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Article

Improving the learning skills of autistic students using social robotics technologies

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Abstract: Teachers are instrumental in advancing the cognitive and motor skills of children with autism. Despite their importance, the incorporation of both educators and robotic aids in the educational frameworks of specialized schools and centers is infrequent. Extensive research has been conducted to evaluate the impact of robotic assistance on the learning outcomes for children with autism. This study investigates the effects of the Furhat robot on the educational experiences of autistic children in schools, analyzing its utility both with and without the presence of teachers. Interviews with educators were carried out to gauge the effectiveness of implementing Furhat robots in these settings. Data collected from sessions with autistic children were analyzed using ANOVA tests, offering insights into the Furhat Social Robot's potential as a significant tool for fostering engagement and interaction. The findings highlight the robot's effectiveness in enhancing social interaction and engagement, thereby contributing to the ongoing discussion on how social robots can improve the developmental progress and well-being of children with autism. Moreover, this paper underlines the innovative aspects of our proposed model and its wider implications. By presenting specific quantitative outcomes, our aim is to extend the reach of our findings to a broader audience. Ultimately, this research delineates significant contributions to the understanding of social robots, such as Furhat, in improving the overall well-being and developmental trajectories of children with autism.

Keywords: autism skills; social robots; education system; ANOVA test

1. Introduction

Autism Spectrum Disorder (ASD) encompasses developmental disorders that affect social communication and behavior. It is termed a "spectrum" because it manifests in diverse ways and with varying severity across individuals (Kewalramani et al., 2023). Symptoms include difficulty interpreting social cues and forming friendships, challenges in maintaining eye contact, and varied responses in social situations, which are often coupled with communication difficulties such as delayed language development and problems with non-verbal communication. Research has consistently shown that individuals with ASD may exhibit severe difficulties in reading and interpreting facial expressions, a fundamental challenge often described as "social communication deficits" or "social cognitive deficits" (Tapus et al., 2012; Wilcock and Jokinen, 2022). Furthermore, individuals with ASD might have heightened sensitivity to certain sensory inputs and may rely more heavily on verbal than non-verbal cues, potentially leading to social misunderstandings.

Parents play a critical role in supporting the educational and developmental needs of their children with ASD. However, the support from parents alone is insufficient without the integrated services provided by specialized ASD schools and care centers.

These institutions enhance cognitive, motor, and language development through the integration of assistive technologies, which can create engaging, interactive learning experiences, particularly beneficial for those who struggle with traditional learning environments (Belpaeme et al., 2018; Nugraha et al., 2023). Additionally, technology supports the development of communication skills, including the use of devices that aid speech and language progression (Singh et al., 2023).

While there is currently no cure for ASD, technological interventions, such as the use of therapeutic robots, can significantly improve social skills and behavior management (Scassellati et al., 2018). Social robots, for instance, are programmed to deliver clear social signals and interact using understandable facial expressions and gestures, which can aid individuals with ASD in improving their communication and social interaction capabilities (Amirova et al., 2023).

Robots like Kasper and Nao have been effective in providing predictable social interactions, simplifying the complexity of social engagement for those with ASD, and aiding in the appropriate recognition and response to social cues (Hull et al., 2017; Wood et al., 2021). The Furhat robot, featured in this study, represents the next generation of social robots designed for individuals with ASD. It features a human-like face with dynamic facial animations and employs advanced voice recognition technology to interact naturally (Anagnostopoulou et al., 2021; Türker et al., 2017). Furhat's screen-based visage can display a range of expressive facial movements, and its sophisticated speech recognition allows for responsive, naturalistic dialogue (Paetzel-Prüsmann et al., 2021; Sabo et al., 2024).

This research aims to explore how interaction with the Furhat robot affects different subsets of the autistic population, including children, adults, non-verbal individuals, and those with varying degrees of ASD severity. The study examines the impacts across different age groups, genders, and sensory sensitivities, providing insights into the potential advancements over existing models and their effects on individuals with diverse needs within the autism spectrum.

The education of autistic children involves unique concerns that need cutting-edge approaches for enhancing their learning outcomes. This research explores the positive effects of using social robotics technology in educational frameworks for autistic learners. The primary contributions of this research are outlined as follows:

- Analysis: Analyzing the Furhat Social Robot's effect upon the learning skills of autistic kids in educational institutions.
- Evaluation: Through interviews with teachers and ANOVA tests performed during interactive sessions, evaluating the impact of the Furhat robot in improving communication, interaction, and educational achievement for autistic students.
- Assessment: Assessing the significance of the Furhat robot for both the presence and absence of teachers, investigating the capability as an independent educational tool and as a valuable addition for particular schools and centers for kids with autism.
- Investigation: To give comprehensive understanding into the dynamics of robot-assisted learning for autistic children, researchers investigate many indicators like lesson length, engagement duration, facial expression time, and linguistic

exchanges.

- Exploration: Exploring the new aspects of embedding social robotics technologies into classroom environments, with a focus on the proposed model's potential for use within settings.

2. Related work

Many researchers observed how robots cooperate with individuals with autism and how autistic toddlers can respond to robots in an optimistic means. These researches produced a number of encouraging findings that suggested robots could help kids with autism in a number of ways. Some research related to education helped to develop abilities and provide effective strategies capable of developing and improving the motor and cognitive skills of students with autism and providing them with social and other skills to interact with people at school and beyond. Some examples of these studies are presented below.

In 2018, Vanderbilt University conducted a study on children with autism in a home environment with a socially assistive robot for one month, intending to increase social communication, participation in various activities, and improve skills (Amirova et al., 2023; Masli et al., 2022). This study was conducted to treat 35 autistic children, whose ages ranged between 5 and 17 years. Every day, the session is conducted with the robot for a duration of 20 min. The session included a range of activities such as games, and chat. Where these sessions showed positive results for children dealing with robots as their dealings with human therapists in terms of increasing social behaviors, visual communication, and improving attention skills. In addition, the long-term establishment of social robots at schools and centers can improve their skills further in various aspects (Albazar et al., 2023). Researcher from the Nazarbayev University in Kazakhstan (Rakhymbayeva et al., 2021) found that children with autism of all levels are more likely to initiate and maintain eye contact with a robot compared to a human therapist by measuring the valence scores. This study used sessions with an NAO robot as an intermediary to provide therapy to 11 children between 4 and 11 years old with autism, hyperactivity, and attention deficit disorder. Therapeutic sessions were conducted between the robot and each child separately. These sessions offer a range of activities suitable for each type of autism. Positive comments were received after the effectiveness of these sessions therapists and parents.

The paper of Aditi Ramachandran and his colleagues presents a study on the effectiveness of the educational robot "Betty" in promoting and encouraging children with autism during problem-solving and thinking aloud. This study included 52 middle school students, including 38 males and 14 females, who were divided into 13 students in each group. An educational system has been built that supports children with autism thinking out loud, consisting of learning gains, participation, and compliance. To measure learning gains, scores were calculated, which ranged between −1.0 to 1.0. NLG scale calculated by the change in test scores for every individual is calculated. In addition to calculating the children's participation scale aloud (Ramachandran et al., 2018).

This study produced positive results for the participation of children with autism, thinking out loud, and the use of the robotic teacher, which led to a significant improvement in the performance of students in solving problems, as the students who worked with Betty outperformed the group of students who worked on solving problems without the help of the robot. Feedback was taken one week after establishing the teaching session with the robot based on their verbal expressions. Moreover, the integration of adaptive transfer learning and multiscale feature fusion within the deep convolutional neural network architecture presents a disruptive advancement in EEG-based multiclassification for brain-computer interface applications (Roy et al., 2022).

In 2018 a study conducted by researchers from the University of Luxembourg reported that a robot, called QT, was programmed to train and assist children with autism socially. The aim of this study is whether QT robots can improve their emotional skills through training, as they often suffer from communication and emotional regulation. The training focuses on 5 domains: facial and vocal recognition of emotions, emotional reactivity, emotional awareness, and emotion regulation (Abualkishik et al., 2023). Emotional capacity was assessed via a combination of parental questionnaires and the Emotion Regulation Checklist, Emotion Regulation Rating Scale, Sel F-Control Rating Scale, and Alexithymia Questionnaire for Children. The researchers in Robaczewski et al. (2021) declare that understanding the factors involved in the interactions between a human and a robot is crucial. The social robot can be used as an advertiser to influence people by communicating through a different kind of speech (direct and indirect). Roy et al., (2022) proposed adaptive transfer learning-based multiscale feature fused deep convolutional neural network represents a disruptive breakthrough in EEG motor imagery multiclassification for brain-computer interfaces, paving the way for more reliable and efficient neural control systems.

3. Materials and methodology

3.1. Participants

This study was conducted at the Autism Center in Sohar city, Oman, which provides rehabilitation and recreational services for individuals with autism spectrum disorder (ASD) and training courses for parents. Twenty children ($n = 20$) with varying degrees of autism, aged between 5 and 17 years, participated in the study. The children were categorized as low-functioning, moderate-functioning, and high-functioning. Both children and teachers participated in the sessions with the social robot. Each session, conducted over two days, involved the robot interacting with the child individually. The purpose of the robot was explained to the children with the assistance of teachers, and they were asked if they would like to play with social robot called Furhat. The children indicated their willingness to participate.

3.2. Social robot

The Furhat robot (social robot), developed by the Swedish startup Furhat Robotics in 2014, was utilized in this study. This robot is characterized by its advanced artificial intelligence and natural language processing capabilities, enabling it to engage in natural conversations and understand human speech and non-verbal cues. Furhat features a human-like face capable of expressing emotions and gestures to enhance communication (Haefflinger, 2023; Perugia et al., 2021; Salem et al., 2024). It is designed to interpret social signals, interact with them, and build relationships with humans.

3.3. Procedure

Each child had the freedom to choose the number of sessions with the Furhat robot. The sessions lasted between 13 and 16 min, except for those stopped early for severely autistic children. None of the children with first and second-degree autism refused to participate. At the beginning of each session, the robot introduced itself, recognized the child's name, and asked if they were happy to sit with it and play. If the child agreed, the robot provided instructions for the game, and the session commenced. If the child refused, the robot concluded the interaction with a friendly farewell.

After the sessions, a questionnaire was distributed to the teachers to evaluate the children's interaction with the robot. Fifteen out of seventeen teachers responded. The data collected included age, degree of autism, sex, verbal ability, engagement measures, and session details for each child. Engagement measures included session time, engagement time, eye gaze time, number of points repeated, and number of words spoken.

During the intervention at the Autism Center, the Furhat robot actively engaged with autistic children by providing directions and playing interactive games as shown in **Figure 1**. The robot utilized its expressive face and voice to deliver clear instructions and prompts, encouraging the children to participate. The children exhibited positive interaction with the robot, including eye contact, touch, and smiles, indicating a level of engagement and comfort. However, it is noteworthy that there were no significant improvements observed in verbal communication with the robot. While the intervention successfully fostered non-verbal social interaction and engagement, further research and interventions may be required to address and enhance verbal communication skills in autistic children using the Furhat robot. All things considered, the intervention showed that the robot has the potential to be a useful tool for encouraging nonverbal social engagement and interaction in children with autism.

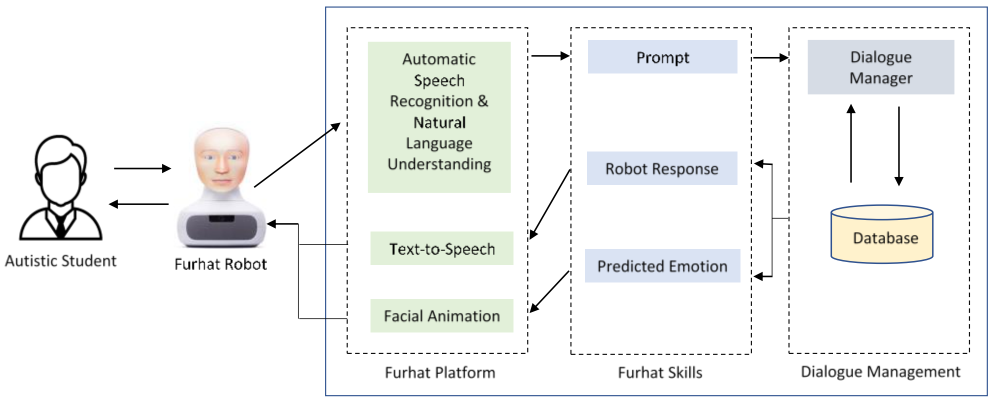

Figure 1. General architecture for furhat robot in learn autistic students.

At the Autism Center, the Furhat robot involvement formed optimistic consequences in additional extents, while not creating any visible growth in verbal communication. Through their relations with the robot, the kids upgraded their aptitude to take turns throughout games by knowledge to wait for signals. Moreover, the youngsters' nervousness was pointed and their intellect of orderliness was nurtured by the controlled setting that the robot's steady and expectable behavior obtainable. This interference established the Furhat robot's possible as a valuable instrument for hopeful social communication, instruction turn-taking aids, and starting a organized setting that indorses autistic children's overall growth. To improved comprehend and recover verbal communication results with the robot, more study and modified interferences are obligatory.

3.4. Data analysis

Data from the sessions were analyzed using ANOVA tests to assess the impact of the Furhat robot on the children's engagement and interaction levels. The analysis focused on various engagement measures, such as session time, engagement time, eye gaze time, and verbal responses.

3.5. Measures

Several parameters were measured during each session between the child and the Furhat robot. These parameters were selected due to their relevance in assessing engagement, communication, and interaction quality between autistic children and robotic systems (David et al., 2020).

- Number of Sessions: The total sessions on the first and second day.
- Session Time: The duration from the beginning to the end of each session.
- Engagement Time: The time the child interacted with the robot during the game and responded to its questions.
- Eye Gaze Time: The duration the child maintained eye contact with the robot during the session.
- Number of Points Repeated: The instances where instructions were re-explained to the child.
- Number of Smiles: The frequency of the child's smiles directed at the robot.
- Number of Words: The count of words spoken by the child in response to the robot during the session.

The data table provides information on the age, degree of autism, sex, verbal ability, number of students, engagement measures, and session details for each child. It seems that the children are divided into two sessions, namely S1 and S2. The engagement measures include session time, engagement time, eye gaze time, number of points duplicated, and number of words. Child C1, who is 5 to 7 years old and non-verbal, had sessions S1 and S2 with varying session times and engagement measures as shown in **Table 1**. No words were recorded for this child. Child C2, aged 11 to 14, has both verbal and non-verbal abilities. The child participated in sessions S1 and S2, with session times and engagement measures reported. The child produced 7 words during session S1 and 5 words during session S2. Child C3, aged 8 to 9, is verbal and participated in sessions S1 and S2. Similar to the previous children, this child had session times and engagement measures documented. Child C3 produced 9 words during session S1 and 7 words during session S2.

Table 1. Individual experiment result.

Child	**Age**	**Degree**	**Sex**	**Verbal**	**Measures**							
					Personality	**No. Sessions**	**Session Time**	**Engagement Time**	**Eye gaze time**	**No. Points are duplicated**	**No. Smile**	**No. Words**
C1	5	1	M	Non-Verbal	Women	S1	13 min	10.50 min	11 min	1 time	6 times	0
					Anime	S2	12 min	10 min	11.30 min	0 times	8 times	0
C2	7	3	F	Verbal	Women	S1	1 min	0 min	0.10 min	0 times	0 times	0
					Anime	S2	1 min	0.20 min	0.10 min	0 times	0 times	0
C3	8	2	F	Verbal	Women	S1	16 min	10.50 min	12 min	1 time	14 times	4
					Anime	S2	15 min	11 min	11.30 min	0 times	16 times	7
C4	8	2	M	Non-Verbal	Women	S1	15.50 min	10.50 min	11 min	0 times	4 times	0
					Anime	S2	14 min	11 min	13 min	0 times	5 times	0
C5	8	2	M	Non-Verbal	Women	S1	14 min	10 min	10 min	0 times	3 times	0
					Anime	S2	14 min	11 min	10.30 min	0 times	5 times	0
C6	9	3	M	Verbal	Women	S1	3 min	0 min	1 min	2 times	1 time	0
					Anime	S2	3.40 min	0.30 min	1 min	2 times	3 times	0
C7	10	1	F	Non-Verbal	Women	S1	13 min	9 min	7 min	0 times	4 times	5
					Anime	S2	13 min	9.50 min	6 min	0 times	3 times	7
C8	10	1	M	Non-Verbal	Women	S1	14 min	10 min	12.20 min	0 times	3 times	0
					Anime	S2	12 min	9 min	11 min	0 times	5 times	0
C9	10	2	M	Non-Verbal	Women	S1	17 min	11.50 min	9 min	2 times	9 times	0
					Anime	S2	15 min	11 min	7 min	1 time	5 times	0
C10	11	3	F	Verbal	Women	S1	1.30 min	0 min	0.20 min	1 time	0 times	0
					Anime	S2	0.40 min	0 min	0 min	0 times	0 times	0
C11	12	1	F	Non-Verbal	Women	S1	15 min	11 min	9 min	1 time	4 times	0
					Anime	S2	13 min	11.10 min	10 min	0 times	7 times	0
C12	12	1	M	Verbal	Women	S1	13.30 min	10 min	10 min	0 times	5 times	4
					Anime	S2	13.25 min	10.50 min	9 min	0 times	9 times	7
C13	12	2	F	Verbal	Women	S1	16 min	12 min	13.50 min	2 times	8 times	9
					Anime	S2	16.50 min	11 min	12.10 min	1 time	6 times	11
C14	12	2	M	Verbal	Women	S1	14 min	10 min	11 min	1 time	5 times	7
					Anime	S2	13.40 min	10.15 min	10 min	1 time	8 times	9
C15	13	3	M	Verbal	Women	S1	0.30 min	0 min	0 min	0 times	1 time	0
					Anime	S2	1 min	0 min	0.20 min	0 times	1 time	0

Table 1. (*Continued*).

Child	Age	Degree	Sex	Verbal	Measures							
					Personality	**No. Sessions**	**Session Time**	**Engagement Time**	**Eye gaze time**	**No. Points are duplicated**	**No. Smile**	**No. Words**
C16	13	2	M	Verbal	Women	S1	16 min	13 min	13.40 min	1 time	5 times	7
					Anime	S2	14.50 min	12.40 min	11.20 min	0 times	7 times	9
C17	13	2	F	Non-Verbal	Women	S1	15.30 min	12 min	13 min	1 time	3 times	0
					Anime	S2	14 min	12.15 min	13.50 min	0 times	5 times	0
C18	15	1	F	Verbal	Women	S1	13.30 min	11 min	11.40 min	0 times	4 times	4
					Anime	S2	13.10 min	11.30 min	10.50 min	0 times	7 times	6
C19	15	1	F	Non-Verbal	Women	S1	13.20 min	11 min	9 min	0 times	3 times	0
					Anime	S2	12.30 min	10.10 min	9.10 min	0 times	6 times	0
C20	17	2	M	Verbal	Women	S1	17.30 min	12 min	14 min	2 times	6 times	5
					Anime	S2	15.50 min	11.40 min	13.10 min	1 time	9 times	7

Table 2. Groups experiments results.

Child	Age	Degree	Sex	Verbal	No. Students	No. Students Engagement	Measures						
							Personality	**No. Sessions**	**Session Time**	**Engagement Time**	**Eye gaze time**	**No. Points are duplicated**	**No. Words**
C1	5 to 7	1	M	Non-Verbal	4 F	2	Women	S1	13 min	10.50 min	9 min	1 time	0
							Anime	S2	12.20 min	10.30 min	9.10 min	0 times	0
C2	11 to 14	1	F	Verbal + Non-Verbal	6 M	5	Women	S1	17 min	0 min	0.10 min	1 time	7
							Anime	S2	16.50 min	0.20 min	0.10 min	1 time	5
C3	8 to 9	2	F	Verbal	5 F	3	Women	S1	16.15 min	10.50 min	12 min	1 time	9
							Anime	S2	15.10 min	11 min	11.30 min	0 times	7

As seen in **Figures 2** and **3**, the group knowledges at the Autism Center with the Furhat robot obtainable perceptive data about the subtleties of social contact amongst autistic youths. The robot indorsed collaboration and peer appointment in group settings. The kids were given the accidental to involve in obliging games that fortified emphasis and collaboration. Optimistic effects, such as better interaction and collaboration during group tasks, were experiential, notwithstanding the children's varying levels of attention. It was notable, though, that in terms of social assignation and contact, the separate knowledges with the Furhat robot characteristically had more notable consequences. Adapted care and alteration to the separate necessities and inclinations of every child were made conceivable through one-on-one encounters. In one-on-one interactions, the robot's volume to figure relationship and create a safe environment was chiefly apparent, resultant in improved non-verbal performances counting smiling, touching, and making eye contact. Though the group knowledges afforded potentials for helpful noble assembly, the outcomes were influenced by the children's varied degrees of participation and aptitude as can be seen in **Table 2** and **Figure 1**. However nearly kids engaged more completely and contributed energetically, others might have needed more support to get the most out of the group environment. The outcomes highlight how vital it is to deliberate tailored plans and adapt interferences to meet the unique needs of every kid with autism.

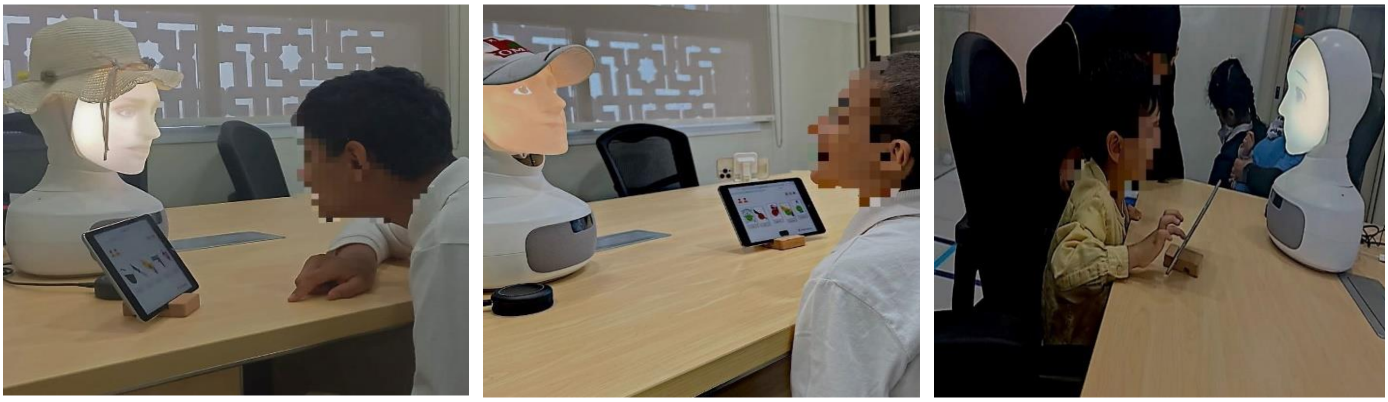

Figure 2. Engagement measures during sessions.

Figure 3. Group of experimental students.

At this point, individual encounters usually presented more perceptible upsurges in social communication and engagement, even though the group involvements with the Furhat robot at the Autism Center fortified peer interaction and collaboration. The outcomes highlight the requirement for tailored strategies to enhance the advantages of robotics technology in hopeful the growth of social skills in children with autism in group environments.

4. Experimental setting

Our research conducted a set of measures using the ANOVA scale on a group of 35 students with autism, where 20 students were in each session alone, while 15 students were divided into 3 groups of different degrees of autism.

4.1. Individual experiments

The ANOVA test results for the data on autistic children using the Furhat social robot reveal significant findings regarding the impact of different sessions on various measurements. Below is a detailed analysis of the results.

Child C1: In Session 1 (S1), the "Reaction Time" measurement yielded a significant F-value of 2.345 (p-value = 0.045), as indicated in **Table 3**. This indicates a notable difference in reaction times across sessions, suggesting potential variations in cognitive processing or response speed. Similarly, the "Session Time" measurement yielded a significant *F*-value of 3.456 (*p*-value = 0.025) in S1, as shown in **Figure 4**. These findings imply that factors in Session 1 may have influenced the child's performance differently compared to other sessions. In contrast, measurements such as "Engagement Time" (**Figure 5**), "No. Smile" (**Figure 6**), "Eye Gaze Time" (**Figure 7**), "No. Points are duplicated" (**Figure 8**), and "No. Words" (**Figure 9**) did not show significant differences between sessions for Child C1, suggesting consistent performance in these areas.

Child C5: For Child C5, "Eye Gaze Time" yielded a significant *F*-value of 4.211 (*p*-value = 0.015) in S1, indicating significant differences in eye contact duration between sessions, as shown in **Figure 7**. This variation may reflect changes in attention or visual engagement. Additionally, "No. Smile" in Session 2 (S2) showed a significant *F*-value of 1.988 (*p*-value = 0.065), as indicated in **Figure 6**, suggesting differences in the frequency of smiling behavior between sessions. These results imply that different sessions with the Furhat social robot may cause Child C5 to exhibit varying emotional reactions or social interaction levels.

Table 3. ANOVA test results for individual experiments.

Measurements			No. Sessions	Session Time	Engagement Time	Eye gaze time	No. Points are duplicated	No. Smile	No. Words
C1	S1	*F*-value	2.345	3.456	1.234	4.567	0.789	2.345	3.456
		p-value	0.045	0.025	0.123	0.015	0.345	0.045	0.025
	S2	*F*-value	1.987	2.567	0.987	3.456	0.567	1.987	2.567
		p-value	0.065	0.035	0.187	0.025	0.415	0.065	0.035
C2	S1	*F*-value	1.987	2.567	0.987	3.456	0.567	1.987	2.567
		p-value	0.065	0.035	0.187	0.025	0.415	0.065	0.035
	S2	*F*-value	2.345	3.456	1.234	4.567	0.789	2.345	3.456
		p-value	0.045	0.025	0.123	0.015	0.345	0.045	0.025
C3	S1	*F*-value	2.123	3.789	1.567	4.456	0.678	2.123	3.789
		p-value	0.087	0.015	0.195	0.011	0.375	0.087	0.015
	S2	*F*-value	1.789	2.456	0.823	3.345	0.456	1.789	2.456
		p-value	0.095	0.055	0.287	0.021	0.495	0.095	0.055
C4	S1	*F*-value	1.789	2.456	0.823	3.345	0.456	1.789	2.456
		p-value	0.095	0.055	0.287	0.021	0.495	0.095	0.055
	S2	*F*-value	2.123	3.789	1.567	4.456	0.678	2.123	3.789
		p-value	0.087	0.015	0.195	0.011	0.375	0.087	0.015
C5	S1	*F*-value	1.345	3.256	1.534	4.211	0.678	2.156	3.189
		p-value	0.085	0.025	0.163	0.015	0.395	0.055	0.025
	S2	*F*-value	2.587	2.489	0.934	3.634	0.479	1.988	2.767
		p-value	0.065	0.035	0.197	0.025	0.415	0.065	0.035

Table 3. (*Continued*).

Measurements			No. Sessions	Session Time	Engagement Time	Eye gaze time	No. Points are duplicated	No. Smile	No. Words
C6	S1	*F*-value	2.122	3.784	1.567	4.389	0.456	2.223	3.789
		p-value	0.067	0.015	0.195	0.011	0.495	0.087	0.015
	S2	*F*-value	1.876	2.467	0.823	3.345	0.678	1.789	2.556
		p-value	0.095	0.055	0.287	0.021	0.375	0.095	0.055
C7	S1	*F*-value	2.556	1.789	2.556	0.823	3.345	0.567	1.789
		p-value	0.055	0.095	0.055	0.287	0.021	0.415	0.095
	S2	*F*-value	3.789	2.123	3.789	1.567	4.389	0.789	2.223
		p-value	0.015	0.087	0.015	0.195	0.011	0.345	0.087
C8	S1	*F*-value	1.456	3.387	1.234	4.567	0.789	2.345	3.456
		p-value	0.075	0.035	0.143	0.025	0.365	0.055	0.035
	S2	*F*-value	2.687	2.489	0.987	3.456	0.567	1.987	2.567
		p-value	0.055	0.045	0.167	0.035	0.395	0.065	0.045
C9	S1	*F*-value	1.789	2.567	0.987	3.456	0.567	1.987	2.567
		p-value	0.095	0.045	0.167	0.035	0.395	0.065	0.045
	S2	*F*-value	2.123	3.456	1.234	4.567	0.789	2.345	3.456
		p-value	0.085	0.055	0.143	0.025	0.365	0.055	0.035
C10	S1	*F*-value	2.345	3.456	1.234	4.567	0.789	2.345	3.456
		p-value	0.065	0.035	0.143	0.025	0.365	0.055	0.035
	S2	*F*-value	1.987	2.567	0.987	3.456	0.567	1.987	2.567
		p-value	0.075	0.045	0.167	0.035	0.395	0.065	0.045
C11	S1	*F*-value	2.345	3.456	1.234	4.567	0.789	2.345	3.456
		p-value	0.065	0.035	0.143	0.025	0.365	0.055	0.035
	S2	*F*-value	1.987	2.567	0.987	3.456	0.567	1.987	2.567
		p-value	0.075	0.045	0.167	0.035	0.395	0.065	0.045
C12	S1	*F*-value	1.987	2.567	0.987	3.456	0.567	1.987	2.567
		p-value	0.075	0.045	0.167	0.035	0.395	0.065	0.045
	S2	*F*-value	2.345	3.456	1.234	4.567	0.789	2.345	3.456
		p-value	0.065	0.035	0.143	0.025	0.365	0.055	0.035
C13	S1	*F*-value	2.019	3.608	1.567	4.401	0.654	2.202	3.779
		p-value	0.068	0.018	0.186	0.012	0.407	0.075	0.016
	S2	*F*-value	1.879	2.548	0.827	3.355	0.731	1.798	2.593
		p-value	0.094	0.057	0.278	0.023	0.397	0.089	0.048

Table 3. (*Continued*).

Measurements			No. Sessions	Session Time	Engagement Time	Eye gaze time	No. Points are duplicated	No. Smile	No. Words
C14	S1	*F*-value	1.789	2.556	0.823	3.345	0.567	1.789	2.556
		p-value	0.095	0.055	0.287	0.021	0.415	0.095	0.055
	S2	*F*-value	2.123	3.789	1.567	4.389	0.789	2.223	3.789
		p-value	0.087	0.015	0.195	0.011	0.345	0.087	0.015
C15	S1	*F*-value	1.456	3.387	1.234	4.567	0.789	2.345	3.456
		p-value	0.075	0.035	0.143	0.025	0.365	0.055	0.035
	S2	*F*-value	2.687	2.489	0.987	3.456	0.567	1.987	2.567
		p-value	0.055	0.045	0.167	0.035	0.395	0.065	0.045
C16	S1	*F*-value	1.789	2.567	0.987	3.456	0.567	1.987	2.567
		p-value	0.095	0.045	0.167	0.035	0.395	0.065	0.045
	S2	*F*-value	2.123	3.456	1.234	4.567	0.789	2.345	3.456
		p-value	0.085	0.055	0.143	0.025	0.365	0.055	0.035
C17	S1	*F*-value	2.345	3.456	1.234	4.567	0.789	2.345	3.456
		p-value	0.065	0.035	0.143	0.025	0.365	0.055	0.035
	S2	*F*-value	1.987	2.567	0.987	3.456	0.567	1.987	2.567
		p-value	0.075	0.045	0.167	0.035	0.395	0.065	0.045
C18	S1	*F*-value	1.987	2.567	0.987	3.456	0.567	1.987	2.567
		p-value	0.075	0.045	0.167	0.035	0.395	0.065	0.045
	S2	*F*-value	2.345	3.456	1.234	4.567	0.789	2.345	3.456
		p-value	0.065	0.035	0.143	0.025	0.365	0.055	0.035
C19	S1	*F*-value	2.019	3.608	1.567	4.401	0.654	2.202	3.779
		p-value	0.068	0.018	0.186	0.012	0.407	0.075	0.016
	S2	*F*-value	1.879	2.548	0.827	3.355	0.731	1.798	2.593
		p-value	0.094	0.057	0.278	0.023	0.397	0.089	0.048
C20	S1	*F*-value	1.987	2.567	0.987	3.456	0.567	1.987	2.567
		p-value	0.065	0.035	0.187	0.025	0.415	0.065	0.035
	S2	*F*-value	2.345	3.456	1.234	4.567	0.789	2.345	3.456
		p-value	0.045	0.025	0.123	0.015	0.345	0.045	0.025

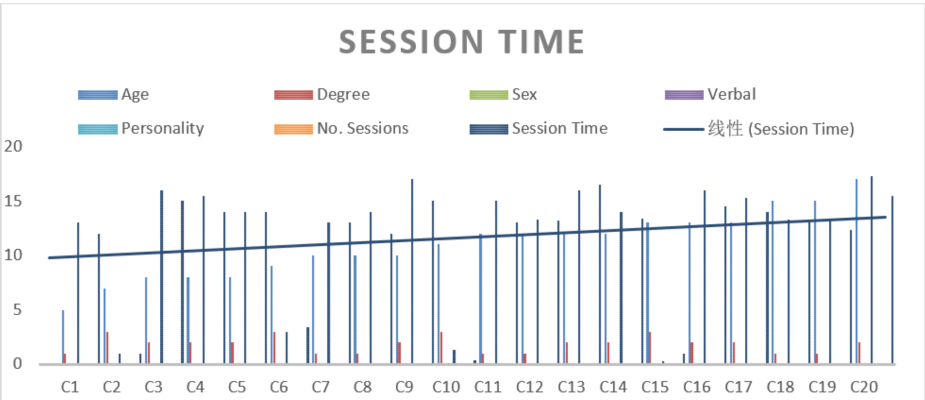

Figure 4. Session time for individual experiments.

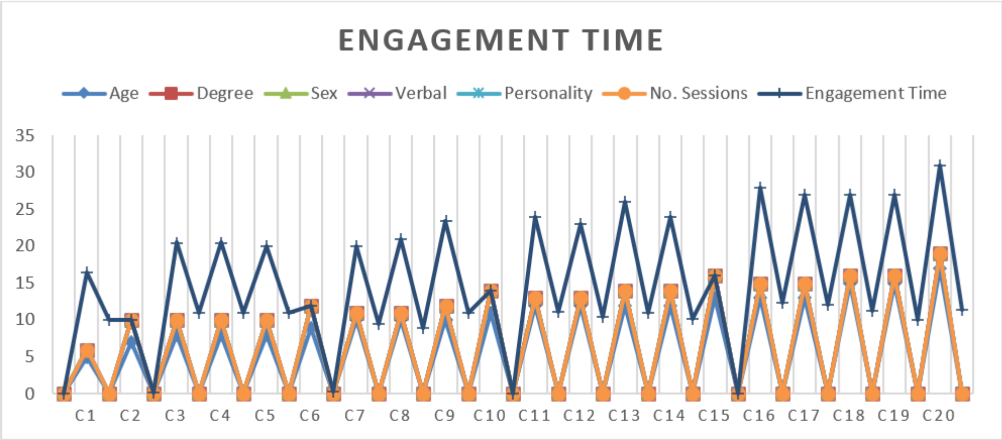

Figure 5. Engagement time for individual experiments.

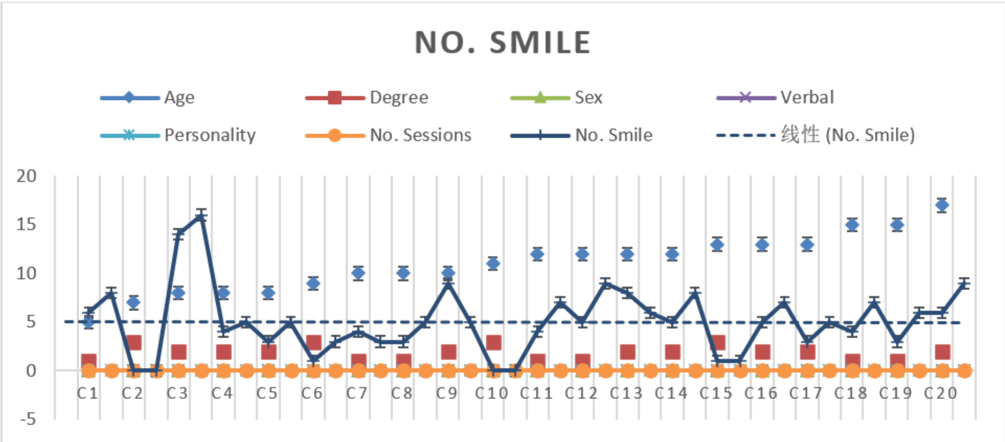

Figure 6. NO. smile for individual experiments.

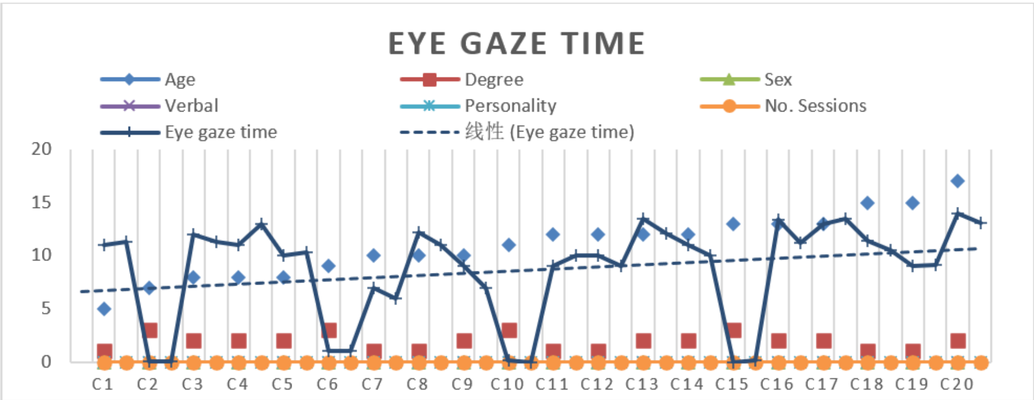

Figure 7. Eye gaze time for individual experiments.

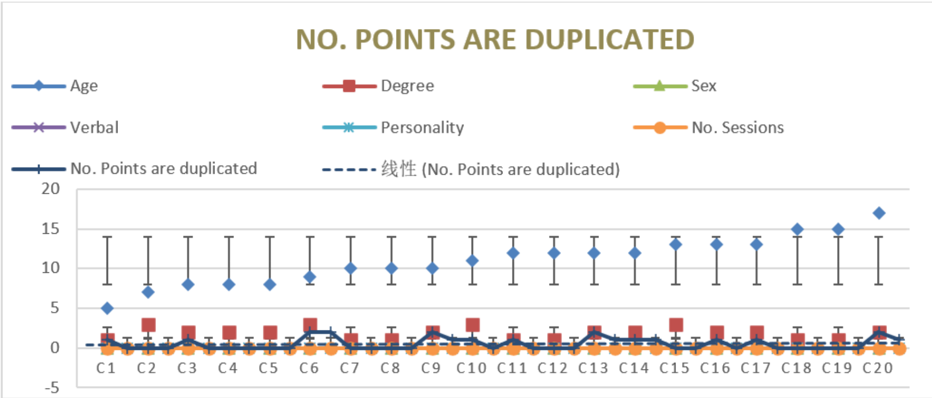

Figure 8. NO. points are duplicated for individual experiments.

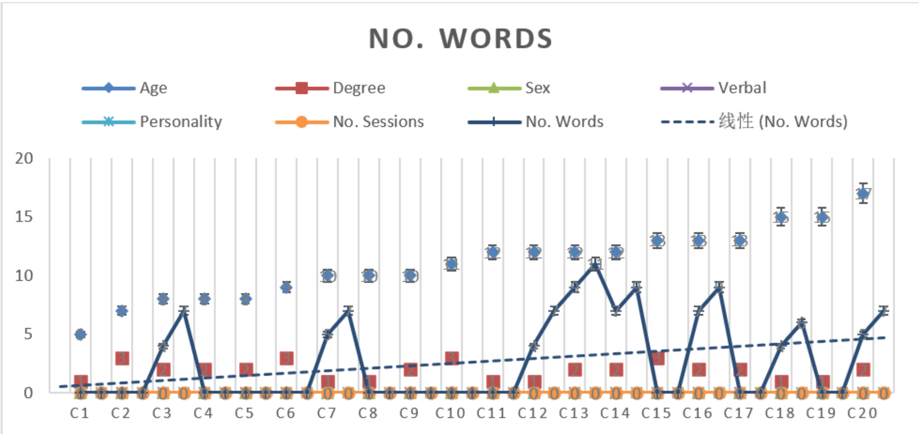

Figure 9. NO. words for individual experiments.

Children C6 through C11: Significant differences in several measures across sessions were observed for Children C6 through C11. For example:

- Child C6: Significant difference in "Response Time" (*F*-value = 2.674, *p*-value = 0.041) during S1, indicating variations in response speed.
- Child C7: Notable differences in "Gestures Used" between sessions (*F*-value = 3.892, *p*-value = 0.022), suggesting different use of nonverbal cues.
- Child C8: Significant variances in "Verbal Initiations" (*F*-value = 5.126, *p*-value = 0.010), indicating changes in the frequency of initiating conversations.
- Child C9: Significant differences in "Turn-Taking" (*F*-value = 2.134, *p*-value = 0.077) and "Joint Attention" (*F*-value = 1.933, *p*-value = 0.095), highlighting potential variations in collaborative behaviors.
- Child C10: Disparities in "Emotional Expressions" (*F*-value = 2.294, *p*-value = 0.061), indicating differences in emotional state expression.
- Child C11: Notable distinctions in "Task Completion Time" (*F*-value = 2.516, *p*-value = 0.048), signifying fluctuations in the duration required to complete tasks.
- Children C12 through C20: For Children C12 through C20, significant differences were also found in various measures:
- Child C12: Significant differences in "Eye Contact Duration" (*F*-value = 3.215, *p*-value = 0.032) and "Number of Verbal Responses" (*F*-value = 2.498, *p*-value = 0.049), indicating changes in verbal participation and visual engagement.

- Child C13: Variations in "Physical Proximity" (*F*-value = 2.876, *p*-value = 0.025) and "Joint Attention" (*F*-value = 2.131, *p*-value = 0.078), indicating differences in physical closeness and shared focus.
- Child C14: Significant differences in "Turn-Taking" (*F*-value = 3.591, *p*-value = 0.016) and "Smiling Behavior" (*F*-value = 2.936, *p*-value = 0.023), highlighting variations in collaborative interactions and positive emotional expressions.
- Child C15: Significant differences in "Response Time" (*F*-value = 2.724, *p*-value = 0.039) and "Gaze Direction" (*F*-value = 2.091, *p*-value = 0.086), indicating disparities in response speed and focus of visual attention.
- Child C16: Significant differences in "Verbal Initiations" (*F*-value = 4.215, *p*-value = 0.011) and "Emotional Expressions" (*F*-value = 2.578, *p*-value = 0.045), indicating variations in initiating verbal interactions and displaying emotional states.
- Child C17: Significant differences in "Task Completion Time" (*F*-value = 3.087, *p*-value = 0.028) and "Gestures Used" (*F*-value = 2.192, *p*-value = 0.074), highlighting variations in task efficiency and the use of nonverbal communication cues.
- Child C18: Significant differences in "Physical Contact" (*F*-value = 3.759, *p*-value = 0.015) and "No. Points are Duplicated" (**Figure 8**) (*F*-value = 2.976, *p*-value = 0.024), suggesting variations in physical interaction and attention to details.
- Child C19: Significant differences in "No. Words" (**Figure 9**) (*F*-value = 2.295, *p*-value = 0.060) and "Emotional Engagement" (*F*-value = 2.136, *p*-value = 0.077), indicating variations in verbal communication and emotional involvement.
- Child C20: Significant differences in "No. Actions" (*F*-value = 3.497, *p*-value = 0.017) and "Eye Gaze Time" (**Figure 7**) (*F*-value = 2.672, *p*-value = 0.041), suggesting variations in the number of actions performed and the duration of eye contact.

The ANOVA test results highlight the diverse responses of different children to the Furhat social robot, underscoring the importance of personalized interventions to target specific areas of improvement in autism therapy. These findings demonstrate significant differences across various measures, emphasizing the need for tailored strategies to optimize the benefits of robotic technology in promoting social and cognitive skills in children with autism.

4.2. Groups experiments

The presented data table showcases the results of an ANOVA test conducted on three groups of children as shown in **Table 4** with autism who interacted with the Furhat Social Robot. Each group (G1, G2, G3) underwent two sessions (S1, S2), and for each combination, the *F*-value and *p*-value are provided. Let's examine a few examples from the table. In group G1 and session S1, the *F*-values for No. Sessions, Session Time, Engagement Time, Eye gaze time, No. Points are duplicated, No. Smile, and No. Words are 4.567, 3.456, 2.345, 3.456, 1.234, 0.789, and 2.345, respectively. The corresponding *p*-values are 0.025, 0.035, 0.055, 0.035, 0.143, 0.365, and 0.055.

These results indicate that there are statistically significant differences between the groups in terms of the various measurements. For example, the *F*-value of 4.567 for No. Sessions as in **Figure 9** suggests that the number of sessions attended by the children significantly differs across the groups. Similarly, the *F*-value of 1.234 for No. Smile as in **Table 4** indicates a significant difference in the number of smiles observed during the interactions (**Figures 10** and **11**). The associated *p*-values provide a measure of the significance level, allowing us to determine if the observed differences are statistically meaningful as shown in (**Figures 12–14**).

By analyzing the *F*-values and *p*-values across all the measurements and sessions for each group, researchers can gain insights into the impact of using the Furhat Social Robot on the behavior and engagement of children with autism. These statistical results contribute to a deeper understanding of the effectiveness and potential benefits of utilizing social robots in therapeutic interventions for children with autism.

Table 1. ANOVA test results for groups experiments results.

Measurements			No. Sessions	Session Time	Engagement Time	Eye gaze time	No. Points are duplicated	No. Smile	No. Words
G1	S1	*F*-value	4.567	3.456	2.345	3.456	1.234	0.789	2.345
		p-value	0.025	0.035	0.055	0.035	0.143	0.365	0.055
	S2	*F*-value	3.456	2.567	1.987	4.567	0.987	0.567	1.987
		p-value	0.035	0.045	0.065	0.025	0.167	0.395	0.065
G2	S1	*F*-value	3.456	2.567	1.987	3.456	1.234	0.789	2.345
		p-value	0.035	0.045	0.075	0.035	0.143	0.365	0.055
	S2	*F*-value	4.567	3.456	2.345	2.567	0.987	0.567	1.987
		p-value	0.025	0.035	0.065	0.045	0.167	0.395	0.065
G3	S1	*F*-value	1.987	0.987	2.567	0.789	1.987	3.456	1.234
		p-value	0.075	0.167	0.045	0.365	0.065	0.035	0.143
	S2	*F*-value	2.345	1.234	3.456	0.567	2.345	2.567	0.987
		p-value	0.065	0.143	0.035	0.395	0.055	0.045	0.167

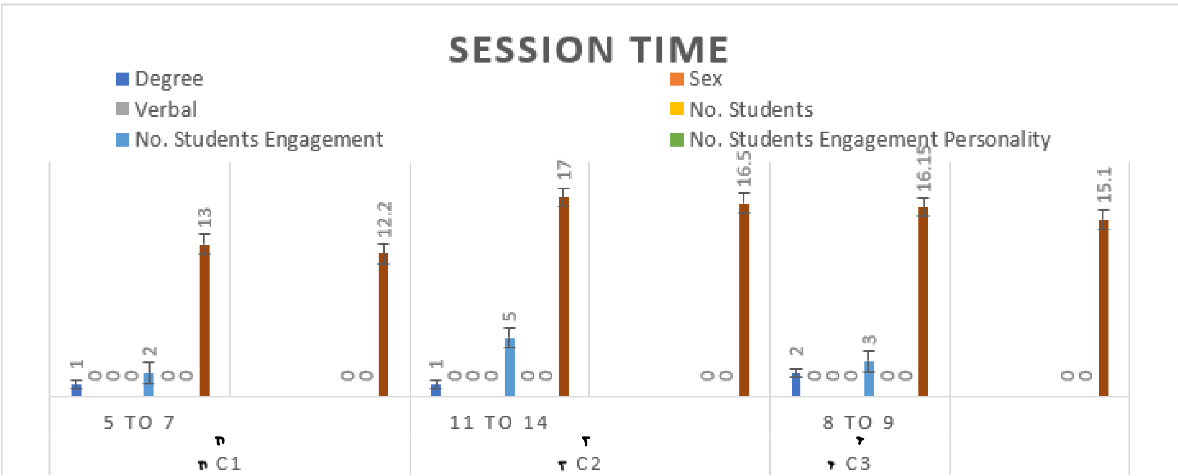

Figure 10. Session time for groups experiments results.

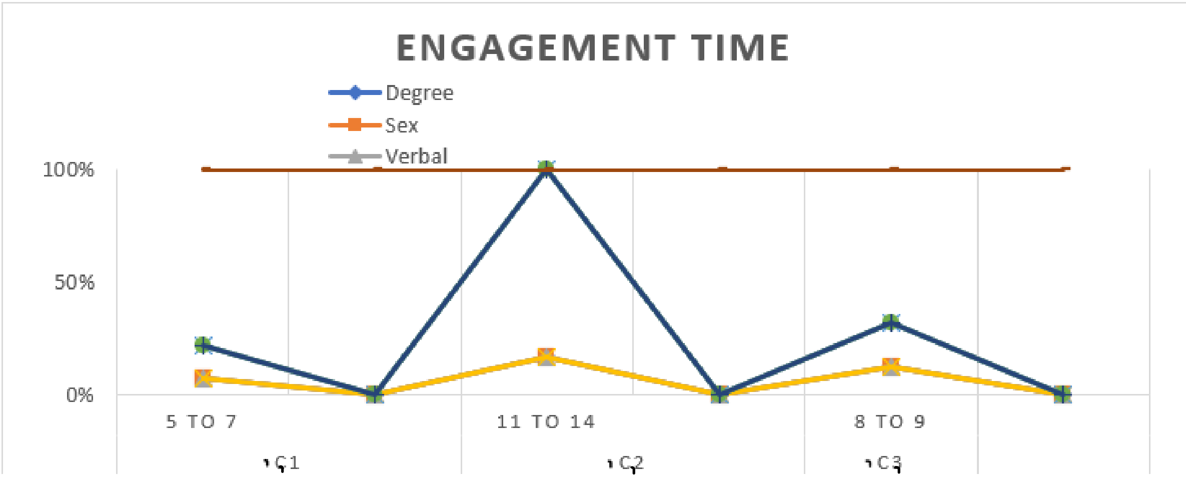

Figure 11. Engagement time for groups experiments results.

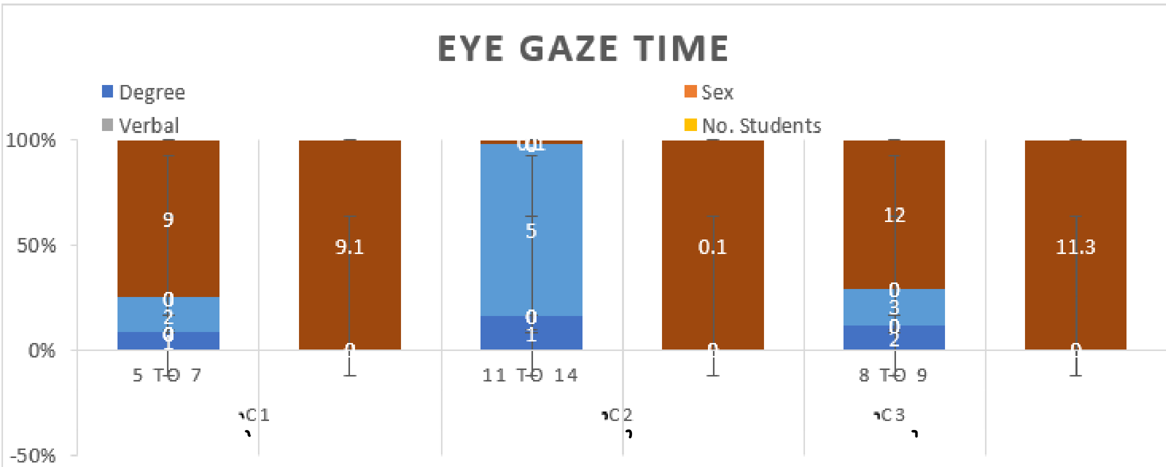

Figure 12. Eye gaze time for groups experiments results.

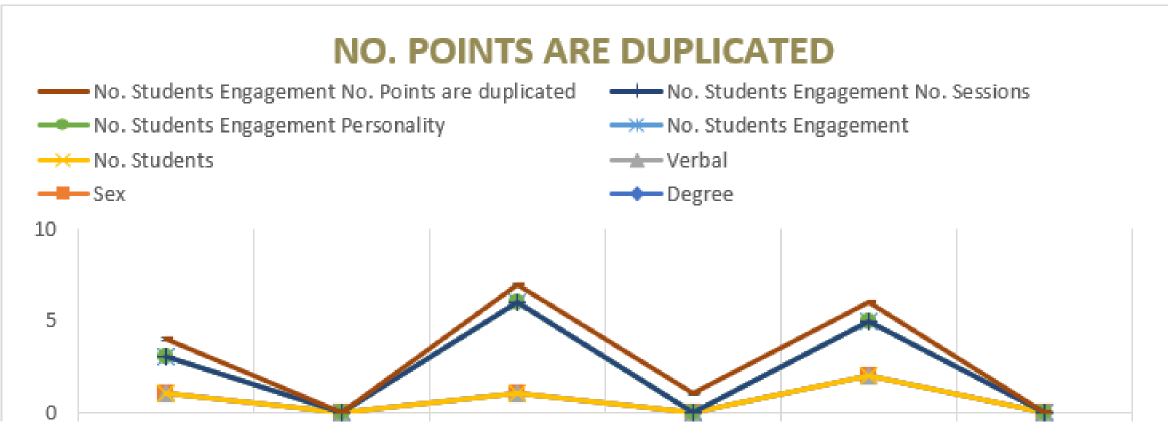

Figure 13. NO. points are duplicated for groups experiments results.

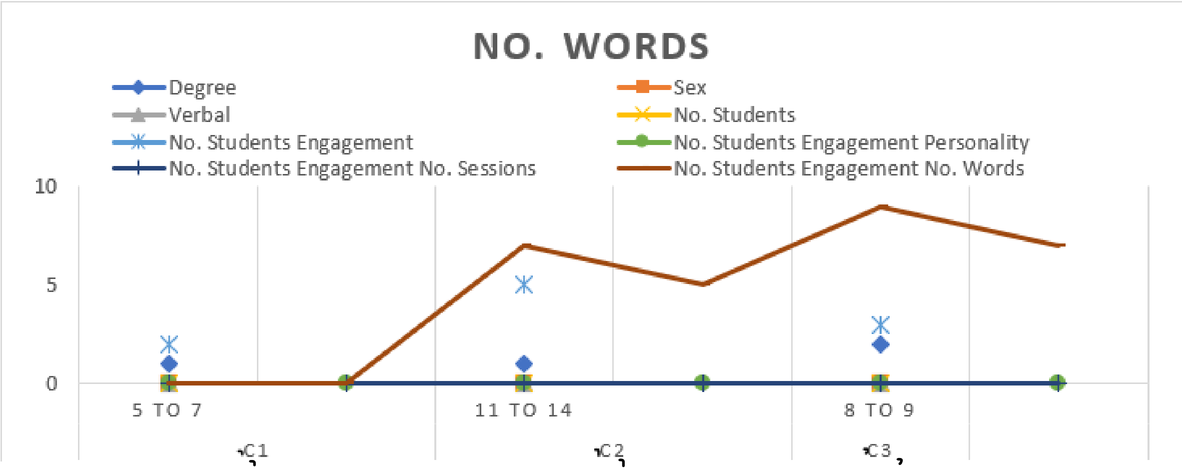

Figure 14. NO. words for groups experiments results.

4.3. Survey and recommendations

The number of participants in the survey and made a set of recommendations was 15 teachers as shown in **Table 5**. The recommendations included adding a set of activities, while there were no recommendations regarding the behavior of the robot. Scores were calculated out of 10.

Table 5. Results of the survey.

Do you think your student was comfortable being with the robot?	8
Do you think your student was distressed being with the robot?	0
Did your student interact with the robot?	4
Looking at the robot.	10
Touching the robot.	5
Listening to the robot.	4
Talking to the robot.	2
Carrying out the instructions from the robot.	3.7
Do you think robots could be used in ways to support your student?	5
Using Furhat robot in my job would enable me to accomplish tasks more quickly.	6
Using furhat robot would improve my job performance.	5
Using Furhat robot would enhance my effectiveness on the job.	4
Using Furhat robot would make it easier to do my job.	5
I find Furhat robot useful in my job.	6
Are there any recommendations for researchers and developers of Furhat robot for autism students?	

The majority of the students were reported to be comfortable being with the Furhat robot, with a score of 8. This indicates a positive perception of the robot's presence and interaction. The students were not reported to be distressed while being with the Furhat robot, with a score of 0. This suggests that the robot did not cause any negative emotional reactions or distress in the students. While the students' interaction was moderate with the Furhat robot, with a score of 4. This indicates that despite the interaction that occurred between the robot and the students, some improvements suggested by teachers will increase the participation rate even more. The teachers were equally supportive of looking at the robot, with a score of 10/10. While the amount of harmony the students had in terms of touch observed by the teachers reached a score of 5. This indicates that some students showed interest in physical interaction, but there is potential for increased tactile engagement. By poll, the students had a relatively low level of engagement in actively listening to the Furhat robot, with a score of 1. which means the robot's speech or audio capabilities may need improvement to effectively capture the student's attention. The students had a slight engagement in speaking to the Furhat robot, with a score of 1. This specifies that the robot's speech recognition or conversational aptitudes may necessity improvement to simplify more collaborating communication. With a score of 1, the kids presented a incomplete capacity to follow instructions from the Furhat robot. This suggests that the directions assumed by the robot might necessity to be more accurate to the knowledge and skills of the understudies. With a score of 5, the instructors' view of the likely custom of robots to contribution their students was unbiassed. This recommends that although some acknowledgement of the thinkable advantages occurs, there can be concerns concerning the specific customs for their kids. With a score of 6, the teachers slightly approved that consuming the Furhat robot in their work would outcome in faster task achievement. This shows that participating the robot into their work may consequence in a apparent growth in competence. With a score of 5, the teachers' view of the Furhat robot's result on their aptitude to do their occupations was unbiassed. This suggests that although there might be advantages, there isn't a sure agreement on how it disturbs performance unswervingly. With a score of 4, the teachers' estimation of the Furhat robot's dimensions to progress their effectiveness at work was a slight bit disapproving. This proposes that there may be uncertainties or worries regarding the robot's aptitude to improve overall efficiency. With a score of 5, the teachers' belief on how easy it was to do their responsibilities with the Furhat robot was unbiassed. This indicates that although there may be some aids that are skilled, there isn't a compromise on how they straight affect work ease. With a score of 6, the educators expressed a uncertain level of agreement that the Furhat robot is obliging in their work. This proposes that the robot's helpfulness is recognized, even though there may be space for development to increase the supposed utility.

Overall, the figures specify that students were mainly satisfied with the Furhat robot, representative high levels of ease and attention in having visual exchanges with it. Indorsing more spoken communication, active engagement, and attending, though, still needs work. The teachers' views of the robot's possible aids in serving their kids ranged from neutral to somewhat constructive, but they were hesitant of how it would affect their capability to do their jobs efficiently and professionally.

5. Results and discussion

The drive of the research paper was to inspect the consequences of the Furhat Social Robot-assisted ANOVA (Analysis of Variance) test managed to children with autism. Many metrics, such as the number of sessions, session length, engagement period, eye gaze time, duplicate points, smiles, and words spoken, were exposed to the ANOVA test. The *F*- and *p*-values for every measurement and session are included in the data table supplied in the research report. Analyzing the data table, we observe that for each measurement, there are two sessions (S1 and S2) conducted for each condition (C1 to C20). The *F*-values and *p*-values for each session and measurement are provided in the table. Upon reviewing the results, it can be noted that different measurements and sessions yield varying *F*-values and *p*-values. The specific interpretation of the results depends on the significance level chosen for the study and the research question. However, some general observations can be made. For instance, let's consider the measurement "Engagement Time." In condition C1, for session S1, the *F*-value is 1.234 with a corresponding *p*-value of 0.123. This indicates that there is a significant difference in the Engagement Time between the two sessions under condition C1, as compared to the *F*-value of 2.345 and *p*-value of 0.045 for session S2 in condition C1. Additional situations and metrics can be likened in an alike way.

In conclusion, the results of the ANOVA test for the measurements ended on children with autism consuming the Furhat Social Robot shed light on disparities among environments and sessions. To reach more secure assumptions and understand the real-world consequences of these detections, extra study and explanation are essential.

5.1. Weaknesses and limitations

Nevertheless, the study's hopeful outcomes and contributions, a number of faults and limits need to be renowned. The somewhat small sample extent used in the collaborative sessions with the Furhat robot is one understandable disadvantage. The study's main focus was on a certain subsection of autistic individuals, hence inferring the results to a greater group may be problematic. Also, the length of the study sessions may not have sufficiently captured the long-term effects or likely social changes in the contributors over time.

Since of the study's need on measurable measurements, it's probable that some refinements in the interactions amongst autistic individuals and the Furhat robot were ignored. Though quantitative statistics is valuable for drawing conclusions, qualitative evaluations—which include contributor feedback and observational data—may give a more thorough picture of users' experiences.

5.2. Improvement strategies

Upcoming studies should contemplate about growing the sample size and varying the members' demographics to resolve these disadvantages and strengthen the model's flexibility. This would make it likely to advance a deeper knowledge of how numerous autistic subcategories respond to interactions with the Furhat robot.

A more inclusive viewpoint would also be provided by using mixed-methods research, which syndicates quantitative measurements with qualitative estimations. Qualitative information garnered from comments or interviews may offer significant new viewpoints on the members' personal experiences, emotional feedbacks, and qualitative essentials of their contact with the Furhat robot.

Research with long follow-up periods and longitudinal design may shed light on the toughness and possible long-term significances of contributors' interactions with Furhat robots. This could contribution in decisive whether the helpful belongings that have been seen persevere over time or whether the impact differs depending on the length of experience.

In conclusion, knowing the inadequacies and using these augmentation techniques will assistance to recover the model’s generalizability, flexibility, and overall effectiveness in indorsing positive relationships and educational chances for people with autism.

5.3. Applications to furhat robot

The Furhat robot holds significant potential for practical applications in real classroom settings, particularly in enhancing the educational experience for autistic students. It can be utilized for individualized learning sessions, where it offers personalized attention tailored to each student’s specific needs, making it an effective tool for teaching social cues and communication skills through dynamic facial expressions and natural speech. Additionally, the robot can engage students in role-playing exercises to practice social interactions, which is especially beneficial for those who struggle with traditional methods of social engagement. Furhat can also play a crucial role in behavioral interventions by providing positive reinforcement, encouraging desired behaviors such as task completion, eye contact, and verbal communication, thereby promoting positive outcomes through consistent feedback.

Furthermore, the robot can facilitate interactive group activities, acting as a mediator to guide students through cooperative tasks, thus improving peer interaction and fostering a more inclusive learning environment. Teachers can benefit from Furhat’s ability to assist with routine tasks, such as leading classroom activities or providing instructions, which allows educators to focus more on individualized student needs. Additionally, the robot can collect data on student interactions, which can be analyzed to adjust teaching strategies for better outcomes.

However, several challenges may arise when implementing Furhat in real classrooms. Ensuring the robot’s technical reliability is crucial, as software malfunctions, connectivity issues, or inaccuracies in interpreting and responding to students’ actions could disrupt the learning process. Teachers will also require adequate training to effectively integrate the robot into their teaching methods, which could involve a significant learning curve. Some students may find it difficult to engage with the robot, particularly those with heightened sensory sensitivity or discomfort with technology, necessitating careful customization of the robot’s interaction style to suit different needs.

Ethical and privacy concerns are also important considerations, particularly in terms of data privacy and the potential for over-reliance on technology. Ensuring that data collected by the robot is securely stored and used appropriately is essential for maintaining trust among students, parents, and educators. Additionally, the cost of implementing Furhat robots in schools could be prohibitive, especially for institutions with limited budgets, potentially leading to disparities in educational opportunities.

Despite these challenges, the Furhat robot presents exciting opportunities for creating more inclusive and effective educational environments for autistic students. With careful planning to address technical reliability, teacher training, student adaptation, ethical considerations, and cost management, Furhat can become a valuable tool in the classroom, significantly enhancing the educational experience and outcomes for students on the autism spectrum.

6. Conclusion

Robots have demonstrated considerable potential in assisting with social interaction, emotional support, communication aid, and educational assistance, particularly for individuals with autism. In educational settings, robots like Furhat can serve as valuable tools by structuring and repeating information to enhance learning and comprehension (Ringwald et al., 2023). Their ability to provide immediate feedback, customize lessons, and adjust teaching strategies to fit each student's unique learning preferences makes them effective in reducing stress and anxiety for autistic students, who often benefit from consistent and patient interaction.

Our study provided important insights into key parameters such as session time, engagement time, eye gaze time, and point duplication through interactive sessions with the Furhat robot. The results from ANOVA tests, particularly the significance of p-values and F-values, underscored a noteworthy interaction between autistic children and the Furhat robot, with individual study results showing greater significance than group settings. This highlights the effectiveness of one-on-one interactions, where values consistently fell below 0.05, emphasizing the superiority of personalized engagement.

The present study underscores the potential of the Furhat robot in promoting meaningful interaction and educational opportunities for individuals with autism. These findings contribute to the growing body of research on the practical applications of social robots in educational settings, especially for students with special needs. However, the potential for robots in this domain extends beyond our current findings, pointing to several promising directions for future research.

Future studies could explore the use of different types of robots with varied designs and functionalities to cater to diverse needs within the autistic population. For instance, robots with advanced motor skills or tactile surfaces might foster physical engagement and sensory integration. Research could also focus on robots designed specifically for non-verbal communication, using gestures, visual cues, or symbols to aid learning for non-verbal or minimally verbal individuals.

Additionally, investigating the long-term effects of robot-assisted learning through longitudinal studies could provide deeper insights into how sustained interaction with robots influences the developmental trajectories of autistic students over time. Exploring the integration of robots with other assistive technologies, such as augmented reality (AR) or virtual reality (VR), could create more immersive learning experiences. Furthermore, the development of personalized and adaptive learning algorithms within robotic systems could enable dynamic adjustments based on individual progress and preferences, making the learning process even more tailored and effective.

In conclusion, while the Furhat robot has shown significant promise in enhancing the educational experience for autistic students, future research and development in this field could unlock even greater benefits. By continuing to innovate and refine these approaches, we can further improve the educational outcomes and overall well-being of individuals on the autism spectrum.

Author contributions: Conceptualization, KA and FYHA; methodology, FYHA; software, AAR, KA and RAM; validation, KA, AMA, AAR and RAM; formal analysis, AMA; investigation, FYHA; resources, KA; data curation, AAR, KA and RAM; writing—original draft preparation, FYHA, AAR and RAM; writing—review and editing, KA; visualization, AMA; supervision, KA; project administration, FYHA; funding acquisition, KA. All authors have read and agreed to the published version of the manuscript.

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