, message passing across various topics between processes, and the maintenance of consistent packages. A ROS system can have numerous interconnected nodes across multiple devices. However, this configuration depends on the system's distribution and setup, potentially requiring each node to communicate with all other nodes at any given moment [41].

The robotic control device (tablet) houses the implemented ROS Master, which is responsible for generating the material list and subscription services to other nodes within the ROS system. It also grants the necessary permissions for individual ROS nodes to determine each other's locations. On the other hand, the robotic assistant receives

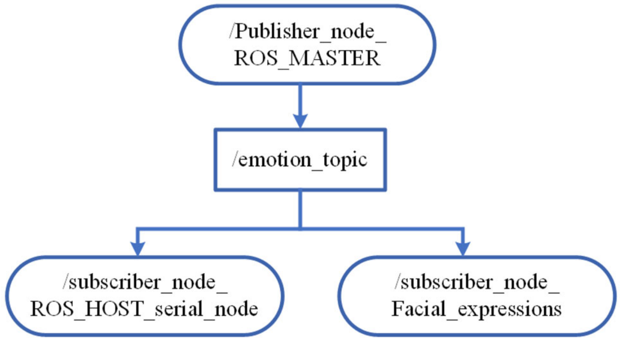

Fig. 4 Remote communication with a Robot Operating System (ROS)

commands from the Master through messaging on topics facilitated by the implementation of ROS Host on that system. Once these nodes are configured, the publisher node and subscriber nodes communicate with each other. Figure 4 illustrates the ROS communication system, where the publisher_node publishes messages via the emotion_topic, which are subsequently distributed to the subscriber_nodes for internal serial port communication and animation display on the screen, respectively.

3.2 Emotional State Generation

Essentially, an emotional state refers to a person's subjective and qualitative experience in response to certain stimuli, events, or thoughts. In the context of a robot, artificial emotional states are primarily conveyed through facial expressions accompanied by body movements. The core objective is to enhance HRI and create a more natural and satisfying experience for individuals engaging with the robot. Additionally, the psychology of color aids autistic children in perceiving their behavior and interpreting their emotional states based on different colors. It's important to work with a range of warm or pastel shades, avoiding colors that may be overstimulating for children [42]; otherwise, incorrect usage of colors could lead to rejection in the case of the study.

Facial expressions for 7 basic emotions, according to Ekman [17] are accompanied by subtle yet highly expressive movements. This is particularly important as the ability to focus on and recognize facial expressions and body language is a crucial aspect for children with ASD. These expressions are projected on the screen located on the robot's face. Additionally, sets of movements were developed to accentuate emotional expressions, generating nonverbal communication. This approach draws from observed experiences in interaction processes of other social robots such as NAO and Cozmo [32, 33]. Furthermore, non-phonetic guttural sounds were recorded to complement the expression of the robotic assistant. To coordinate the robot's facial expressions, sounds, and movements, we enlisted the expertise of a team of university professors specializing in the fields of social communication, psychology, and artistic expression.

The robot's expressions are characterized by four variables: facial animation, color, movement, and sounds. This set of features enables the technological tool to become highly expressive, closely resembling the emotional generation of an average human. Captures of the 7 emotions corresponding to both female and male characters are shown in Figs. 5 and 6, respectively. The control of emotional state generation was developed through a mobile application on a tablet. This setup allows the evaluator to test all available expressions on the robotic assistant.

4 Method

The robotic assistant evaluation was conducted in two stages. In both stages, a structured survey consisting of 23 Likert-scale questions and an additional 7 questions collecting demographic information were used as a foundation. Likert scale utilized ranged from 1= Strongly disagree to 5= Strongly agree. In the second stage, questions were added to gauge interpreting emotional states' perceived complexity or simplicity. To answer these questions, evaluators interacted with the robot beforehand, allowing them to analyze both its physical form and functionality.

The questions in the structured survey are grouped into four analytical variables: appearance, social skills, mood, and therapy use. Table 1 shows the questions along with their corresponding variables. Below are the question groups categorized based on their focused criteria:

- *Therapy use* This criterion aims to determine the usefulness of the robotic assistant for therapy development, the feasibility of incorporating it into daily activities of therapists or psychologists, and the willingness of experts to use the robot. This criterion encompasses 6 questions.
- *Appearance* This criterion focuses on the physical characteristics of the robot, such as colors of structure and face, the sounds it emits, the robot's movement speed, and its dimensions. This criterion comprises 6 questions.
- *Social skills* The aim of this criterion is to ascertain whether experts believe the robot generates nonverbal language, the level of empathy it can evoke in children when displaying its emotions, the robot's expressiveness, and whether the implemented expressions are adequate for therapeutic interventions focused on emotional teaching and learning. In total, 4 questions are grouped under this criterion.
- Mood Generation: This criterion aims to determine if the robot is capable of generating various moods that can be utilized in therapeutic processes for children. It evaluates the robot's ability to express the following moods: neu-

Fig. 5 Emotional states of the Robotic Assistant (female character)

Fig. 6 Emotional states of the Robotic Assistant (male character)

tral, joyful, sad, fear, disgust, surprise, and angry. In total, 7 questions are grouped under this criterion.

4.1 Expert Peer Evaluation

The first stage involves the evaluation conducted by expert peers using a structured survey that analyzes fundamental aspects of the robot's design and functionality. This evaluation aims to identify consensus in participants' responses through the use of Kendall's Coefficient of Concordance ω [43].

In Table 2, the profile of experts who participated in the evaluation is shown. Experts are professionals who are in charge of centers for children with ASD, all of them have academic training related to autism. They possess extensive experience in working with and attending to individuals with ASD (mean = 10.4 years, SD = 5.727). The age range of experts spans from 31 to 58 years (mean = 44.6 years, SD = 10.18). Kendall's Coefficient of Concordance ω was employed to determine the existence of consensus among the experts, following a similar process as demonstrated in [44]. This coefficient was used for analyzing the survey results, which was organized into two major blocks. The first block included 7 demographic questions (names, gender, age, years of experience in working with individuals with ASD, workplace, current activity), while the second block contained 23 Likert-scale questions.

4.2 Evaluation of Professionals' Perception in ASD

The second stage evaluates the perception of professionals (therapists, doctors, nurses, teachers) working with children with ASD. In the experimentation process, 36 professionals participated (21 female, 15 male), with ages ranging from 26 to 63 years (mean = 38.088 years, SD = 9.04) and experience in caring for individuals with ASD spanning from 1 to 20 years (mean = 6.73, SD = 4.7). In this case, the instrument was validated using Cronbach's Alpha (α = 0.94), and results were analyzed using descriptive statistics. Alongside the Likert-scale questions, other multiple-choice questions were included to understand user criteria regarding the complexity or simplicity of interpreting the robot's emotional states and the suitable age range for its use. The specific questions are shown in the Table 3.

During the interaction process, evaluators were provided with basic instructions on how to use the robot and generate emotional states using the control tablet. All participants signed an informed consent form granting permission to use the evaluation results for academic and research purposes. Immediately after completing the interaction, and with the aim of gauging the perception of end-users, the survey was administered.

5 Results and Discussion

5.1 Expert Peer Evaluation Results

In this evaluation, an inter-rater agreement analysis was conducted to determine if there was consensus among the experts. For this purpose, Kendall's Coefficient of Concordance ω was calculated. The calculation process was performed using the statistical software R (version 4.1.2), and the following hypotheses were formulated concerning the agreement among the experts, considering a pair of hypotheses for each criterion:

H_0: Experts have no consensus on the proposed criterion.
H_a: Experts have a consensus on the proposed criterion.

As shown in Table 4, for Kendall's Coefficient of Concordance ω, the interpretation proposed by [45] was used:

$0.00 \leq \omega < 0.20 \rightarrow$ Slight agreement
$0.20 \leq \omega < 0.40 \rightarrow$ Fair agreement
$0.40 \leq \omega < 0.60 \rightarrow$ Moderate agreement
$0.60 \leq \omega < 0.80 \rightarrow$ Substantial agreement
$\omega \geq 0.80 \rightarrow$ Almost perfect agreement

According to Kendall's Coefficient, it can be observed that there is "Substantial agreement" for the "Appearance" criterion of the robot. The consensus for the "Therapy use" and "Social skills" criteria is "moderate". In the case of "Mood generation" criterion, the consensus is "slight". This is because experts disagree that the generation of emotions corresponds to the robot's expression on the screen. Therefore, as future work, improvements will be made in this aspect by generating a new set of images and animations that will prevent confusion when distinguishing between emotions. Similarly, it can be noted that p-value is less than 0.05 (statistically significant) for all criteria (except the "Mood generation" criterion). Likewise, the calculation was performed for the level of consensus considering all question groups together, resulting in a "moderate" consensus level and a statistically significant p-value of 0.00078.

With the aim of observing the consensus levels between each pair of experts, a graphical analysis was conducted using the Bland-Altman method [46]. For this, a total of 10 pairs of possible unique combinations were calculated.

$$Combinations = \left(\frac{N \cdot (N-1)}{2} \right) = 10 \tag{2}$$

where N represents the total number of experts, and a graph was generated for each pair of analyzed experts.

In Fig. 7, consensus analysis between expert 1 and the other 4 experts is depicted. The mean differences (bias) are

Table 1 Questions included in the survey applied and variables evaluated

N.	Question	Variable
1	What is your opinion on the use of robots as support for therapies with individuals with Autism Spectrum Disorder (ASD)?	Therapy use
2	What is your opinion on the overall appearance of the robot?	Appearance
3	What is your opinion on the colors of the robot's structure?	Appearance
4	What is your opinion on the colors of the robot's face?	Appearance
5	What is your opinion on the dimensions of the robot?	Appearance
6	What is your opinion on the sounds emitted by the robot?	Appearance
7	What is your opinion on the speed of the robot's movements?	Appearance
8	Do you believe the robot has the necessary movements to generate nonverbal language?	Social skills
9	How would you rate the level of empathy generated towards the robot during the development of emotional states?	Social skills
10	What is your opinion on the expressiveness of the robot as a whole?	Social skills
11	What is your opinion on the Neutral animation displayed by the robot through its screen?	Mood
12	What is your opinion on the Happiness animation displayed by the robot through its screen?	Mood
13	What is your opinion on the Sadness animation displayed by the robot through its screen?	Mood
14	What is your opinion on the Fear animation displayed by the robot through its screen?	Mood
15	What is your opinion on the Disgust animation displayed by the robot through its screen?	Mood
16	What is your opinion on the Surprise animation displayed by the robot through its screen?	Mood
17	What is your opinion on the Anger animation displayed by the robot through its screen?	Mood
18	Do you consider these basic expressions sufficient to generate a therapeutic intervention focused on emotional teaching-learning?	Social skills
19	Do you believe the robot can help improve the social interaction of individuals with ASD?	Therapy use
20	Do you consider that, in the current state, the robot can be used as support for therapeutic interventions in individuals with ASD?	Therapy use
21	How would you rate the level of complexity when incorporating the robot as part of the planning of therapeutic sessions for individuals with ASD?	Therapy use
22	Would you be willing to use our robot as part of your therapeutic interventions?	Therapy use
23	What do you think would be the reaction of individuals with ASD when interacting with our robot?	Therapy use

Table 2 Profiles of experts who took part in the robotic assistant assessment

Expert	Gender	Age	Experience in ASD (years)	Occupation
1	F	50	10	Child psychologist
2	F	58	10	Speech therapist
3	F	44	12	Psychologist
4	M	31	2	Neurologist, pediatrician
5	F	40	18	Teacher

In gender column: M = male, F = female

Table 3 Multiple-choice questions included in the survey for professionals

N.	Question
1	What do you consider to be the simplest expression to identify?
2	What do you consider to be the most challenging expression to identify?
3	In what age range do you consider that the robotic assistant can help individuals with Autism Spectrum Disorder (ASD)?

Table 4 Kendall's Coefficient of Concordance ω obtained for inter-rater agreement analysis

Criterion	Kendalls' ω	χ^2	p-value	Agreement level
Therapy use	0.451	11.29	0.04592	moderate
Appearance	0.709	17.74	0.00328	substantial
Social skills	0.542	8.13	0.04337	moderate
Mood generation	**0.183***	5.51	**0.4794***	slight
Overall agreement	0.446	49.06	0.00078	moderate

The values marked with an asterisk indicate the criterion that does not meet an adequate level of consensus and has a $p - value$ greater than 0.05. This criterion must be improved in future work

smaller between the pairs of experts 1–2 and 1–4, with values of 0.04 and 0, respectively. However, the highest consensus level is observed between experts 1 and 3, with a ω value of 0.772 and a p-value of 0.049 (significant). For the other pairs, it can be inferred that the consensus values are not significant due to the following reasons:

- Peer 1–2: points are observed above the upper limit, which is confirmed by calculating the ω value (0.62) and the p-value (0.2).
- Peer 1–4: points are observed below the lower limit, which is confirmed by calculating the ω value (0.51) and the p-value (0.43).
- Peer 1–5: while there are no points outside the lower and upper limits, it can be observed that the mean difference is −0.35, a value greater than that of pair 1–3 (−0.26). Therefore, even though the ω value is close to that of pair 1–3 (0.733), the p-value is greater than 0.05 (0.073).

Below, we describe the most relevant elements of the Bland-Altman plots [47]:

- The O symbols represent the differences between corresponding measurements obtained by the two methods being compared for each data point (rater's scores in this case). This difference is calculated by subtracting the value of one rater from the other for each paired measurement.
- The $y - axis$ represents the difference between two raters' scores for each criterion being evaluated. So, each O symbol would show the difference between Rater A's and Rater B's scores for a specific case.
- Bland-Altman plots typically focus on individual differences between the two methods (raters in this case). So, each O symbol represents the difference between individual ratings by two specific raters for a single criterion.

Similarly, in Fig. 8, consensus levels between expert 2 and the other 3 experts are represented, and in the final quadrant, analysis between experts 3 and 4 is shown. The mean differences (bias) are the lowest in the expert pair 2–4, with a value of −0.04. However, for this case, none of the expert pairs have a significant p-value. The results obtained are detailed below:

- Peer 2–3: points are observed below the lower limit, which is confirmed by calculating the ω value (0.74) and the p-value (0.065).
- Peer 2–4: points are observed below the lower limit, which is confirmed by calculating the ω value (0.689) and the p-value (0.11).
- Peer 2–5: points are observed below the lower limit, which is confirmed by calculating the ω value (0.611) and the p-value (0.21).
- Peer 3–4: points are observed below the lower limit, which is confirmed by calculating the ω value (0.556) and the p-value (0.32).

Finally, in Fig. 9, the results obtained for the expert pairs 3–5 and 4–5 are observed. In these cases, we can see that there is no significant consensus either, as there are points above the upper limit. The values obtained for the ω and p-value pairs are 0.757, 0.0574 and 0.621, and 0.198, respectively.

With this analysis, it has been demonstrated that there is a significant consensus between experts 1 and 3. This is likely supported by the fact that both experts share a similar professional profile, which possibly enables them to analyze the robotic assistant and its functionalities from a more common perspective.

However, we have observed that despite the variety in the experts' profiles, there are points of great interest where everyone agrees, and overall, the level of consensus is moderate.

5.2 Evaluation of Professionals' Perception Results

Table 5 shows the summary of results obtained from the Likert-scale questions. Descriptive analysis has been conducted based on measures of dispersion (mean, mode, and variance) to gain a general understanding of the participants' perceptions regarding specific variables of the robot.

The first question (Q01) evaluates the perception of the use of robots as therapeutic support. This question aims to contextualize the evaluators about the robot's purpose and gauge

Table 5 Results of perception survey conducted on professionals in ASD

N.	Question	Mean	Mode	Variance
Q01	What is your opinion on the use of robots as support for therapies with individuals with Autism Spectrum Disorder (ASD)?	4,56	5,00	0,41
Q02	What is your opinion on the overall appearance of the robot?	4,50	5,00	0,53
Q03	What is your opinion on the colors of the robot's structure?	4,36	5,00	0,68
Q04	What is your opinion on the colors of the robot's face?	4,33	5,00	0,44
Q05	What is your opinion on the dimensions of the robot?	2,86	3,00	0,29
Q06	What is your opinion on the sounds emitted by the robot?	3,83	4,00	0,58
Q07	What is your opinion on the speed of the robot's movements?	3,97	4,00	0,42
Q08	Do you believe the robot has the necessary movements to generate nonverbal language?	3,89	5,00	1,32
Q09	How would you rate the level of empathy generated towards the robot during the development of emotional states?	3,86	4,00	0,90
Q10	What is your opinion on the expressiveness of the robot as a whole?	4,33	4,00	0,50
Q11	What is your opinion on the Neutral animation displayed by the robot through its screen?	4,33	4,00	0,44
Q12	What is your opinion on the Happiness animation displayed by the robot through its screen?	4,28	4,00	0,42
Q13	What is your opinion on the Sadness animation displayed by the robot through its screen?	4,42	5,00	0,47
Q14	What is your opinion on the Fear animation displayed by the robot through its screen?	4,36	4,00	0,40
Q15	What is your opinion on the Disgust animation displayed by the robot through its screen?	3,94	4,00	1,16
Q16	What is your opinion on the Surprise animation displayed by the robot through its screen?	4,31	5,00	0,77
Q17	What is your opinion on the Anger animation displayed by the robot through its screen?	4,33	5,00	0,67
Q18	Do you consider these basic expressions sufficient to generate a therapeutic intervention focused on emotional teaching-learning?	3,92	4,00	0,85
Q19	Do you believe the robot can help improve the social interaction of individuals with ASD?	4,31	5,00	0,71
Q20	Do you consider that, in the current state, the robot can be used as support for therapeutic interventions in individuals with ASD?	4,11	5,00	1,04
Q21	How would you rate the level of complexity when incorporating the robot as part of the planning of therapeutic sessions for individuals with ASD?	3,97	4,00	0,97
Q22	Would you be willing to use our robot as part of your therapeutic interventions?	4,25	4,00	0,52
Q23	What do you think would be the reaction of individuals with ASD when interacting with our robot?	4,14	4,00	0,56

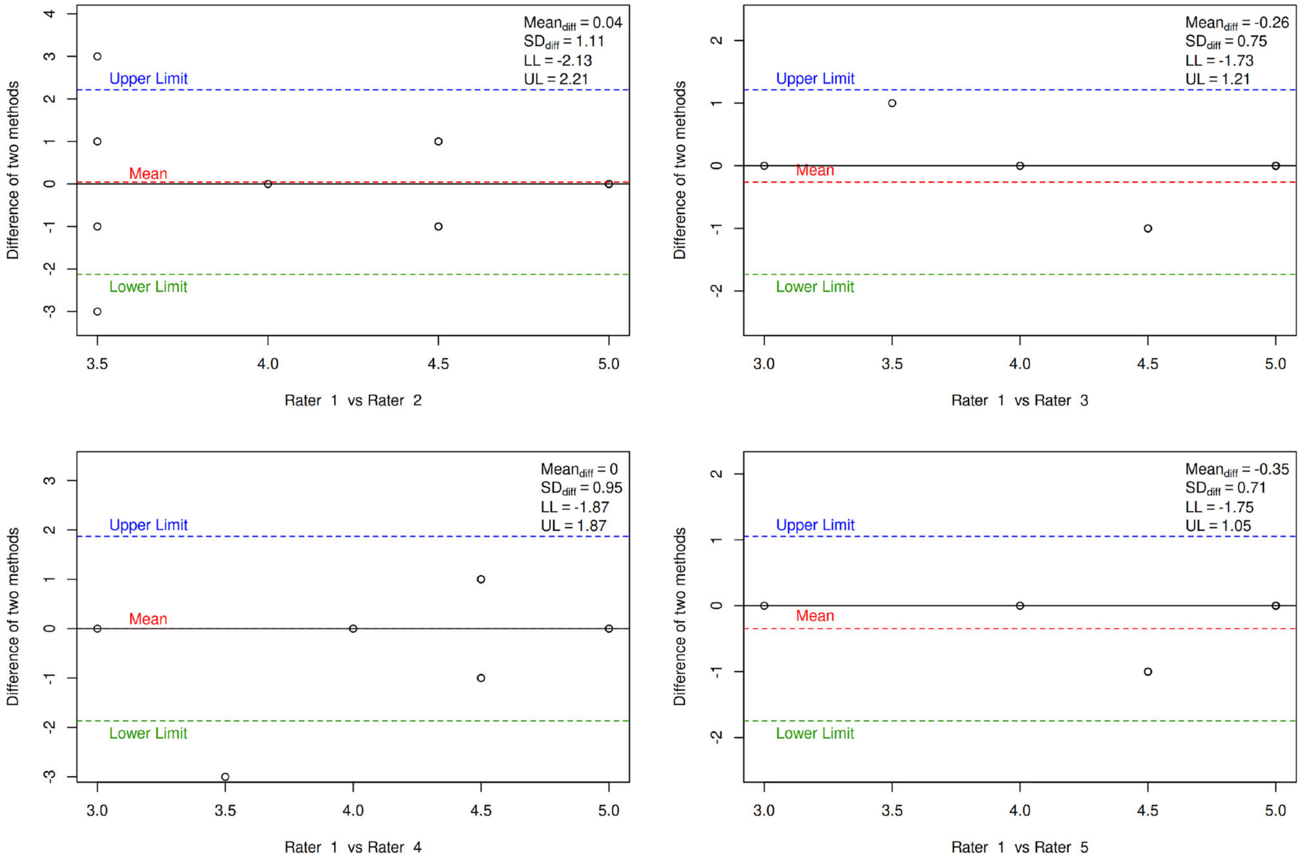

Fig. 7 Results of consensus analysis among the top 4 experts using a representation based on the Bland-Altman comparison method [46]

their openness to incorporating new techniques into traditional processes. According to the data, most respondents have provided positive values and are in favor of using robotic assistants. With this in mind, the following 6 questions (Q02–Q07) are posed to understand the evaluators' perception regarding the physical robot's appearance. Responses with high and very high values are observed in variables such as the overall appearance, structure colors, and facial colors. However, this is not the case for the robot dimensions, where responses are distributed with an intermediate average value. In other words, there was no general acceptance concerning the robot's size. Similar patterns are observed in terms of the sounds emitted by the robot and the speed of its movements. This clearly indicates that there is a need to improve these variables in later versions of our robot. However, the overall perception of this version is acceptable to begin the experimentation stage.

Next question (Q08), queries the evaluators about the perception of non-verbal language generation based on the robot's movements. In this case, although the majority of respondents provide a very high value (36.11% rated it as 5.00, and the same percentage responded with 4.00.), the mean and variance indicate that there were responses significantly below the average. This suggests that this variable should also be considered for improvement in the robot's perception. On the other hand, question Q09 assesses the level of empathy that participants developed towards the robot during the generation of emotional states. Results indicate that there isn't a high degree of empathy, although the results are above average. It is expected that these values could be improved with greater overall expressiveness of the robot.

Questions Q10 to Q18 assess the perception related to the robot's emotional states. Responses remain in a high range in terms of overall expressiveness and neutral, happiness, and fear emotional states. Regarding sadness, surprise, and anger states, the most frequent responses are those of very high, suggesting that these emotions are better achieved and easily identifiable. The emotional state that received the lowest responses was disgust. Although its average value is below 4, it reflects that several evaluators did not perceive this emotion adequately. While this is not a reason to remove it from the emotional state's repertoire, based on the feedback from the evaluators, it will be improved, its inclusion in therapeutic processes will be left to the discretion of therapists. Specifically, in question Q18, it can be analyzed that the generated emotional states are sufficient for use in therapeutic inter-

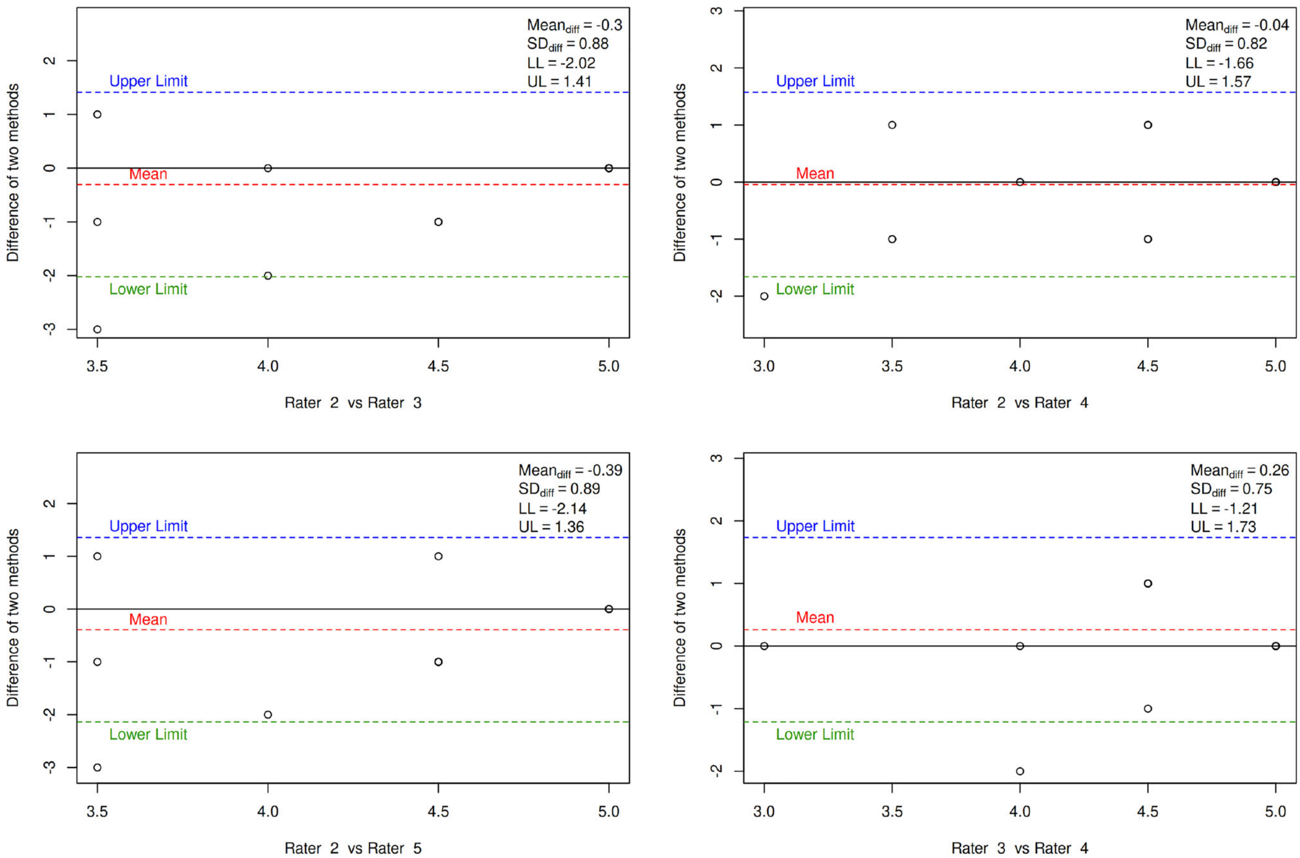

Fig. 8 Results of consensus analysis between expert 2 and the other experts, and between experts 3 and 4

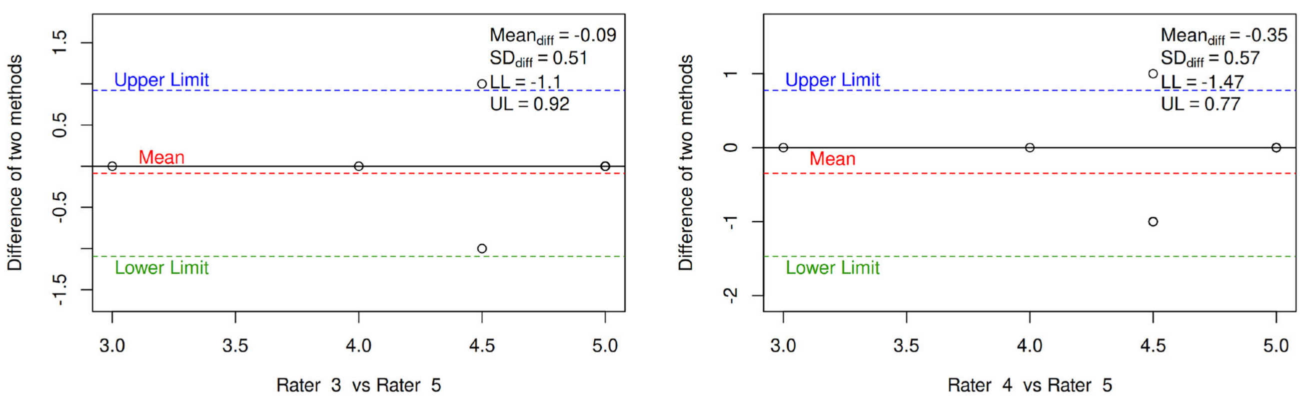

Fig. 9 Results of consensus analysis between expert pairs 3–5 and 4–5

Table 6 Perception of simplicity or complexity in emotions identification

Variable	Joyful (%)	Sad (%)	Fear (%)	Disgust (%)	Angry (%)	Surprise (%)	Neutral (%)
Simple	52.78	2.78	16.67	0.00	25.00	2.78	0.00
Complex	5.56	5.56	5.56	44.44	0.00	25.00	13.89

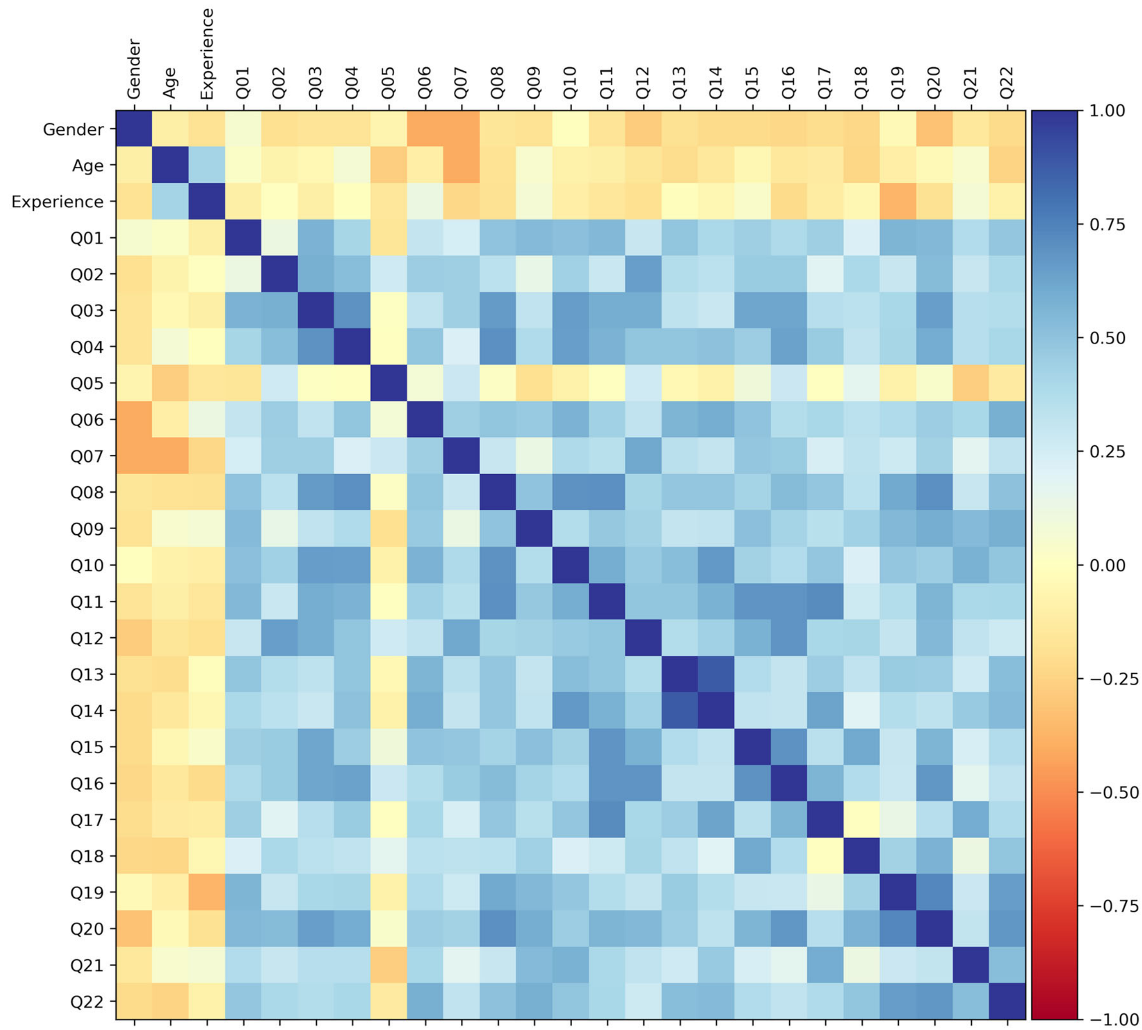

Fig. 10 Heatmap representing the correlation matrix of survey responses and demographic variables. The x-axis and y-axis labels (Q01–Q22) correspond to individual survey questions. The additional variables 'Gender,' 'Age,' and 'Experience' are also included in the matrix to show their correlation with the survey questions. The color bar on the right indicates the strength and direction of the correlations, ranging from −1 (strong negative correlation) to 1 (strong positive correlation), with blue hues representing negative correlations and red hues representing positive correlations. (Colour figure online)

ventions. However, expanding the range of emotional states could enhance the comprehensiveness of planning.

Questions Q19 to Q23 aim to understand the evaluators' perception regarding the integration of our robotic assistant into their therapeutic interventions for individuals with ASD. On the one hand, a high level of acceptance towards the robotic assistant is observed, considering that it can help improve social interaction (Q19) and serve as therapeutic support (Q20). On the other hand, the evaluators perceive that incorporating the robot into their intervention processes does not pose a significant challenge (Q21), and they express their willingness to use it (Q22). Furthermore, there is a generally positive perception among the evaluators towards the reactions they assume individuals with Autism Spectrum Disorder (ASD) might exhibit towards the robot (Q23).

Figure 10 depicts the correlations between the 23 survey questions and 3 demographic variables of the evaluators (gender, age, and experience). The Ordinary Least Square (OLS) method was employed, generating a heatmap that reflects the correlation levels. As expected, professional experience correlates with age; however, the variables gender, age, and experience do not exhibit a high level of correlation with the survey responses. This lack of correlation can be interpreted positively as it reflects the impartiality of the evaluators regardless of their age, gender, or experience.

Most variables show correlations among themselves except for Q05 (robot's dimensions–appearance). This differ-

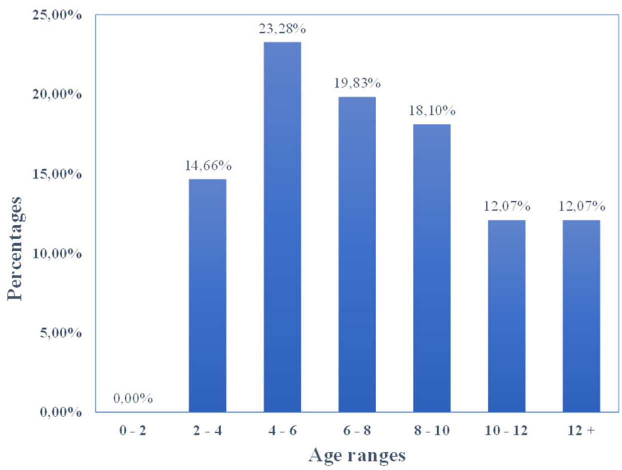

Fig. 11 Recommended ages for robot usage

ence in results highlights a clear action point for improvement or adaptation according to expert criteria. Although other variables also had average ratings below 4, it's observed that only variable Q05 exhibits this behavior. Other variables such as Q07 (robot's movements speed - appearance), Q09 (empathy generated towards the robot–social skills), Q18 (sufficient moods for therapeutic interventions–social skills), and Q21 (robot incorporation in therapeutic planning–therapy use), also show low correlations, which coincides with an average rating below 4. It is worth considering these variables as other points of attention for future improvements of the prototype before interacting with individuals with ASD.

In addition to the Likert-scale questions, multiple-choice questions were included to understand the users' criteria regarding the complexity or simplicity of interpreting emotional states and appropriate age ranges for the robot's use.

Table 6 presents the results related to which emotional state was considered easier and which was more difficult to interpret. It is observed that emotions like happiness, anger, and fear are easier to interpret, whereas emotions like disgust, surprise, and the neutral state are considered more complex. These results align with the findings expressed earlier and reflect the need to improve specific emotional states within the generated emotional repertoire.

The final question of the survey tests the evaluators' criteria regarding the age range in which the robot should be used. Results are shown in Fig. 11 and vary across a range from 0 to 12 years or older, but the simple majority (23.28%) believe that the appropriate range is between 4 and 6 years. Looking ahead to the experimental process in the next stages, interventions will aim to be developed with children between 4 and 6 years old, but also considering the range of 6 to 10 years (6–8 years 19.83%, 8–10 years 18.10%), which has also received an appropriate response.

6 Conclusions

Evaluations conducted on the robotic assistant have allowed us to identify specific aspects that can be improved to create an effective tool for therapeutic support for individuals with ASD. We consider it important that, prior to the pilot testing stage with the target group, prototypes undergo an evaluation protocol where experts in the field can test their functionality and provide feedback on appearance and utility. While in the literature, most prototypes proceed directly to an experimental stage [9], the pre-evaluations allow for refining prototypes, addressing deficiencies that could impact the effectiveness of therapeutic interventions. This becomes even more crucial when working with individuals with ASD, whose repetitive and restricted behavior could lead to a rejection of the robotic assistant, potentially hindering the continuation of therapeutic interventions. Given this reality, we believe the protocol we have followed in this work is necessary before proceeding with experimental processes, especially involving individuals with ASD.

Based on the experts' perception of the robotic assistant, it can be considered a useful tool in developing therapeutic interventions for individuals with ASD. There are certain characteristics that can be improved, but overall, there is a strong acceptance of the use of our tool. Considering the results, it can be concluded that the first experimental stage is successful, and we can proceed with pilot experimental stages involving both neurotypical children and children with ASD. It's important to design the experimental setup while taking into consideration the previous results, which could positively correlate with the efficiency of therapeutic sessions, participant comfort, and their willingness to participate again.

The use of trajectory-based movements has allowed for smooth and pleasant robot kinematics; however, faster movements are required to generate more expressive emotional states. This should be considered before proceeding with experimentation in the next stages. It's also necessary to include new audio components for each emotion, providing the therapist with the option to choose the volume and tone of the sounds. This consideration is important due to the potential presence of sound hypersensitivity often experienced by individuals with autism.

The inclusion of a depth-sensing camera as part of the prototype is a valuable addition for future work. It will enable the detection and estimation of postures and facial expressions, facilitating smoother interactions and the potential development of robot behaviors based on perceived environmental information. Facial recognition through computer vision could lead to empathetic behaviors and emotional interpretation. Additionally, the implementation of sensors at strategic points in the robot's structure is proposed to enhance the autonomous interaction of the robotic assistant with individuals with Autism Spectrum Disorder (ASD). These additional sensors can facilitate haptic interaction, serving as a complementary process to social interaction.

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Availability of data and materials Data and materials are available upon reasonable request to the authors. With these data, any researcher will be able to run any other type of statistical analysis.

Declarations

Conflict of interest The authors declare that they have no Conflict of interest.

Ethical Standard All participants were healthy adults who were informed that if they so wished, they could withdraw from the experiment at any time.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent for publication Not applicable.

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