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Article

The Quantitative Case-by-Case Analyses of the Socio-Emotional Outcomes of Children with ASD in Robot-Assisted Autism Therapy

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Abstract: With its focus on robot-assisted autism therapy, this paper presents case-by-case analyses of socio-emotional outcomes of 34 children aged 3–12 years old, with different cases of Autism Spectrum Disorder (ASD) and Attention Deficit Hyperactivity Disorder (ADHD). We grouped children by the following characteristics: ASD alone (*n* = 22), ASD+ADHD (*n* = 12), verbal (*n* = 11), non-verbal (*n* = 23), low-functioning autism (*n* = 24), and high-functioning autism (*n* = 10). This paper provides a series of separate quantitative analyses across the first and last sessions, adaptive and non-adaptive sessions, and parent and no-parent sessions, to present child experiences with the NAO robot, during play-based activities. The results suggest that robots are able to interact with children in social ways and influence their social behaviors over time. Each child with ASD is a unique case and needs an individualized approach to practice and learn social skills with the robot. We, finally, present specific child–robot intricacies that affect how children engage and learn over time as well as across different sessions.

Keywords: robot-mediated therapy; ASD; individual differences; parental presence; adaptivity

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1. Introduction

With innovation and technology evolving rapidly, social robots are transforming our lives, in significant ways. They can play an integral role in maintaining children's social and emotional well-being. Past studies on child–robot interaction have shown that social robots are, mainly, utilized as tutors, which may support learners with educational difficulties [1], visual impairments [2], and neurodevelopmental disorders, such as ASD (Autism Spectrum Disorders) and ADHD (Attention Deficit Hyperactivity Disorder) [3]. To date, large-scale interdisciplinary projects, such as DREAM [4], AuRoRa [5], SAR [6], and INSIDE [7] have studied the ways of using social robots that are able to support social, emotional, and cognitive growth in some children with ASD. In these works, children with ASD tend to find social robots appealing because of the easy-to-follow and play-based interaction. Social robots may be programmed to be predictable and interact in simple ways, for instance, their physical embodiment enables social communication with a child and, oftentimes, helps to reduce the stress for children with ASD [8–12]. These commonly referred to benefits may explain the willingness of children to interact with robots. They hold a capacity to elicit children's prosocial behaviors, which are observed to be less developed, to maintain joint attention, imitation, and engagement [13]. During robot-assisted autism therapy (RAAT), robots take on the roles of mediators [14,15] and assistants [16,17]. Due to a variety of robotic applications, methodological limitations, and variations in autism symptoms [18], each research work presents a unique case and context across a wider community of human–robot interaction (HRI) researchers. Overall, related works on RAAT show higher variations in how children with ASD experience robot-assisted therapy and respond to the robot and co-participants. A deeper look into single cases of autism brings valuable contributions to the robot-mediated child–robot interaction (CRI), as those studies reflect on and delineate individual characteristics as well as response patterns, for other group-focused studies.

The case-by-case analyses are rare among HRI studies, as there seem to be specific methodological challenges with the interpretation and transferability of results [19,20]. We should mention that we do not claim to use a case-study-design approach, as it was not the main method used for data collection. The case study is viewed as a qualitative research approach, through which researchers study one particular situation or a few participants, extensively, which allows researchers to learn about complex situations and phenomena in real-life contexts [19]. We should acknowledge the seminal HRI research pioneered by Dautenhahn and Robins. They are the first ones to apply the case study, through conversational and video analyses, to present observational data from children with ASD, who interacted with a KASPAR robot or other robotics toys over time. Their principal findings show that: (1) social robots can act as a social mediator, for joint attention [21] and other social behaviors [22]; (2) the participation of the experimenter, with training in autism therapy, is advisable to address the social and therapeutic needs of children with ASD, in an effective and timely manner [23]. Years later, other case studies focused on comparative analyses of different behavioral criteria, such as eye gaze and movements [24], music therapy for imitation skills [25], co-robot therapy for joint attention [26], and robot-assisted group games (e.g., for two siblings) [27].

Our research motivation lies in designing and providing personalized and adaptive experiences for children with ASD, who are facing life-long challenges with expressing and understanding social cues, in their day-to-day lives. Over the past four years of conducting research and handling different kinds of data, we came to understand that we cannot draw conclusions on child experiences across different subtypes or subgroups of autism symptoms. We have attempted to discuss group differences based on severity level, verbality, co-occurrence of ADHD, and many other factors [28]. However, we realized that we could not provide in-depth analyses and observations in full detail. The present work discusses the exploratory case-by-case analyses for each child, across three comparative instances: the first and last sessions, adaptive and non-adaptive sessions, and parent and no-parent sessions. We try to answer whether these factors would help us answer more specific questions, that we did not cover in our prior works: what kind of engagement patterns do children show, when interacting with the robot? This paper aims to present more up-close and child-centered data obtained during our self-developed robot-assisted autism therapy, with four cohorts of children with ASD. The analysis presented in this paper includes case-by-case data, extracted from 11 engagement and socio-emotional measures, across multi-purpose and play-based activities with the robot.

2. Autism Spectrum Disorders

ASD is a neurodevelopmental disorder, characterized by impairments in social communication, perception, memory, and emotional processing, which can exist in ways as unique as the individuals themselves [29]. Social communication development could be considered the most challenging area for children with ASD, considering their difficulties with the expression of verbal and non-verbal behaviors, body language, and social interaction with peers [30,31]. According to recent studies [32,33], symptoms of ASD are dependent on each person, affecting measured intelligence, interest in social interaction, and (non)verbal communication, which can range from intense and mild behaviors to non-responsiveness and (un)coordinated motor skills (para.1). Specifically, degrees of autism, usually, vary in individuals with either milder or severe forms. Severe autism may lead to aggression and other complex behaviors, such as lack of eye contact, verbal skills, and intellectual challenges, while moderate autism includes problems with making friendships, repeating certain activities, and restricted interests [34]. Children with ASD often have co-occurring ADHD. In fact, from 31% to 61% of children with ASD develop ADHD symptoms, which generally affect around 7% of the world population [35]. These children are prone to a lack of concentration, working memory, visual attention, problem-solving, and spatial-planning skills [3,36]. The current statistics show that both disorders are more common in males than in females, and gender differences are usually found as one of the hallmark characteristics [37,38]. Despite various implications for ASD treatments, past studies [39,40] have demonstrated that behavioral and interactive intervention can become one practical approach to help children with ASD ameliorate severe symptoms and open up a space for the improvement of social skills. Early treatment and peer-based interaction can make a difference and improve the overall condition of an individual with ASD, increasing positive and lasting effects in later life [41,42].

3. Materials and Methods

This research study obtained ethical approval from the Ethics Committees of Nazarbayev University and the Republican Children's Rehabilitation Centre (RCRC). We collected informed consent forms from the parents of the children with ASD, before the first intervention. The experiments were conducted on the premises of the RCRC, where children with their parents were admitted for three weeks, to receive traditional autism therapy (i.e., art, music therapy, physiotherapy, and others). The center's medical staff conducted diagnostic assessments, while the therapists involved in our study observed and documented the children's characteristics and behaviors. Overall, four cohorts of children with ASD received the proposed RAAT.

3.1. Participants

A total of 34 children with ASD (2 females and 32 males), aged 3–12 years old, participated in this study. The mean age of the children was 5.7 years (SD = 2.2 years), as shown in Table 1. Twenty-two children had only ASD, while the remaining twelve were diagnosed with ASD comorbid with ADHD. The RCDC-employed therapist conducted an ADOS-2 scoring test [43], with all children at the center. The therapist has significant experience with the ADOS-2 test and performs it regularly. It is a standard diagnostic test, evaluating autism across age, developmental levels, and social skills. It helps therapists observe a child's social behaviors, during play-based games, tasks, and simple interactions. The severity of ASD levels is divided into two widely accepted forms: a score from 3 to 5 defines high-functioning autism (HFA), while scores in the 6–9 range represent low-functioning autism (LFA) [44]. Ten children had HFA, while twenty-four were with LFA. There were 11 verbal children, who were able to speak words.

Table 1. Children's demographics and other characteristics (ADOS-2 score, ASD form, presence of co-occurring ADHD, verbal, or non-verbal), and the number of attended sessions.

ID	**Age**	**ADOS-2**	**ASD Form**	**ADHD**	**Verbal**	***N***
C1	5	8	LFA	-	-	6
C2	5	5	HFA	-	-	6
C3	8	8	LFA	-	-	6
C4	4	3	HFA	-	✓	5
C5	5	4	HFA	-	✓	5
C6	6	6	LFA	✓	✓	5
C7	7	7	LFA	-	-	4
C8	4	5	HFA	-	-	2
C9	6	4	HFA	-	-	2
C10	4	3	HFA	-	✓	2

Table 1. *Cont.*

ID	Age	ADOS-2	ASD Form	ADHD	Verbal	*N*
C11	8	9	LFA	-	✓	2
C12	5	6	LFA	-	-	10
C13	10	9	LFA	✓	✓	9
C14	7	9	LFA	✓	-	9
C15	5	8	LFA	✓	-	8
C16	5	8	LFA	✓	-	8
C17	5	6	LFA	✓	-	8
C18	5	7	LFA	✓	-	8
C19	10	9	LFA	-	✓	7
C20	6	8	LFA	-	-	7
C21	12	9	LFA	-	-	6
C22	8	8	LFA	-	✓	5
C23	9	8	LFA	✓	✓	6
C24	3	6	LFA	✓	-	5
C25	5	6	LFA	✓	-	4
C26	3	5	HFA	✓	-	3
C27	5	6	LFA	✓	-	7
C28	3	7	LFA	-	-	6
C29	4	5	HFA	-	✓	7
C30	5	7	LFA	-	-	5
C31	3	5	HFA	-	-	4
C32	4	5	HFA	-	-	4
C33	7	7	LFA	-	✓	6
C34	3	6	LFA	-	-	2

3.2. Robot

The programmable humanoid robot, NAO, by SoftBank Robotics was used. A recent survey [45] reported that NAO has been the most used social robot in autism therapy, over the past decade. It has several functional and technical characteristics suitable for child–robot interaction research. There are basic modules, such as speech recognition, touch sensors, face recognition, and different gestures and body postures, to convey human-like communicative behaviors.

3.3. Setup

The experiment room was small and bright, without any furniture. There were sports mats of different colors on the floor and walls. A child was seated on the ground, in front of the robot, and could see it clearly. Figure 1 displays the setup. There were two recording cameras in the room: the first for child behaviors and the second for the whole room. The robot was connected via a Wi-Fi router. The researcher controlled the sessions, by launching robotic applications through a command-line interface on a laptop.

Figure 1. Experimental setup.

3.4. Intervention Framework

Following previous research works and consultation with ASD therapists and parents, we designed various robot-performed activities. Overall, there were 7 activity blocks (“Songs”, “Dances”, “Emotions”, “Touch me”, “Storytelling”, “Imitation”, and “Social Acts”) with a total of 26 sub-activities per block, in two languages (Kazakh and Russian). These multi-purpose activities focus on practising social and emotional skills, by integrating tasks on joint attention, imitation, turn-taking, emotions, and other social and behavioral skills. These activities followed an iterative design process, discussed in [46]. First, we learned about the needs of children with diverse forms of ASD and collected data on robotic applications, by consulting previous works and collaborating with therapists. Then, we identified requirements for the treatment setup, establishing a collaboration with the Children’s Rehabilitation Center. Afterwards, we prepared hardware and software, which included a webcam on a laptop, a Wi-Fi router, two robots, and two laptops to control the robot and record the sessions. Meanwhile, we, also, obtained ethical approvals from the university’s and hospital’s separate ethical committees. Finally, we recruited children on the premises of the hospital, by introducing the robot to parents and children.

Next, we describe each block, separately, and provide a therapeutic framework for robot behaviors. More detailed information can be found in our previous works [47,48]. In “Dances”, the robot performs off-the-shelf dances, such as “Gangnam Style” and “Macarena”, and motivates children to make body movements. The robot is programmed to perform a simple choreography during the “Songs” block, with matching songs, such as “Clock”, “Spider”, “Mother”, “Painter”, and others. The robot demonstrates five emotions, along with its printed images, during the “Emotions” block. Here, children practice identifying and expressing emotions. For tactile interaction and recognition of body parts, the robot asks a child to touch one of its body parts (e.g., “brush my head”, “press my right toes”, “feel my left hand’s blue spot”), within the “Touch Me” block. In the “Storytelling” block, the robot is a storyteller and acts out well-known fairy tales (e.g., “The Turnip”), accompanying its speech with whole-body movements to demonstrate actions (e.g., pulling) and imitate the main characters (e.g., a mouse). In the “Imitation” block, the robot demonstrates different sports (e.g., boxing), transports (e.g., a bus), and animals (e.g., an elephant), and it encourages the child to imitate as such. All of these activities hold social purposes; there might be slight overlaps between targeted skills, but each activity, primarily, focuses on one specific skill. Video recordings of the activities are available at the following link: bit.ly/rat-nu.

The robot behaviors and activities, mainly, followed Applied Behavior Analysis (ABA) principles and used its various techniques for prosocial and emotional skills [48]. Positive reinforcement was used for stimulation and reward, provided by the robot, for the children to practice new behaviors and build sustained daily habits. There were specific examples of verbal praise, such as “Well done”, “Keep up the good work”, and “Perfect”. We, also, provided non-verbal stimuli, such as hands clapping, cheering sounds, and raising our arms above our head. The use of Picture Exchange Communication Systems (PECS) allowed children to learn emotions from real people’s emotions in printed images, such as emotional scenes or situations (e.g., feeling bored, while waiting for public transport). Besides, there were printed images of various types of transports, animals, and sports, imitated by the robot with lively animations and corresponding sounds, during the “Imitations” block. Errorless teaching was used, to teach the child to learn skills through occasional prompts accurately. For example, in the “Touch Me” activity, the therapist showed children where to press the robot’s sensors, by touching its arms and legs. This action was done when a child did not comply with the robot’s or therapist’s instructions.

3.5. Procedure

Each child was encouraged to take part in 15 min sessions with the NAO robot, for ten days. However, the average number of sessions attended by the children was counted as 7 out of 10. The children who skipped some sessions had either personal reasons (e.g., falling asleep) or health issues (e.g., catching a cold). Parents were, also, welcome to monitor their children during the sessions, but most of them either decided not to attend or attended only some of the sessions, initially. At the start of each session, the robot greeted and introduced itself to the child. After that, the robot and the child started playing their first game, and other activities were, gradually, introduced during the session. If the first sessions were almost the same for all of the children, in later sessions, the order of the activities played was adapted, by observing the children’s preferences about activities, along with the therapist’s judgement. For example, in the first session, the robot could play some songs and dance activities, tell a fairy tale, and play “Touch Me”. The following sessions introduced some additional types of activities. As the children’s preferences, on the robot applications, could differ a lot, it was difficult to follow the same interaction pattern with each child. Despite this, most children had a chance to play their favorite robot games, according to their reaction and performance from session to session.

3.6. Session Labeling

While analyzing our data, we observed variations not only between subgroups (e.g., HFA vs LFA, age groups, etc. [28]) but also within a subgroup or session condition (with or without parents [48], adaptive vs. non-adaptive sessions [47]. Therefore, this paper’s data analysis exploits similar session labeling, to understand and interpret diverse autism symptoms, case by case.

- Individual sessions: child outcomes from session to session.
- Adaptive (A): sessions consisting of only previously seen, familiar, and liked activities.
- Non-adaptive (NA): sessions introducing unseen and unfamiliar activities.
- Parent (P): sessions involving a parent in the experimental room.
- No-parent (NP): sessions without a parent in the experimental room.

3.7. Measures

In order to code the children’s behaviors from the videos of the sessions, two researchers applied ELAN software. The total duration of the video-coded material was 46 h and 7 min. 80% of the video material was coded by one researcher, and the remaining 20% was cross-coded by another researcher. The total agreement score, for 20% of the data, amounted to 82.6% ,by pair-wise ICC of the coders. In a study by Kim et al. [11], the video fragments were divided by 10 s, to be coded, and the approach found in another study by Rudovic et al. [49] was to code the target task, until one of the engagement scores was met. We combined both of these approaches. Engagement and valence scores were coded, in accordance with the duration of the activities. A 5-point Likert scale was applied, to measure engagement and valence scores: in engagement, 1 refers to the child being completely disengaged, and 5 to being completely involved in the activity; and in valence, 1 corresponds to being extremely negative (anger, fear, crying) about the activity, and 5 to expressing positive emotions (happy, pleased, smiling) toward the games [47].

The methods, to code other measurements, were adopted from numerous works on RAAT, as listed in Table 2. All measurements consisted of n variables for 1-n sessions. Based on previous works cited in Table 2, we used engagement metrics, such as engagement time, smiling time, eye-gaze time, stereotyped behaviors, affection time, aggression time, and curiosity time, by their percentage relative to the whole duration of the session. For instance, if the duration of one of these measures during a session was counted for 3 min out of 15 min, it was given a value of 20%.

Table 2. The list of all measures and their descriptions.

Measures	Descriptions	Types	Range	From
Aggression Time	Actions: pushing, biting, hitting, pulling fingers	Duration in %	[0–100]	[50,51]
Affection Time	Actions: kissing, hugging, tender touching, scratching, petting. etc.	Duration in %	[0–100]	[51]
Chest Button	Chest button being pressed in a session	Frequency	[0-N]	-
Curiosity Time	Actions: opening, rotating, touching body parts	Duration in %	[0–100]	[49,51]
Valence	Mean of valence scores in a session	Likert Scale	[1–5]	[11,49]
Engagement	Mean of engagement scores per session	Likert Scale	[1–5]	[11,50]
Engagement Time	A child being engaged in a session during one session	Duration in %	[0–100]	[11,49]
Eye-Gaze Time	A child's looking at the robot	Duration in %	[0–100]	[50,52]
Smiling Time	A child's smiling	Duration in %	[0–100]	[49,50]
Stereotyped Behaviors [53]	Actions: hand flapping, hands biting, body rocking, toe walking, spinning objects, echolalia, etc.	Duration in %	[0–100]	[50,51]
Words	Number of spoken words in a session	Frequency	[0–N]	[51]

4. Results

We have conducted several ANOVA tests, analyzing 34 children's sessions by individual sessions, session adaptivity, and parental presence. Here, we only introduce significant results, to avoid over-presentation and provide a logical flow of information.

4.1. Individual Sessions

Further, individual analyses were conducted to find out if there were differences in all 11 measurements during the therapy. The linear-regression results showed some significant changes (Figures 2 and 3). For example, C1 was more curious about the robot at the beginning of the therapy sessions rather than at the end: first session (6.9), second session (4.27), third session (2.65), fourth session (0.00), fifth session (0.00) and sixth session (0.95): $F(1,4) = 14.23, p = 0.019$. There is, also, a significant difference in smiling and affection for C3, between the initial sessions and the rest. The significant increase was detected in the time of smiling responses between the first two sessions, (3.59) and (3.88), and the last session (13.36). A slight growth was revealed in affection for the robot between the first and the last sessions: 0.00 and 0.14. For C6, a linear regression yielded significant differences in affection: $F(1,3) = 83.24, p = 0.002$ and valence: $F(1,3) = 17.86, p = 0.024$. There is, also, a gentle rise in the curiosity actions between sessions, for child 7: 8.24, 9.72, 11.24, and 11.38. There was, in addition, a notable increase found in the number of words spoken by C13, across their nine sessions. At the beginning, the child expressed only a few words, 7, while at the end of the therapy, the child talked more frequently, 182. The amount of engagement time showed a significant increase between the first (33) and last (98) sessions: $F(1,7) = 6.484, p = 0.038$. C14 smiled more frequently session by session, which showed a significant difference: $F(1,7) = 7.863, p = 0.002$, while the engagement and valence rates showed a minor growth between each session: engagement $F(1,7) = 13.41$, p = 0.008, and valence: $F(1,7) = 10.39, p = 0.014$. C18's linear-regression results have shown some significant increase in valence and engagement time measurements, as the child become more engaged by the last therapy sessions, compared with the first: valence $F(1,6) = 6.13, p = 0.048$ and engagement $F(1,6) = 7.483, p = 0.034$. C19, also, had a significant increase in engagement time, as this value gradually increased session by session: $F(1,5) = 36.66, p = 0.002$. Both negative and positive significant increases were detected in C20's results, as the values of stereotype behavior and engagement time had a sharp increase by the last session: stereotype behavior $F(1,5) = 7.165, p = 0.044$ and engagement time $F(1,5) = 31.94, p = 0.002$. There was a significant decrease in C21's valence, as the child became disengaged and complied with the robot's instructions less in the last session, compared with the first one: $F(1,4) = 9.947, p = 0.034$. Another notable rise in words measurement was detected in C22's result, as there were only 22 words spoken at the first session and 116 words at the fifth session ($F(1,3) = 18.31, p = 0.023$). There were, also, some significant decreases in some children. For instance, C23's seriously decreased their eye gaze by the sixth session (38.2), compared with the first one (98.3): $F(1,4) = 8.038, p = 0.047$. However, C24 and C29 showed some notable increases in their engagement time (child 24: $F(1,3) = 69.41, p = 0.004$ and child 29 $F(1,7) = 13.41$, p = 0.008). These values, gradually, increased session by session. Moreover, C29 improved not only their engagement time but also their engagement measurement itself. It, also, increased session after session, starting from 2 and reaching 3.3 by the seventh session ($F(1,5) = 22.35, p = 0.005$).

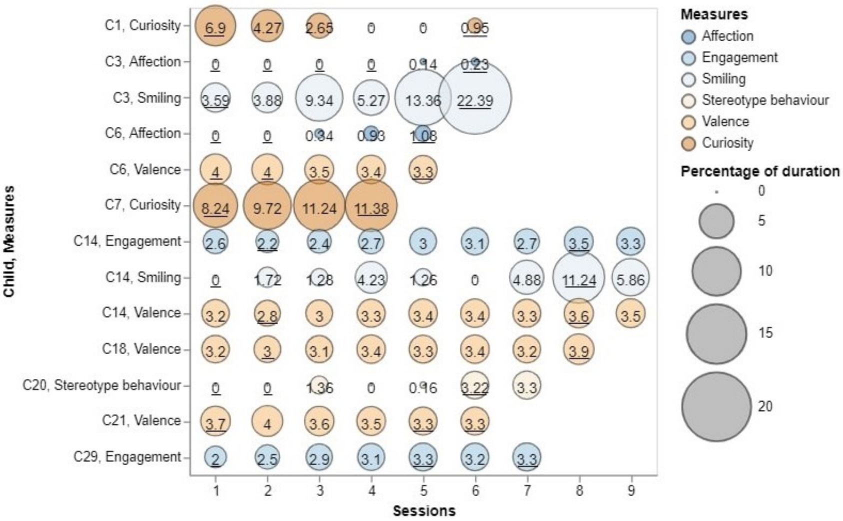

Figure 2. The significant differences of individual analyses over sessions. $\underline{n}$ for $p < 0.05$.

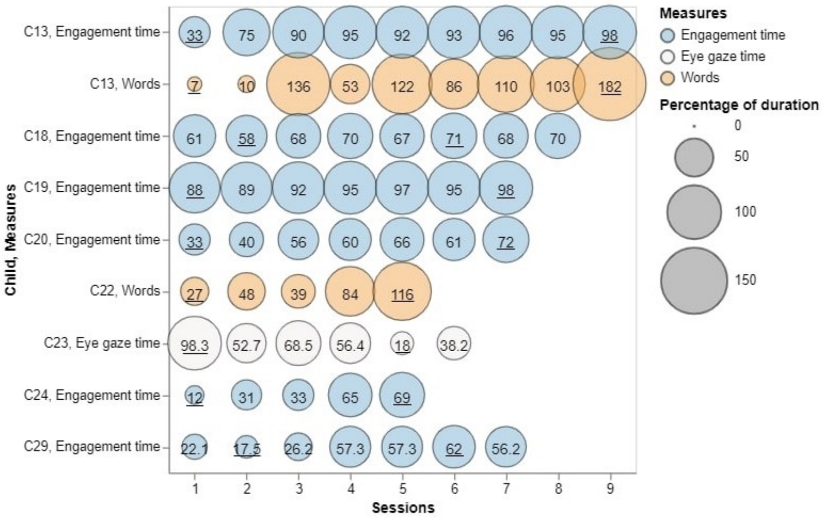

Figure 3. The significant differences of individual analyses over sessions. $\underline{n}$ for $p < 0.05$.

4.2. Adaptive vs. Non-Adaptive

We applied the repeated measures ANOVA test, in order to see how different the children's measurements were, during adaptive and non-adaptive sessions. The results revealed some significant changes (Figures 4 and 5). There was a statistically significant effect of valence in C2: $F(1,4) = 10$, $p = 0.034$. This child showed more interest and compliance during the adaptive sessions (3.78 ± 0.11) than the non-adaptive ones (3.4). C3 showed significant differences, in terms of valence, $F(1,4) = 37.497$ and $p = 0.004$, and engagement, $F(1,4) = 56.167$ and $p = 0.002$. In adaptive sessions, C3 was more engaged (4.233 ± 0.115) and interested (4.167 ± 0.153), compared to non-adaptive sessions (3.287 ± 0.186 and 3.49 ± 0.115). There were other significant changes for C4, in aggression ($F(1,3) = 18.2$, $p = 0.024$) and chest button ($F(1,3) = 33.8$, $p = 0.01$). C4 was more aggressive (3.869) and pressed the robot's chest button more (7) in non-adaptive sessions. Regarding C5, the child smiled more ($F(1,3) = 11.101$, $p = 0.045$), when the sessions were non-adaptive (2.425 ± 0.997) rather than adaptive (0.47 ± 0.35). The results revealed significant changes in three measurements for C17: smile ($F(1,6) = 11.787$, $p = 0.014$), valence ($F(1,6) = 8.953$, $p = 0.024$), and engagement time ($F(1,6) = 7.043$, $p = 0.038$). This child smiled more (3.173 ± 1.525), was more interested (3.333 ± 0.115), and was engaged longer (46 ± 5.292), during the non-adaptive sessions. The chest button was pressed more during the non-adaptive sessions, by C18, as the results show ($F(1,6) = 28.125$, $p = 0.002$). Moreover, C19 ($F(1,5) = 24.097$, $p = 0.004$) and C24 ($F(1,3) = 22.59$, $p = 0.018$) were both engaged for a longer time, during the adaptive sessions. There was a slight difference between the adaptive (3.425 ± 0.15) and non-adaptive (3.85 ± 0.212) sessions, in terms of valence, for C21. The child was more interested in activities, when they were not adaptive. C22's results demonstrated a significant change between the two types of sessions, with regard to curiosity level ($F(1,3) = 31.28$, $p = 0.011$). The child showed curiosity toward the robot and the activities, when the sessions were non-adaptive. Another outstanding change was detected in C28. The child spoke more during the non-adaptive sessions (90 ± 28.792) than the adaptive ones (36.333 ± 9.292). There was a notable difference in C29's results, in terms of engagement ($F(1,5) = 24.958$, $p = 0.004$) and engagement time ($F(1,5) = 8.607$, $p = 0.032$). The child demonstrated a higher engagement rate (3.16 ± 0.167) and longer engagement time (51.8 ± 14.485), in adaptive sessions. However, C31 showed an opposite trend. They maintained eye contact with the robot and were interested in the activities, when the sessions were non-adaptive ($F(1,2) = 36.571$, $p = 0.026$, $F(1,2) = 19.962$, $p = 0.047$). For C33, there were significant changes in three measurements: curiosity ($F(1,4) = 47.981$, $p = 0.002$), words ($F(1,4) = 8.727$, $p = 0.042$), and engagement ($F(1,4) = 66.385$, $p = 0.001$). The child was more curious (0.171) and spoke more words (363) during the non-adaptive sessions, but the engagement level was greater in adaptive sessions (4.78 ± 0.148).

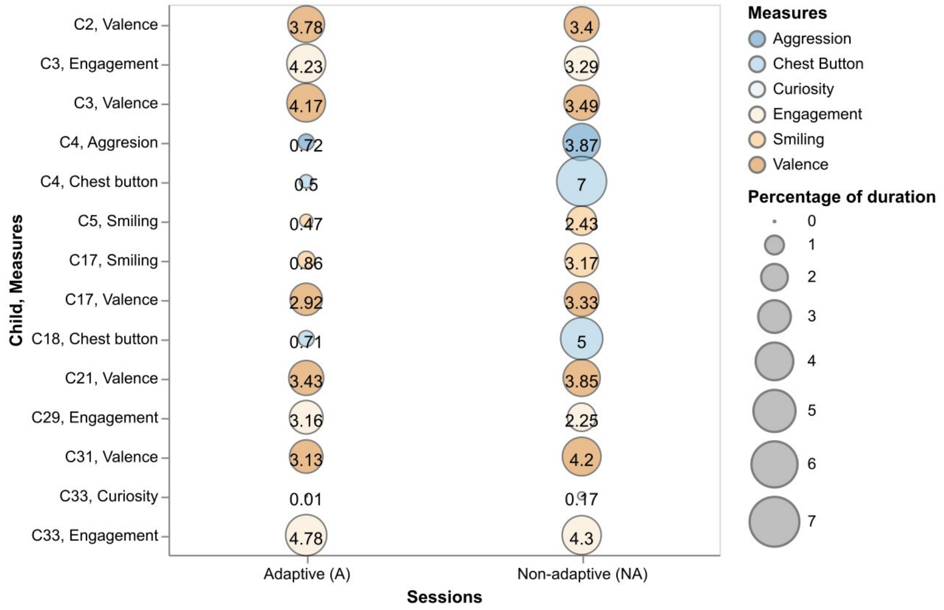

Figure 4. The significant differences of individual analyses across adaptive and non-adaptive sessions. $\underline{n}$ for $p < 0.05$.

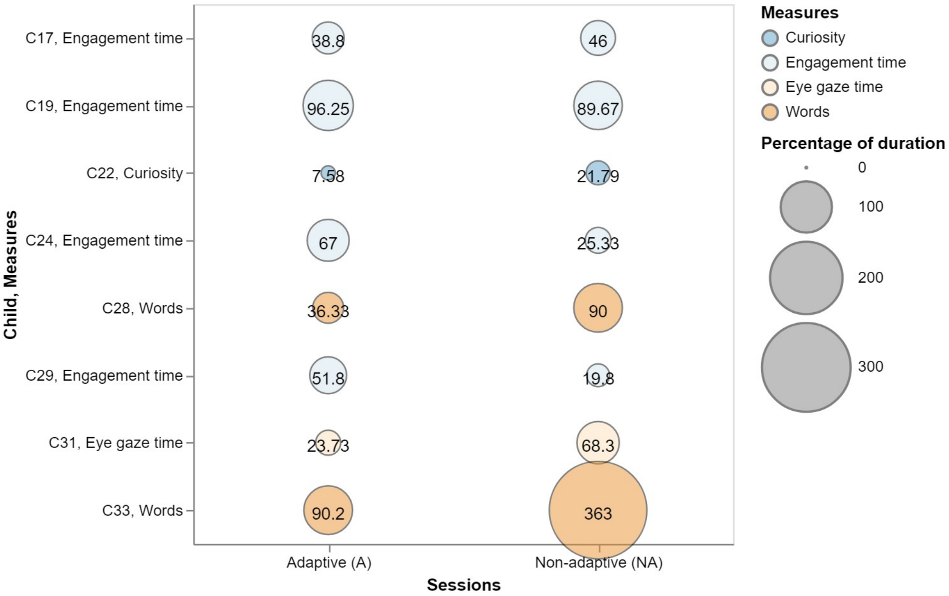

Figure 5. The significant differences of individual analyses across adaptive and non-adaptive sessions. $\underline{n}$ for $p < 0.05$.

4.3. Parental Presence

We conducted the repeated measures ANOVA test on 11 measurements, for each child, to compare sessions with parents and without (Figures 6 and 7). This test determined that the eye-gaze duration of C2 differed significantly: $F(1,4) = 9.079, p = 0.039$. The duration of eye gaze was longer during the sessions with parents (93.95 ± 3.89) than without (71.4 ± 9.72). Similarly, C7 had more engagement scores in sessions with parents (3.5 ± 0.2), compared to sessions without them (2.3 ± 0): $F(1,2) = 27, p = 0.035$. However, C13 showed aggressive and stereotypical behaviors more in sessions with parents (2.68 ± 2.62), compared to sessions without them(0.31 ± 0.65): $F(1,7) = 6.47, p = 0.038$. The duration of actions that show curiosity was higher in sessions with parents (2.83 ± 3.25) than in sessions without (0.01 ± 0.03): $F(1,7) = 8.188, p = 0.024$. Compared to C13, C14 was less curious during sessions with parents (1.1 ± 1.32) compared to sessions without them

(7.17 ± 0): $F(1,7) = 18.663, p = 0.003$. However, they were happier when with parents, since the valence score was higher (3.34 ± 0.18) than in sessions without parents (2.80 ± 0): $F(1,7) = 7.529, p = 0.029$. However, the duration of their eye gaze was higher during sessions without parents (86.70 ± 0), compared to sessions with parents (64.16 ± 6.18): $F(1,7) = 11.907, p = 0.017$. Similar to C14, children C15 and C21 were happier and their valence score was higher (3.15 ± 0.3 (C15) and 3.77 ± 0.21 (C21)) than in sessions without parents (2.63 ± 0.19 (C15) and 3.37 ± 0.12 (C21)): $F(1,6) = 8.762, p = 0.025$ and $F(1,4) = 8.471, p = 0.044$, respectively. Additionally, there is a significant difference in engagement score, for C15, between sessions with (2.65 ± 0.29) and without parents (2.1 ± 0.24): $F(1,6) = 8.442, p = 0.027$. The duration of stereotyped behavior for C23 was higher in sessions without parents (4.95 ± 1.38), compared to sessions with parents (0.00 ± 0): $F(1,6) = 0, p = 0$. Although, they were speaking fewer words during sessions with parents (26.00 ± 0) than in sessions without parents (69 ± 40.08): $F(1,6) = 0, p = 0$. Similarly, C27 had more duration of engagement in sessions without parents (61.2 ± 13.16) compared to sessions with parents (90.6 ± 0.28): $F(1,5) = 8.918, p = 0.031$.

Overall, the results showed a positive effect of parental presence on children (C2, C7, C15, and C21) during the therapy. In contrast, children C13, C14, C23, and C27 showed negative effects of parental presence.

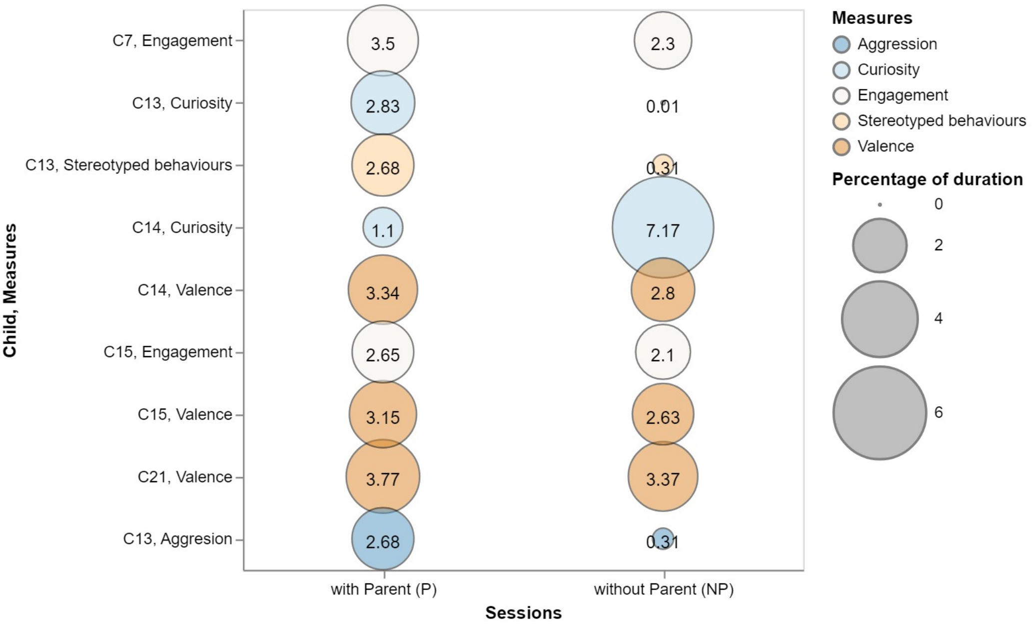

Figure 6. The significant differences of individual analyses of sessions with and without parental presence. $\underline{n}$ for $p < 0.05$.

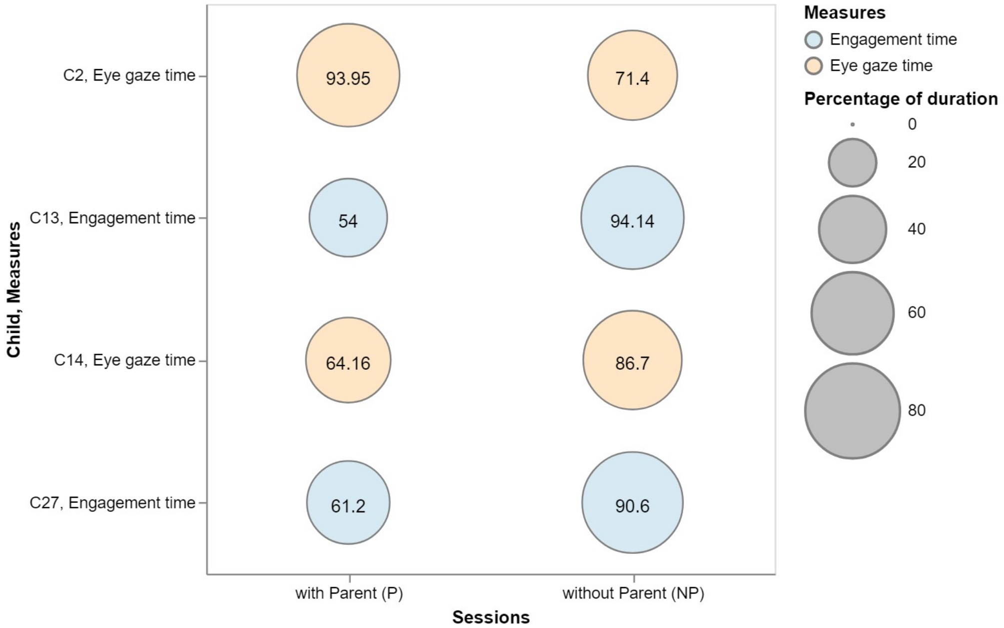

Figure 7. The significant differences of individual analyses of sessions with and without parental presence. $\underline{n}$ for $p < 0.05$.

5. Discussion

This paper presented case-specific analyses of the socio-emotional behaviors, of 34 children with ASD, who received a series of robot-assisted autism interventions, for three weeks. We discuss the findings in three aspects: child outcomes over the sessions as well as the effects of session adaptability and parental presence.

5.1. Changes over Individual Sessions

First, we looked into how children's outcomes changed over time, across 11 measures. As expected, the behavioral differences revolved around child characteristics. While five-year-old C1 increased their curiosity, seven-year-old C7 decreased theirs. Although these children had similar LFA symptoms, there was a difference in age and the number of attended sessions, between C1 ($N = 6$) and C7 (C = 4). Affective behaviors increased for C3 and C6. While C6, similar to C21, lost positive affect (i.e., valence) over time, it was high for C14 and C18. The latter children had a higher number of sessions. Smiling behavior was significantly greater for C3 and C14. Most children increased engagement scores over time: overall engagement (C14), or engagement time (C13, C18, C19, C20, C24), or both (C29). This might be explained by the number of sessions they attended, and, particularly, these children had a higher number of sessions, from 7 to 9 sessions (out of 10). The number of spoken words was significantly high among verbal C13 and C22. We observed that the more sessions children attended, the more engaged they became. In addition, all children, except C29, were diagnosed with LFA. We see, here, that children with severe conditions may benefit more from interacting with the robot, as compared to their peers with milder autistic symptoms.

5.2. Changes over Adaptive and Non-Adaptive Sessions

Child outcomes over adaptive and non-adaptive sessions vary significantly. However, deeper analyses may account for why children had varied interaction effects. Interestingly, overall engagement and engagement time was higher for C3, C19, C24, C29, and C33. When we launched activities upon children's play preferences, they had significant gains in adaptive sessions. We did not observe significant negative results for other children in adaptive sessions. Thus, we assume that the adaptive nature of activities helped children engage with the robot and practice social skills. Previous research has shown that adaptive and targeted support brings longitudinal benefits, in spontaneous communication and joint attention [54] as well as social engagement [55] among children with ASD, when their behavioral heterogeneity and therapeutic needs are considered.

Nevertheless, some controversial results emerge, if we consider what other child outcomes improved in the non-adaptive sessions. In most cases, affective outcomes were better in the non-adaptive sessions than in the adaptive sessions. For instance, valence scores were significantly high in the adaptive sessions for a few children (C2, C3), but some children (C17, C21, C31) were positive in the NA sessions. Furthermore, the rate of curiosity (C22 and C33) and the frequency of smiling (C5, C17) increased in the NA sessions. However, we consider that these results are explained by the nature of unfamiliar and unseen activities, which tend to increase such reactions. This suggests that children attribute positive affect and emotions, when interacting with the robot in novel scenarios and activities. Only C28 and C33 spoke significantly more words in the NA sessions. However, aggressive behaviors (C4) and pressing the robot's chest button (C4, C18) were common in the NA sessions. These negative behaviors may be understood as playful and exploratory, since some children may lose interest and show unmanageable and undesirable actions. For instance, we interpreted the "button pressing" as an act of naughtiness, when children repeated it excessively, despite the apparent disapproval on the side of the therapist [48]. Van Den Berk-Smeekens et al. [56] suggested that a child's motivation can be improved, when the interaction with the robot has a purpose for the child, by using game scenarios. In our case, all of our activities followed an engaging play setting, targeting different social needs specific to core autistic symptoms.

5.3. Changes over Sessions with and without a Parent

Finally, we analyzed how child outcomes may change when they interact with the robot, either in the presence or absence of their parents. Overall results show interaction benefits, for the children who had a parent present, helping, and prompting during sessions. Some apparent results were found: valence (C14, C15, C21), eye gaze (C2), curiosity (C13), and overall session-by-session engagement (C7, C15) increased, in parent-involved sessions. There were, however, some positive outcomes in the NP sessions. For instance, the time spent interacting with the robot was significantly high for C13 and C27, and C14 was curious and showed more eye gaze in NP sessions. Thus, parental presence during therapies needs further exploration, in terms of assessing the child–parent relationship quality. It confirms and complements our prior assumptions on parental involvement, which positively affected how children engaged and learned with the robot [48]. A recent review [57] suggested that parent-mediated interventions are favorable, for decreasing disruptive behaviors in children with ASD. In the long term, parents could deliver such robot-assisted interventions at home and in daily-life settings, as the demand for regular autism treatment is, invariably, high.

5.4. Individual Cases

This section provides individual results for some children, to draw upon child-specific social patterns. We, also, add some qualitative observations to explain and support the quantitative results.

C3 communicated through affective cues, partly because they were non-verbal. They increased their affective outcomes, such as smiling and affection over time, especially their engagement and valence, which were significantly high in the adaptive sessions.

Verbal C13 spoke more words and spent more time with the robot from session to session. They were less engaged with their parent. Their engagement dropped, and negative outcomes of aggressive and stereotyped behaviors increased, in the parent sessions. Their co-occurring ADHD condition may trigger these results. Similarly, C14 benefited more from the NP sessions, by being more curious and making eye contact with the robot.

C21's valence score was decreased over sessions, and, especially, it shows that they were less engaged during the adaptive sessions. However, they were more engaged in those sessions where their parent was present. While C18 was more engaged during the sessions, their valence and engagement time scores increased over time. In the non-adaptive sessions, as the activities were new, the child tended to get distracted by the robot's chest button and pressed it more than in the adaptive sessions.

Strikingly, C19, C24, and C29 were constantly engaged with the robot, especially in the adaptive sessions, while C13 and C14 tended to show negative behaviors in the parent sessions.

6. Conclusions

The present paper introduced a case-by-case analyses of the socio-emotional outcomes of 34 children exposed to different types of robot-assisted-treatment conditions. We analyzed and reported the child's behaviors, through 11 measures. Considering all of the above, we can not manifest definitive and convincing results, but, here, we provide what we as researchers believe is essential and worth mentioning, for current and future RAAT contributions. First, we found that regular and repeated/long-term exposure to RAAT may positively affect child outcomes. In other words, the longer children interacted with the robot, the higher their engagement scores were. In addition, children with severe autistic symptoms seem to gain more social gains, as confirmed by their significant engagement scores across sessions. Second, children with ASD are more engaged with and responsive to the robot, when the sessions are tailored to their play preferences and task performance. Not surprisingly, children become affective and positive when they interact with the robot, introducing novel and previously unseen activities. This might be the most straightforward way to increase affective outcomes in children, in case they lose curiosity and other emotional reactions over time. In the meantime, some children may feel overwhelmed in the non-adaptive sessions and convey negative behaviors, such as aggression and other stereotyped behaviors. Third, parental involvement may serve as a supportive system for most children with ASD, as they may need help navigating and becoming accustomed to the new environment. Finally, individual case analyses show significant variations in how children experience and respond to RAAT. This requires researchers to learn about autistic characteristics and social, emotional, and behavioral idiosyncrasies, in depth. This can be achieved through focused collaborations and discussions with behavior scientists and ASD therapists. We encourage future studies to focus on specific ASD populations and address their unique needs, by adopting long-term and individualized design as well as intervention trajectories, within RAAT.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Our dataset is available at https://rb.gy/ufjj1s (accessed on 7 April 2022).

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Abbreviations

The following abbreviations are used in this manuscript:

ABA	Applied Behavioral Analysis
ADHD	Attention Deficit Hyperactivity Disorder
ADOS	Autism Diagnostic Observation Schedule
ASD	Autism Spectrum Disorder
CRI	Child-robot Interaction
HFA	High-functioning Autism
HRI	Human-robot Interaction
LFA	Low-functioning Autism
RAT	Robot-assisted Therapy
RAAT	Robot-assisted Autism Therapy
RCRC	Republican Children's Rehabilitation Centre

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