Adaptive robot-assisted autism intervention for children with ASD

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***Abstract*—Prior literature shows that children with ASD have varying needs that should be addressed in autism treatment. This relatively large-scale study presents results from the robot-assisted autism therapy (RAAT) with 34 children with diverse forms of ASD and ADHD. We conducted a multiple-session study tailored to each child based on the therapist's judgment. We divided sessions into adaptive and non-adaptive conditions to find out to what extent children's engagement differs when comparing two conditions. The quantitative results are presented focusing on individual characteristics, namely, autistic symptoms, the co-occurrence of ADHD, verbality, and age groups.**

INTRODUCTION

Previous research has not yet reached a definitive conclusion on the effectiveness of the robot-assisted autism therapy (RAAT) as there are considerable challenges to be addressed [1]. Primarily, social robots operate in a controlled environment in which they are not autonomous and depend on remote commands. Only a handful of research used closed-loop adaptive robotic systems that allow the robot to act autonomously and provide reinforcement. Similar to traditional autism therapies, generalization remains to be problematic since signs and symptoms of autism represent a heterogeneous nature [2]–[4], which, in turn, requires personalized therapeutic interventions. Numerous studies [5]–[9] have shown that robots should not be one-size-fits-all and instead be flexible to meet specific needs of children with autism spectrum disorder (ASD). The short-term nature of autism therapy with the social robot poses another challenge to the HRI community to generalize progress made about RAAT. Only a few studies have attempted to investigate long-term outcomes of RAAT [8]. Last but not least, it is common for HRI studies to recruit fewer participants as children with ASD are among the hard-to-retain populations. The recent survey has found that only four out of 166 RAAT studies recruited 20 or more participants from 2008 to 2017 [10].

Addressing these challenges, we propose — a large-scale, personalized, and long-term approach to autism intervention — that becomes possible due to a wide variety of activities and their multi-purposeful characteristics. To the best of our knowledge, there is an overall lack of such studies and data that report findings on the deployment of robots within the rehabilitation framework. This paper analyzes quantitative data that we collected from four cohorts of children who participated in the RAAT from 2018 to 2019. Throughout this period, we used reliable measures to evaluate the quality of robot-child interaction based on fifteen metrics for observations. We measured to what extent the adaptability of the intervention improves behavioral outcomes such engagement, valence, and other social skills. Current robot-assisted autism research adjust interventions based on robot behavior adaptation [11] and reinforcement learning [12]. However, our study does not necessarily present technology-based adaptation. Here, we refer to the concept of adaptability, according to which each activity is launched upon a child's preferences and reaction to the robot's behaviors, identified by therapists we employed for this study.

I. METHODS

This study was approved by the Ethics Committees of Nazarbayev University and the RCRC in Kazakhstan. We used the methodology described in our earlier works [13], [14]. We conducted the robot-assisted interventions in the RCRC, where children with their parents underwent a three-week therapy that includes other traditional methods of autism therapy (art, music therapy, and others). Children had diagnostic assessments provided by the doctors, while therapists learned about each child's individual differences.

The study aimed to evaluate a multiple-session RAAT with children with ASD based on behavioral activities tailored to each child's needs. For this purpose, we carried out a long-term and real-world study between 2018 and 2019. The data were collected from video-based observations, for which we used predefined measures to code individual behaviors. Based on the analysis of the related works [5]–[9], the following hypotheses were formulated to test the extent to which the adaptive sessions will lead to increased engagement and valence scores over time.

- H1: Children will increase their engagement in the adaptive sessions compared to the non-adaptive sessions.
- H2: Using activities adapted to each child's individual preferences and characteristics will result in higher engagement scores from session to session.

A. Participants

Thirty-four children aged 3-12 years old diagnosed with ASD and ASD with co-occurring Attention Deficit Hyperactivity Disorder (ADHD) participated in the study conducted on the premises of the RCRC. All children were diagnosed with ASD, while 12 were diagnosed with ASD and ADHD. At the time of the study, the mean age of the children was 5.7 years (SD = 2.2 years). The severity of ASD symptoms was identified according to overall points across three ranges: score in the 3-4 range corresponds to mild symptoms, scores of 5-7 demonstrate the moderate symptoms and the 8-10 range represents severe symptoms. There were four children with mild, 18 children with moderate, and the remaining 12 with severe ASD. 11 children were verbal and able to speak clearly, while 23 were non-verbal or minimally verbal. 10 children were in the age range 3 to 4 years old, 14 children aged 5 to 6, and 10 in the range 7-12.

B. Conditions

Here, we refer to the concept of adaptability. The therapist adapted each session according to child's behavior and reaction to robot activities in order to increase children's involvement and, consequently, to benefit from the therapy. Therefore all sessions were divided into two conditions: adaptive and non-adaptive sessions. Additionally, we have adopted within subject design, as all children attended both sessions.

- **Adaptive**: sessions consisting of only previously seen, familiar and liked activities.
- **Non-adaptive**: sessions introducing unseen and unfamiliar activities.

C. Intervention framework

There are six activity blocks ("Songs", "Dances", "Emotions", "Touch me", "Storytelling", and "Imitation") with 3-4 activities programmed by the researchers then performed by the robot. In "Dances", the robot encourages body movements by performing the off-the-shelf dances, for example, "Gangnam style" and "Macarena". The robot does a simple choreography in the "Songs" block whereby there are matching songs such as "Clock" and "Painter". Children are able to recognize and express five emotions from printed images when engaging with the "Emotions" block presented by the robot. To practice tactile contact, we programmed the "Touch Me" block in which the robot points to different body parts and verbally requests a child to repeat them (e.g., "brush my head"). In the fifth block, the robot acts as a storyteller and acts out famous fairy tales (e.g., "The turnip") using verbal and non-verbal cues. And in the sixth block, children are expected to imitate different sound- and movement-based activities such as animal voices or sports techniques. Our recent study [14] describes each of them in detail.

These activities received inspiration from Applied Behavior Analysis (ABA) principles and generally used various techniques enabling prosocial and emotional behaviors. Primarily, positive reinforcement encourages a child's behavior during the intervention. Studies show that all children benefit from stimulation and reward from the environment to practice new behaviors and succeed in using them in the future. Specific examples of verbal praise include "Well done", "Keep up the good work", "Perfect". We also provided non-verbal stimuli such as clapping hands, cheering, smiling, and raising arms. When the sessions were over, we gave children stickers with different emotions they opted for. The use of picture exchange communication systems (PECS) allowed children to display emotions and imitate the robot's gestures and sounds by matching emotions in cards. Additionally, we used printed images of 5 emotions ("Emotions") and picture cards of 4 types of transports and animals with corresponding sounds ("Imitations"). Next, errorless teaching is an effective teaching strategy in which a child gets prompts to eliminate any mistakes. For instance, in the "Touch Me" activity, a human therapist showed how to press the robot's sensors by touching arms and legs when a child does not react to the robot. Parents also provided prompts to help their children to ensure correct behavior. We know that the traditional ABA therapy involves other children as peers, but in our study, the child-like robot acts as a peer for children with ASD. We applied a peer-mediated strategy across the intervention (e.g., high-five, hugging in "Social acts") where children watched the robot's performance and then emulated its behaviors.

D. Setup

All sessions took place in a small room without furniture. It consisted of only sports mats on the floor and walls. A child sat on the floor to maintain eye contact with the robot and see its behaviors clearly. We placed two recording cameras in the room: the first camera recorded child behaviors, while the second recorded the whole room. The robot was connected via a Wi-Fi router. The researcher sat behind the mats and controlled the sessions by launching applications on a laptop.

E. Procedure

Each child attended a series of 15-minute sessions with the NAO robot. On average, children had six sessions out of 10 on separate days. Some children could not participate in all sessions because of personal reasons, and thus the number of sessions varies between the participants. We employed two therapists to observe the children during RAAT. Before the initial RAAT session, the therapist discussed individual behaviors and activities with parents. They were invited to be in the same room with their children. The robot activities were introduced throughout the sessions. The therapist chose the type of activity for the first session based on parental input and autism-related symptoms of each child (e.g., sensitivity to sounds). The order and type of applications were customized based on observations and the therapist's feedback.

F. Video Coding

We coded child behaviours from videos recorded with a camera embedded with a microphone. 50% of the video were coded by two researchers on the ELAN software. 20% of the video was cross-coded by another researcher. The overall agreement score on 20% of data was computed from pair-wise ICC of the coders and reached 82.6%. Kim et al. (2012) [15] coded fragments of videos that lasted 10 seconds, while Rudovic et al. (2017) [16] coded the overall engagement episode to maintain the context (coding the target task until one of the engagement scores is met). We adopted two Likert scales on engagement and emotions used in Kim et al. (2012) [15] and Rudovic et al. (2017) [16] to measure label engagement.

G. Measures

All measures have n variables for sessions 1-n. Earlier research [15], [16] has shown that affective engagement including valence and smiling can serve as a proxy for children's behavioral engagement. The measures such as, engagement time, eye gaze time, affection, curiosity, aggressive, stereotype behaviours and smiles are calculated relative to the overall time of the session. For example, 3 minutes within a 12 min-session is 25%. Moreover, we calculated means of all measures for sessions grouped by different conditions. There are two mean variables for each metric. Other measures are presented in Table I.

TABLE I
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]	[17], [18]
Affection Time	Actions: kissing, hugging, tender touching, scratching, petting. etc.	Duration in %	[0–100]	[18]
Chest Button	Chest button being pressed in a session	Frequency	[0-N]	-
Curiosity Time	Actions: opening, rotating, touching body parts	Duration in %	[0–100]	[16], [18]
Valence	Mean of valence scores in a session	Likert Scale	[1–5]	[15], [16]
Engagement	Mean of engagement scores per session	Likert Scale	[1–5]	[15], [17]
Engagement Time	A child being engaged in a session during one session	Duration in %	[0–100]	[15], [16]
Eye Gaze Time	A child's looking at the robot	Duration in %	[0–100]	[17], [19]
Smiling Time	A child's smiling	Duration in %	[0–100]	[16], [17]
Stereotyped Behaviors [20]	Actions: hand flapping, hands biting, body rocking, toe walking, spinning objects, echolalia, etc.	Duration in %	[0–100]	[17], [18]
Words	Number of spoken words in a session	Frequency	[0–N]	[18]

II. RESULTS

A series of Kolmogorov-Smirnov (K-S) and Shapiro-Wilk tests were conducted on all dependent variables overall and within groups to check the assumption of normality. Since all scores were normally distributed, a series of one-way repeated measures ANOVA, one-way ANOVA, and mixed ANOVA were used for the statistical data analyses presented in the following sections. We conducted Mauchly's Test of Sphericity to check the assumption of sphericity. When it was violated, we used a Greenhouse-Geisser correction. We report only significant differences due to page constraints.

Engagement time was significantly different in adaptive sessions (66.302 ± 22.347) compared to non-adaptive sessions (56.569 ± 25.115): $F(1, 30) = 6.545, p = 0.016$. Other measures showed marginal increases in adaptive sessions, though statistically insignificant. Then, we decided to analyze if children's individual differences in combination with adaptive factor have an effect on the measures.

1) Severity of ASD: We found a significant difference in engagement time between adaptive (65.139 ± 24.002) and non-adaptive sessions (49.001 ± 26.39) for children with high-functioning (HFA) autism $(ADOS2 < 6)$: $F(1, 14) = 5.179, p = 0.039$. In contrast, children with low-functioning autism (LFA) did not have such differences.

2) Verbality: We found that verbal children were significantly less aggressive in adaptive sessions (0.177 ± 0.270) compared to non-adaptive sessions (0.951 ± 1.209): $F(1, 9) = 5.859, p = 0.039$.

A mixed ANOVA showed that there was a significant difference in aggression for non-verbal children: $F(1, 29) = 6.315, p = 0.018$. Non-verbal children in non-adaptive sessions were less aggressive (0.665 ± 1.221) than in adaptive sessions (1.021 ± 1.805).

Curiosity metric was also significantly different: $F(1, 29) = 6.745, p = 0.015$. Non-verbal children were more curious during adaptive sessions (4.634 ± 5.596) compared to verbal children (2.327 ± 2.408). However, non-adaptive sessions had the opposite pattern: verbal children were more curious (4.843 ± 6.901) then non-verbal children (2.865 ± 2.817).

3) Age: We divided children into three groups: younger (3-4 years), middle (5-6 years) and older children (7-12 years).

Our results showed a significant difference in smiling of children aged 5-6 y.o. $(F(1, 12) = 4.980, p = 0.045)$: they smiled significantly more in non-adaptive sessions (3.261 ± 3.205) than in adaptive sessions (2.222 ± 2.792). There was a significant difference in engagement time between adaptive (57.835 ± 28.311) and non-adaptive sessions (35.040 ± 24.286) for younger kids: $F(1, 8) = 5.823, p = 0.042$.

III. Discussion

We conducted a comparative analysis of 34 children's social behaviors across adaptive and non-adaptive sessions. Our results show that children with ASD had statistically higher engagement when interacted with the robot in adaptive sessions in contrast to non-adaptive sessions. Thus, our H1 is supported. It is also notable that most engagement scores of children was marginally significant or remained stable over time. However, our H2 is supported partially as not all of the metrics yielded significant results. Taken collectively, these results are encouraging and suggest that children with ASD may sustain certain behavioral outcomes after adaptive sessions. There emerged three major findings. First, regarding severity of ASD, children with HFA were more engaged in adaptive sessions compared to non-adaptive sessions. Second, the adaptability of sessions showed different results in aggression and curiosity levels of verbal and non-verbal children. While verbal children were less aggressive and less curious in adaptive sessions, non-verbal children were less aggressive and more curious in adaptive sessions. Third, even though younger kids were less engaged in adaptive sessions, children aged 5-6 years old smiled more in non-adaptive sessions.

The evidence from our year-long research shows that social robots could act as a mediator and assistant and are able to improve social skills in autistic children in unique ways. The adaptation of practice games can improve the target skills at each person' preferred pace [8]. Individualized support for children with ASD may seem challenging for human therapists. It is not tenable for them to adjust to each child. In this case, social robots are more sustainable to perform repetitive tasks and thus intensify child's behavioral development.

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