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Ali, Sara and Mehmood, Faisal and Khan, Muhammad Jawad and Ayaz, Yasar and Asgher, Umer and Sadia, Haleema and Edifor, Ernest and Nawaz, Raheel (2020) A Preliminary Study on Effectiveness of a Standardized Multi-Robot Therapy for Improvement in Collaborative Multi-Human Interaction of Children with ASD. IEEE Access. p. 1.

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2020.3001365, IEEE Access

IEEE Access
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3Date of publication xxxx 00, 0000, date of current version xxxx 00, 0000.

Digital Object Identifier 10.1109/ACCESS.2017.Doi Number

A Preliminary Study on Effectiveness of a Standardized Multi-Robot Therapy for Improvement in Collaborative Multi-Human Interaction of Children with ASD

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This paragraph of the first footnote will contain support information, including sponsor and financial support acknowledgment. For example, "This work was supported in part by the U.S. Department of Commerce under Grant BS123456."

ABSTRACT This research article presents a preliminary longitudinal study to check the improvement in multi-human communication of children with Autism Spectrum Disorder (ASD) using a standardized multi-robot therapy. The research is based on a 3 step framework: 1) Human-Human Interaction, Stage-1 (HHI-S1), 2) Human-Robot Interaction, Stage-2 (HRI-S2), and 3) Human-Human Interaction, Stage-3 (HHI-S3). All three stages of the therapy consist of two command sets: 1) Controls commands and 2) Evaluation commands (auditory commands, visual commands, and combination of both). The concept of multiple robots is introduced to help multi-human communication and discourage isolation in ASD children. The joint attention of an ASD child is improved by the robotic therapy in stage 2 considering it as a key parameter for a multi-human communication scenario. The improvement in joint attention results in better command following in a triad multi-human communication scenario in stage 3 as compared to stage 1. The proposed intervention has been tested on 8 ASD subjects with 10 sessions over a period of two and a half months (10 weeks). Each session of human-human interaction (stage 1 and 3) consisted of 14 cues whereas 18 cues were presented by each robot for human-robot interaction (stage 2). The results indicate an overall 86% improvement in the social communication skills of ASD children in case of a multi-human scenario. Validation of results and effectiveness of the therapy has been further accomplished through the use of the Childhood Autism Rating Scale (CARS) score.

INDEX TERMS Autism Spectrum Disorder (ASD), Multi-robots, Human-robot interaction, Robotic therapy.

I. INTRODUCTION

ASD is a developmental disability that implies impairment in language as well as restricted/repeated stereotyped behaviors along with the difficulty in social communication [1]. The pivotal issues in children with ASD are limitations in joint attention, imitation, communication skills, expression of emotions, and regulation [2]. According to the National Autistic Society [3] and many other researchers [4], the triad of impairments that are the main characteristics children with autism are: social interaction, social communication, and imagination. Children with ASD tend to concentrate their attention on a particular thing of their liking and therefore are considered slow at eye gaze shift or maintaining eye contact. The eye gaze shift and eye contact is important while involved in multi-human interaction, a common social communication scenario. In the past couple

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of decades, a lot of research has been done for early identification and improvement in the behavior of ASD children. This behavior has been addressed with various kinds of robotic therapies [5], [6]. Research shows that ASD children are more inclined towards robots; for this reason, a lot of research is focusing on the use of robots for cognitive therapies [7]. These robot-based therapies aim at the improvement of joint attention, imitation, verbal communication skills, and improvement of social interaction of ASD children [8], [9], [10].

Several methodologies have been implemented for using these robots as tools for improving communication skills and social interaction of ASD children. Research done by Scassellati at el. [11] shows that pre-school and school-aged ASD children had improved social communication to adults because of these robotic therapies as compared to having a therapy session with adults. Goodrich et al. [12] stated that exposing an ASD child with robotic therapies elicits positive social communication behavior. Moreover, there are various therapies e.g., Lego therapy uses collaborative Lego play for improving the social skills of autistic children [13], [14], [15]. Huskens et al. [16] studied the effectiveness of an intervention conducted by a robot and a human trainer. The research concluded that the robotic interventions were more effective in terms of questions that were self-initiated from ASD children. Therefore, it was suggested to deploy robots as mediators for future interventions. However, these interventions do not focus on multi-human communication of ASD children. Parents of ASD children often complain about the lack of interaction and play between their children [17]. To improve the sibling interaction of children with ASD, researchers have developed various interventions e.g., developing interactions based on their thematic ritualistic behavior [18], teaching strategies to the siblings of ASD children for improving the social interaction [19], sibling-implemented reciprocal imitation training [20], etc. However, research using robotic intervention for improving a triad model communication of an ASD child is limited. Huskens et al proposed a concurrent multiple baseline design across three child–sibling pairs using robotic interventions. The research resulted in no statistically significant changes in the collaborative behaviors of children with ASD [21]. Another research done by Fachantidis et al. concluded that a 3D LEGO robot bicycle model as educational robotics appeared to bring a positive change in the attitude of the typically developing students towards the students with ASD [22]. Similarly, the robot-based play-drama intervention also proved to enhance gestural communication, joint attention, play behaviors, and narrative abilities of children with ASD [23]. However, there is no research available that focuses on the joint attention and command following during a triad human-human communication scenario.

The work described in this article is the continuation of S. Ali et. al., MRIS *(Multi-robot-mediated Intervention System)* project [5], which investigates the potential use of multiple robots for the improvement of multi-human communication skills of children with ASD in a practical scenario. The focus of this particular research is to experimentally determine if multi-robot therapy improves a triad multi-human communication based on the above-mentioned factors. The important contribution of this research is to check the improvement in a triad multi-human interaction scenario by observing parameters of joint attention and command following (both visual and auditory commands). The robots act as a non-human therapist during an intervention without any external stimuli interference. Moreover, no body-worn sensors are used in the interventions to observe the effective improvement.

This article presents a longitudinal study with 8 ASD children, to check the multi-human interaction before and after the robotic therapy. The sessions were conducted over 10 weeks. The proposed intervention is based on three steps i.e. human-human interaction, human-robot interaction and human-human interaction to observe an improvement in a child's behavior for multi-human interaction skills. The results show a remarkable improvement in the triad model of

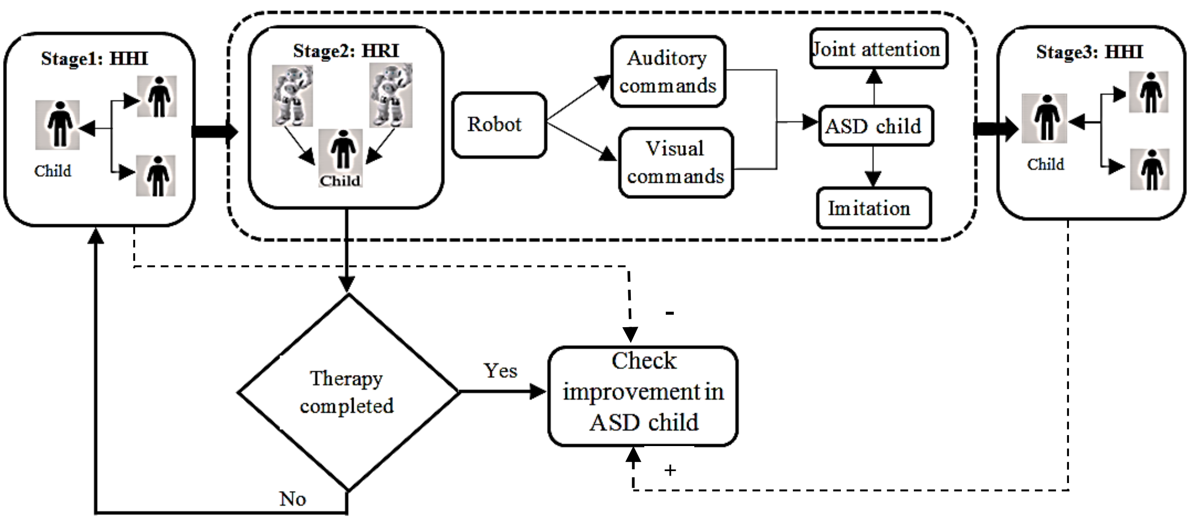

FIGURE 1. System architecture explaining the therapy in three stages.

human-human interaction. The objective of this research is to mark parameters that improve multi-human social interaction skills of ASD children along with the clinical expert's support.

II. SYSTEM ARCHITECTURE

In this research, we aim to present a multi-robot-based therapy focusing on the improvement of social interaction skills of an ASD child. Multi-robot interventions allow ASD children to familiarize themselves with multi-human communications. The triad human communication scenario focused on the parameters of joint attention (also called shared attention: when a person directs his/her attention to other person's focus of attention), command following, and response of an ASD child.

This robot-mediated therapy is based on three stages: 1) human-human interaction, stage-1 (HHI-S1), 2) human-robot interaction, stage-2 (HRI-S2), and 3) human-human interaction, stage-3 (HHI-S3). Pre and post-human interactions of an ASD child are done in Stage 1 and 3 respectively, whereas an improvement in Stage 3 (if any) is observed based on the robot-mediated therapy done in Stage 2. This is to check whether the multi-robot therapy can practically improve multi-human communication in daily life scenario or not. Fig. 1 shows the architecture of this three-stage research for multi-robot therapy to improve a multi-human communication in ASD children.

The architecture for human-robot interaction is shown in Fig. 2 which includes the networking protocol. The detail explanation of this HRI module is as follow:

Each robot was running two main modules: 1) an eye contact module and 2) visual and auditory command modules. The eye contact module is related to the joint attention of an ASD child as it records the eye contact duration of the child and the delay in making eye contact when a stimulus is given. Joint attention is measured using image processing techniques in a NAO robot. For this purpose, "AL Gaze analysis" library is used. The command module has two sets of commands i.e., control commands and evaluation commands. Control commands were initiated to gain the initial attention of an ASD child and therefore were not included in the evaluation process. These commands were: calling child's name by the robot. The evaluation command set includes: 1) auditory commands that includes speech such as "Hi/Hello", 2) visual commands that consists of actions such as sit, stand and wave, and 3) visual + auditory command that include waving along with speech "Hello nice to meet you". The parameter recorded during the human-robot interaction was joint attention of an ASD child when a specific stimulus was given.

Two transmission control protocol (TCP) servers (S1 and S2) are implemented in computers represented by C11, C12, C21, and C22 as shown in Fig. 2. The modules running on the robot were TCP client integrated and they were sharing real-time data to a laptop which was running corresponding TCP servers. This information was being written in a file via file writing process.

The explanation of human-human interaction in S1 and S2 is described in detail under section III, C. Experimental design and setup.

III. MATERIALS AND METHODS

A. SUBJECTS

Eight ASD children (7 males and 1 female) participated in the study. These participants were recruited from the Autism Resource Center (ARC), Islamabad, Pakistan. The participants are already accessed on a clinical scale

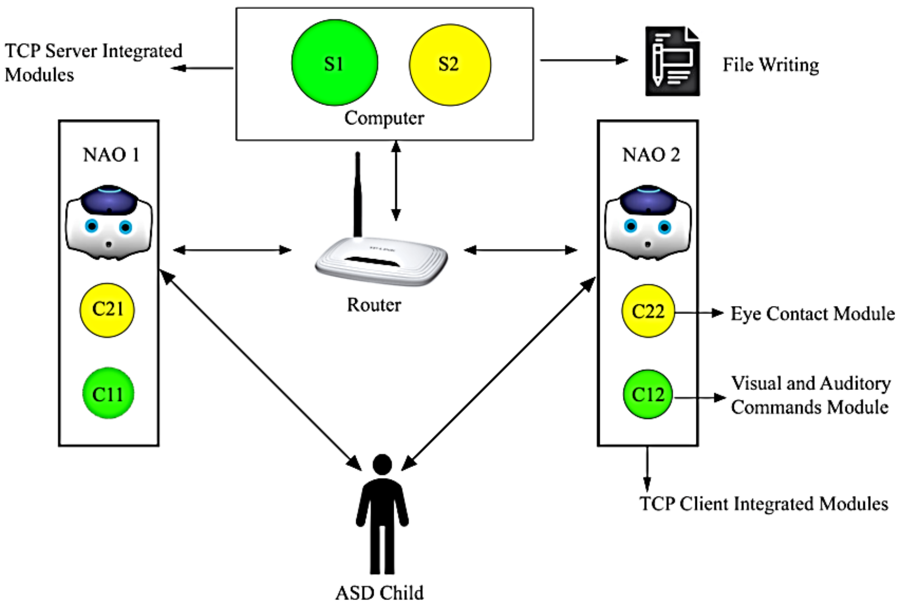

FIGURE 2. Architecture of multi-robot and human interaction along with the networking protocol.

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childhood autism rating scale score (CARS). The therapy was approved by the specialist and director board of the Autism Resource Center.

B. ETHICS STATEMENT

The therapy was approved by the review board and ethics committee of Autism Resource Centre (ARC), Islamabad, Pakistan. All the subjects participated voluntarily and written consent was provided by their parents prior to the experimental procedures.

C. EXPERIMENTAL SETUP AND DESIGN

An experimental setup of the therapy is shown in Fig. 3 for all the three stages. The child sat on a comfortable chair to interact with the human before and after the HRI-S2. During HRI-S2, two robots stood in an arc-like manner at a distance of 1m facing the child. The robots were placed under the same lighting conditions.

In Stage 1, the child interacted with two persons as shown in Fig. 4. The reason for introducing multiple people was to check improvement in multi-communication skills of an ASD child due to human-robot interaction. Both people sat at a distance of 1m from the child. The interaction in Stage 1 was initiated by the introduction of some control commands to gain an ASD child's attention. The number of control commands was dependent on the child's behavior. These commands were not part of the evaluation. The control command session was followed by evaluation commands i.e., auditory, visual, and combination of both commands for an ASD child. An evaluation was done on the basis of commands followed by an ASD child. Each participant was evaluated based on a total of 7 commands. These include 3 auditory, 3 visual, and 1 auditory + visual command. Commands for auditory include the one that involves the speech. These were: stand up, sit down, and jump. The commands for visual includes: passing the ball of a specific color, taking the ball of a specific color from any person during communication, and pointing. A combination the child was asked to wave along with the speech. Each set of command was repeated twice. Therefore, the child was evaluated for a total of 14(7x2) commands. Each command took approximately 60 secs. Therefore, the total time for human-human interaction in Stage 1 was approximately 14 minutes. The commands were given in a random order and the response for each specific command category was recorded.

In stages 2 of the therapy, humans were replaced with NAO robots. The robots were standing at a distance of 1m from each other and from the child too. This arrangement was similar to Stage 1 except humans were replaced by the robots. Lighting conditions for both the robots were uniform. The robots had auditory, visual, and combination of both commands for interaction with an ASD child. The audio command set includes speech "Hi/Hello". The visual command set includes sit, stand, and wave gesture of the robot. A combination of auditory and visual command includes waving along with speech "Hello nice to meet you". Each command was repeated 3 times by each robot. The total time consumed by Stage 2 for the therapy was approximately 15 minutes.

The protocol for Stage 3 is the same as Stage 1. The people, as well as their dresses, were the same when evaluating for pre and post-therapy progress in each session. The similarity of dresses in both stages was maintained to ensure that the only parameter for improvement should be robotic interaction. The total time for this session was 14 minutes. The total number of sessions given to each subject was 10. The experiments were conducted over 10 weeks (2.5 months) to observe effectiveness in multi-human communication by this therapy.

For the times when the child was absent or was not comfortable to conduct the session, he/she was evaluated on another day of the same week. The child was rewarded for the correct response. However, for an incorrect or no response, the therapy was conducted without any change.

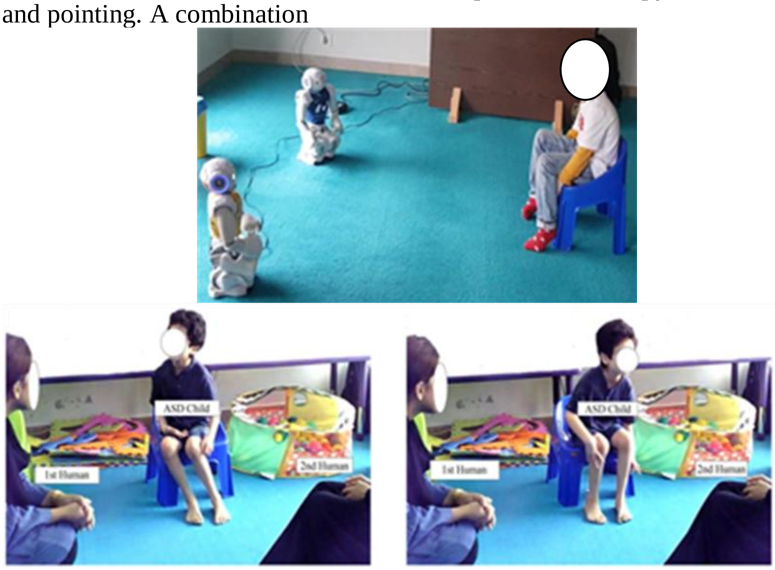

FIGURE 3. Experimental setup of intervention. An ASD child interacting in multi-robot and multi-human scenario.

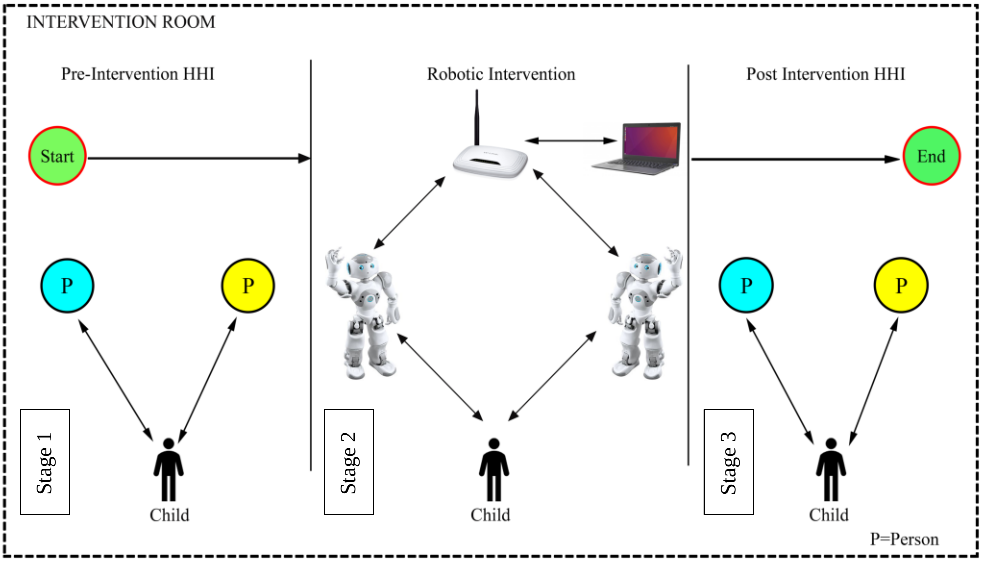

FIGURE 4. Three stage experimental design of therapy for improvement in multi-human interaction.

IV. RESULT

Table I shows the results of all three stages i.e. HHI pre-therapy, HRI, and HHI post-therapy. The illustrated results are at the initial week, mid-therapy and final week to check the improvement in the beginning, middle, and end of the intervention. The overall improvement in HHI is based on the results of pre and post-therapy human-human interaction. The percentage for overall improvement in HHI shown in Table I depicts the number of sessions for which the improvement in stage 3 was observed. The percentage for HHI in stage 1 and stage 3 is calculated based on the total commands followed for all the three types i.e. auditory, visual, and auditory + visual. For Stage 2 i.e., HRI, the percentage in Table I is based on the joint attention of an ASD child when the robot was giving visual, auditory, and visual + auditory commands. The details of different types of commands given and the total number of commands followed are shown in Table II. The abbreviations used in Table II are: VC: visual commands, VC-F: visual commands followed, AC: auditory commands, AC-F: auditory commands followed, (V+A): visual and auditory commands and (V+A)-F: visual and auditory commands followed, TC: total commands, FC: followed commands, ACC: accuracy of results. In order to show the improvement in human-human interaction, the data for each subject regarding an increase in command following for experiment 1 i.e., at the start of intervention and experiment 10 i.e., at the end of the intervention, is shown in Table II .

TABLE I
RESULTS FOR THE PRE AND POST-HUMAN-HUMAN INTERACTION ALONG WITH THE HUMAN-ROBOT

	HHI	HRI	HHI	HHI	HRI	HHI	HHI	HRI	HHI	Overall Improvement in HHI sessions (%)
	Week 1(%)			Week 5(%)			Week 10(%)			
S1	69.24	100	84.77	76	100	81.82	55.61	100	80	100
S2	34.47	19.45	71.43	60.74	50.56	76.2	51.73	13.89	32.44	80
S3	65.22	22.23	96.56	37.97	25	79.17	63.71	58.34	80	90
S4	12.34	16.67	31.25	15.67	56.6	30	27.67	44.45	40	90
S5	87.88	8.34	77.15	56.76	61.12	100	27.86	88.89	86.67	80
S6	45.61	2.78	94.45	33.65	8.34	84.22	76.67	38.89	89.5	90
S7	90	55.56	75	43.23	50	73.08	53.67	52.78	76.54	70
S8	29.42	16.67	47.37	27.28	100	35.49	49.7	100	53.49	90

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Fig. 5 shows the average accuracy of human-human interaction for Stage 1 (HHI-S1) and human-human interaction Stage 3 (HHI-S3). This shows that each subject has improved the command following rate in stage 3 as compared to stage 1. Fig.6 shows the inclination of each subject towards each type of command. The average number of followed commands of different categories i.e. visual, audio, and visual + audio by each subject is shown. Fig. 7 shows the detailed progress of each participant over 10 weeks for all three stages of intervention i.e. HHI (pre-therapy), HRI, and HHI (post-therapy). It is observed that each participant has shown improvement in multi-human communication after the therapy. As it can be seen for S1 that in each week an improvement in stage 3 has been

TABLE II
RESULTS FOR THE PRE AND POST-THERAPY HUMAN-HUMAN INTERACTION FOR DIFFERENT COMMANDS.

Subject	Exp	Stage	VC	VC-F	AC	AC-F	(V+A)	(V+A)-F	TC	FC	ACC
S1	1	HHI-1	6	4	6	4	2	2	14	10	71.43
		HHI-3	6	5	6	5	2	2	14	12	85.71
	10	HHI-1	6	5	6	4	2	1	14	10	71.43
		HHI-3	6	5	6	5	2	1	14	11	78.57
S2	1	HHI-1	6	0	6	0	2	0	14	0	0.00
		HHI-3	6	4	6	5	2	1	14	10	71.43
	10	HHI-1	6	3	6	4	2	1	14	8	57.14
		HHI-3	6	2	6	3	2	0	14	5	35.71
S3	1	HHI-1	6	3	6	4	2	2	14	9	64.29
		HHI-3	6	6	6	6	2	2	14	14	100
	10	HHI-1	6	4	6	3	2	1	14	8	57.14
		HHI-3	6	4	6	5	2	2	14	11	78.57
S4	1	HHI-1	6	6	6	4	2	1	14	11	78.57
		HHI-3	6	2	6	4	2	0	14	6	42.86
	10	HHI-1	6	5	6	4	2	1	14	10	71.43
		HHI-3	6	2	6	2	2	1	14	5	35.71
S5	1	HHI-1	6	5	6	5	2	2	14	12	85.71
		HHI-3	6	5	6	5	2	2	14	12	85.71
	10	HHI-1	6	5	6	5	2	2	14	12	85.71
		HHI-3	6	5	6	5	2	2	14	12	85.71
S6	1	HHI-1	6	5	6	5	2	2	14	12	85.71
		HHI-3	6	5	6	5	2	2	14	12	85.71
	10	HHI-1	6	5	6	5	2	2	14	12	85.71
		HHI-3	6	5	6	5	2	2	14	12	85.71
S7	1	HHI-1	6	0	6	0	2	0	14	0	0.00
		HHI-3	6	6	6	6	2	2	14	14	100
	10	HHI-1	6	4	6	4	2	2	14	10	71.43
		HHI-3	6	5	6	5	2	2	14	12	85.71
S8	1	HHI-1	6	5	6	5	2	2	14	12	85.71
		HHI-3	6	4	6	4	2	2	14	10	71.43
	10	HHI-1	6	5	6	5	2	2	14	12	85.71
		HHI-3	6	4	6	4	2	1	14	9	64.29

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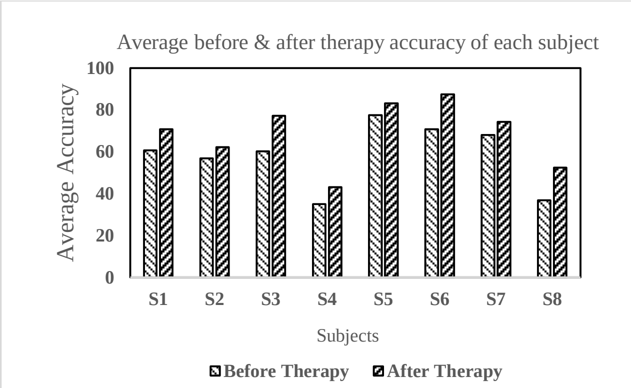

FIGURE 5. Average accuracy of human-human interaction for Stage 1 (HHI-S1) and human-human interaction Stage 3 (HHI-S3).

observed. The "Overall Improvement in HHI sessions (%)" in Table I shows the number of sessions in which the improvement has been observed. In case of S1, the subject has improved the triad human communication in all 10 sessions.

V. STATISTICAL ANALYSIS

We performed "ANOVA single factor" statistical test. According to the analysis, the F value was 2.161 while the F critical value was 2.0891. The p-value was 0.042 for the critical level=0.05. The results from statistical analysis verify that the proposed robotic intervention increases multi-human interaction for an ASD child, therefore supporting our hypothesis of this research.

Fig. 8 shows the statistical analysis graphs of pre-HHI, HRI, and post-HHI interaction over three different instants of time i.e. at the beginning of the intervention, middle of intervention, and at the end of proposed intervention respectively to check the accuracy. It can be seen clearly that the accuracy for pre-HHI is less in all the three cases as compared to post-HHI after the therapy. Thereby justifies the fact that multi-robot therapy is effective for multi-human communication.

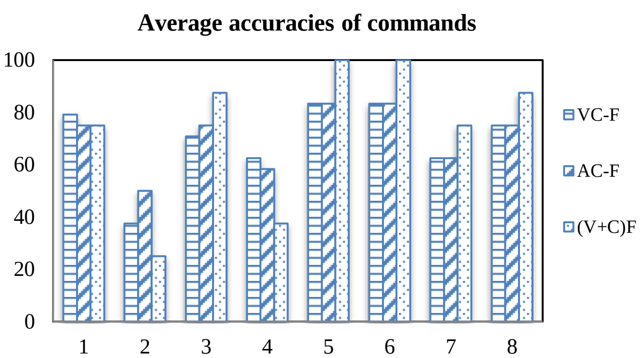

FIGURE 6. Average accuracy of different types of commands followed by the subjects, X-axis represents the subjects' whereas Y-axis represents the average accuracies of commands.

VI. DISCUSSION

The main focus of the proposed therapy is to develop social communication and multi-human interaction skills by using the existing proposed MRIS model of multi-robot interaction. By using the multi-robot communication approach, the aim was to improve the joint attention of ASD children. Results show a noticeable improvement in HHI in stage 3 as compared to stage 1. However, as shown in Fig. 6, no specific conclusion can be drawn regarding the most effective command among visual, auditory, and visual + auditory as the command following for each category is different for every subject and no specific pattern can be observed.

Moreover, to make sure that the observed improvement was as a result of the robotic intervention rather not because of repetition of specific commands during HHI, the effectiveness of the therapy was also proved by the clinical evaluation of ASD children using CARS score as shown in Table III, where Avg_IMI and Avg_JA show average imitation and average joint attention of the subject. The improvement in CARS score can also be seen; verifying that repetition of the command set during HHI is not the reason for the improved interaction. However, for future experimentation, the introduction of a control group and an intervention group shall be considered.

Robot-mediated therapies have some drawbacks e.g. trust issues of parents with these robots, customization of activities to each child as this can complicate the use of robots in schools and institutes [7]. However, there are some

TABLE III
CLINICAL EVALUATION-CARS TABLE

Subjects	Age (Years)	Autism Case	Avg_IMI	Avg_JA	CARS Before	Avg_IMI	Avg_JA	CARS After
S1	9.0	Mild	2.3	2.5	33.5	2.5	2.0	32.5
S2	10	Mild	2.0	2.8	37.0	2.0	2.8	35.0
S3	5.0	Minimal	2.5	2.5	27.5	1.3	1.8	24.0
S4	8.5	Minimal	2.3	2.3	25.0	1.0	1.0	19.5
S5	4.3	Minimal	1.0	1.8	19.5	1.3	1.0	17.5
S6	3.7	Minimal	1.5	1.3	19.0	1.3	1.3	18.0
S7	9.9	Minimal	1.5	1.5	20.5	1.3	1.3	19.5
S8	9.4	Mild	1.8	2.3	31.0	1.5	2.3	30.0

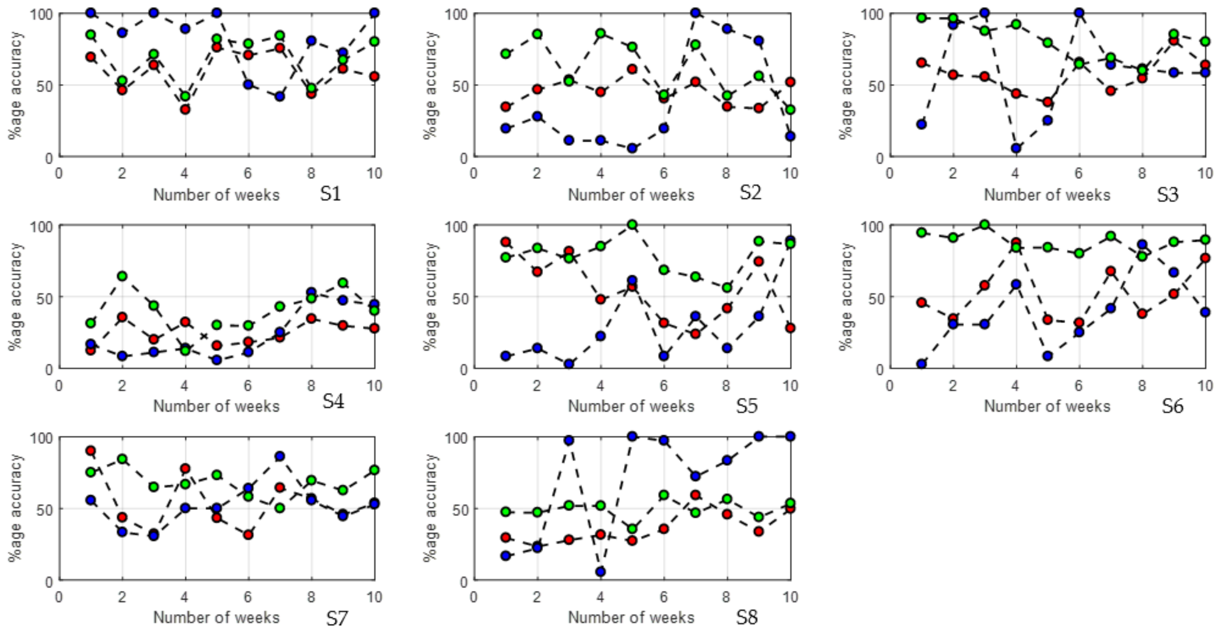

FIGURE 7. Results for all three stages of intervention for 8 subjects from week 1 to week 10

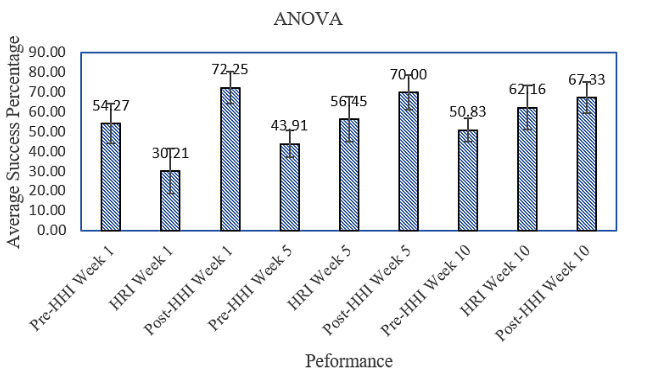

FIGURE 8. "ANOVA" Statistical analysis bar graph for intervention showing higher accuracies for post-HHI.

open-ended questions e.g. what is the best way to integrate a robot in a therapy [7]? Is there any criterion by which ASD children should be introduced to robot-mediated therapies? These questions are important as each child with ASD is different even though they have the same CARS score. Therefore, therapies should be adaptive and tailored according to the needs of an ASD child. A solution towards this can be making therapies that have levels for each of the specific core impairment.

VII. CONCLUSION

The intervention proposed in this article is the continuation MRIS (Multi-robot-mediated Intervention System) project [5]. The focus of this work is to experimentally investigate the potential use of multiple robots for the improvement in triad multi-human communication skills of children with ASD. Previously research efforts do not focus on joint attention and command following during a triad human-human communication scenario as discussed in the introduction.

The parameters used to observe improvement by comparing the results of stage 1 and stage 3 were: joint attention and command following (both visual and auditory commands). During intervention in stage 2, the robots acted as a non-human therapist without any external stimuli interference.

The proposed intervention is a three-stage therapy using auditory, visual, and auditory + visual cues for evaluation in each stage. In Stage 1, the child interacts with two people creating a usual multi-human communication scenario. In Stage 2 of the proposed intervention, the joint attention of an ASD child is recorded by each robot when a stimulus is given. In Stage 3, the child again interacts with multi-human as in Stage 1. The intervention was tested on 8 ASD children, 10 sessions for each child over 10 weeks (2.5 months). Each session consists of 18 trials by each robot and 14 cues in stage 1 and stage 3 each. The effect of the intervention is measured by noticing the difference in followed commands in Stage 1 and Stage 3 which was because of the improvement in joint attention during robotic therapy in stage 2.

By comparing the results of stage 1 and stage 3, it is reflected that the post-HHI has considerably increased after the therapy done in stage 2. The average improvement shown by our proposed therapy is 86%. A statistical analysis "ANOVA single factor" on the results was also performed to validate our hypothesis that multi-robot communication can improve multi-human interaction, a common social tendency. Moreover, the effectiveness of the therapy was also validated by CARS in order to make sure that the observed improvement was not because of command repetition.

This research contributes towards the current social challenge of children with ASD by introducing the intervention that integrates a triad human-human communication scenario.

ACKNOWLEDGMENT

Authors would like to acknowledge, Autism Resource Centre, Islamabad, Pakistan where this research was carried out.

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