IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received December 27, 2019, accepted January 5, 2020, date of publication January 9, 2020, date of current version January 22, 2020.

Digital Object Identifier 10.1109/ACCESS.2020.2965204

Comparing the Effectiveness of Different Reinforcement Stimuli in a Robotic Therapy for Children With ASD

SARA ALI[1], FAISAL MEHMOOD[1], YASAR AYAZ[1,2], (Senior Member, IEEE), MUHAMMAD JAWAD KHAN[1], HALEEMA SADIA[3], AND RAHEEL NAWAZ[4]

[1]School of Mechanical and Manufacturing Engineering (SMME), National University of Sciences and Technology, Islamabad 44000, Pakistan
[2]National Center of Artificial Intelligence (NCAI), Lahore, Pakistan
[3]Autism Resource Centre, Islamabad 44000, Pakistan
[4]School of Computing, Mathematics and Digital Technology, Manchester Metropolitan University, Manchester M15 6BH, U.K.

Corresponding author: Yasar Ayaz (yasar@smme.nust.edu.pk)

This work was supported by the National University of Sciences and Technology, Islamabad, Pakistan.

ABSTRACT Recent research has shown reliability in robotic therapies for improvement in core impairments of autism. To improve the efficiency of communication using robots, this study evaluates the effectiveness of three different stimuli in a robotic intervention for children with autism spectrum disorder. Three different reinforcement stimuli presented in least-to-most (LTM) order introduced in this therapy using NAO robot are: visual (color variation), auditory and motion cues. The therapy was tested on 12 ASD children, 4 out of 12 children fall under mild category whereas 8 fall under the minimal category of autism. The experimentation was conducted for 2 months. Total 8 experiments were conducted with 1 trial per week. Total 12 cues were given per trial, 4 cues corresponding to each category. In total 96 cues were given per subject, 32 cues from each category. The results indicate a general trend for linking a particular autism category with the most effective stimulus for that category. It can be concluded that visual cue (color variation) is the most effective reinforcement stimulus for children with minimal autism as 8 out of 8 i.e., 100% were more responsive to visual cues whereas for children with mild autism category, 3 out of 4 i.e., 75% are more receptive towards the motion stimulus. The parameters used for assessment were joint attention and the time eye contact is maintained. Single factor ANOVA was used for the statistical analysis of results with alpha is 0.05 and p-value 0.0342, F value is 3.7456 and F critical value is 3.2834. The test was performed on 96 (8x12) trails in total, therefore ensuring the significance and reliability of our results.

INDEX TERMS Autism spectrum disorder (ASD), reinforcement stimulus, robotic therapy, joint attention.

I. INTRODUCTION

Autism spectrum disorder (ASD) is characterized by atypical behaviors and developmental patterns in a child. Children with ASD lack in following major areas: (1) social communication and interaction, (2) non-verbal interaction used for social communication and (3) repetitive pattern of behaviors. The behavior of children with autism is unfortunately yet not fully understood by the general population [1]. This disorder affects 1 in 68 children in the United States [2]. Moreover there are no medical markers available for the diagnosis of this neurodevelopmental disorder among children rather it is based on the behavioral observation of clinical experts who evaluate the child based on different diagnostic scales and tests such as Diagnostic and Statistical Manual of Mental Disorders, currently DSM-V [3] and Autism Diagnostic Observation Schedule (ADOS) [4]. For children with autism, interacting with humans can lead to an uncomfortable situation for them rather than a face-to-face interaction with a robot. Research shows that improvement in joint attention and social skills of children with autism spectrum disorder is relatively higher when exposed to the robotic therapy rather than a human therapist [5], [6], and [7]. This is because the behavior of a robot is predictable and consistent, unlike humans. Moreover, sensor integration in robotic therapy can catch the slightest improvement that the human eye can neglect [8]. Improvement in behavior of ASD children with autism using robot's therapy leads to better perspectives to integrate into

The associate editor coordinating the review of this manuscript and approving it for publication was Ludovico Minati.

the society as they overcome their major impairments that results in better communication ability [9].

Currently, the research trends are more inclined towards the robot therapies for children with autism spectrum disorder both for diagnosis as well improvement in the behavior. There are various technologies to provide cognitive training in the treatment of autism spectrum disorder[10]. For example tablet computers an portable media players are used as speech generating devices for children with ASD [11], augmentative and alternative communication (AAC) interventions have shown effectiveness in order to enhance the communication functions of children with ASD [12] and various type of information technology platforms that are used in computer and robot-assisted therapies for children with autism [13]. The interest of a child with ASD in a robot is the key parameter for indulging him/her in the intervention. This depends on the size, shape, and appearance of the robot that can be anthropomorphic or zoomorphic [14], [15]. Because of the adaptiveness, low cost, accuracy, and mobility, humanoid robots are gaining attention [16].

Early research showed that learning strategies involving reinforcement helped in the improvement of social behavior of child such as social interaction [17], instruction following [18], object naming [19], and imitation [20], etc. These reinforcement learning (RL) strategies come under Applied Behavioral Analysis (ABA) treatment. ABA treatments utilize RL to reduce the atypical behavior of children with autism by improving communication and social skills. Other than the appearance of the robot, the effectiveness of communication in autism therapy is also dependent on the stimulus given to the child. A network of brain regions is sensitive to the hedonic value of stimulus [21]. A study based on touch and color for testing the effectiveness of communication between a robot and individual with ASD showed that participants achieved a better completion rate when color feedback was provided [22]. Another research shows that the abnormal touching behavior of a child with autism was because of his/her inability to understand social cues [23]. Therefore proper communication to improve the interaction is important before the child becomes aggressive [24]. Various researchers are using techniques such as oral naming [25] and ''echolalia'' [26] for a child's verbal repertoire [27]. Different tasks have been used to check the response of children towards affective stimulus such as viewing of static pictures [28], viewing of video clips, rating of emotional and non-emotional features [29]. However, in all these tasks, different physiological responses were quantified such as muscular movements and eye dilation etc. The evidence of the above research clearly states the necessity of a methodical approach for development of communication abilities of children with autism. The effectiveness of the treatment for autism can be enhanced if the interactive robotic system has the ability to evaluate a child's behavior and to respond to it accordingly [30], [17]. To improve the effectiveness of robotic interventions the robot behavior must match the communication skills of the individual child [31]. Therefore this research focuses on relating the particular type of reinforcement stimulus for each category of children with autism.

Several methodologies have been implemented to investigate the preference of children with autism for different types of stimuli. In research done by Gale, C.M. et al., preference for social and non-social stimulus was assessed using portable tablet computers [32]. Hanney NM et al., claims that in teaching methodology compound (auditory stimulus presented with visual cues) stimulus presentation was more effective than isolated (auditory stimulus presented without visual cues) [33]. The robot-child interaction allows the children with ASD to improve communication skills as the environment is highly predictable rather than a complex traditional one [34]. However, no research focuses on effective stimulus for robotic intervention. Therefore the ultimate goal of our research is to develop a method to find effective reinforcement stimulus for interactive robot for children with autism. The present study is an initial step toward relating a particular type of reinforcement stimulus with the autism category so to better facilitate them during the interaction. In this paper we have presented the results of three different stimuli i.e. visual (color variation), speech and motion stimuli to check the level of engagement of a child with autism based on stimulus. The visual cues include: rasta (changing eye color of the robot in cyclic manner) and blink, auditory cues are: hi and hello and motion cues include stand up and sit down along with the waving action. The goal of this research was to have a quantitative measure for the effectiveness of the given stimulus. Parameters used to access the effectiveness of the reinforcement stimulus were joint attention and time to maintain an eye contact of children with autism. The results of this research help in selecting the suitable reinforcement stimulus for robotic interventions to be used in the future for the improvement of autism spectrum disorder. These kinds of therapies are particularly useful as robots are more consistent and relatively immune to fatigue, unlike humans. Moreover, the data is recorded using robot's sensors rather than manual recording, therefore, ensuring the correctness of results.

A. PURPOSE OF STUDY

This study aims to identify the most effective robot's stimulus for interaction of children with ASD to facilitate better human-robot communication. For this purpose, the research focuses on testing the effectiveness of different reinforcement stimuli in a robotic intervention being given to ASD children. Three different reinforcement stimuli considered for this research are visual, auditory and motion stimuli. These three stimuli have been tested on two different categories of autism i.e. minimal and mild autism. This therapy is conducted to check: 1) inclination of ASD children towards any specific type of reinforcement stimulus and 2) whether the level of autism affects the choice of reinforcement stimulus or not?

The experiments were carried out on 12 children with ASD ranging on the spectrum from the minimum to the mild

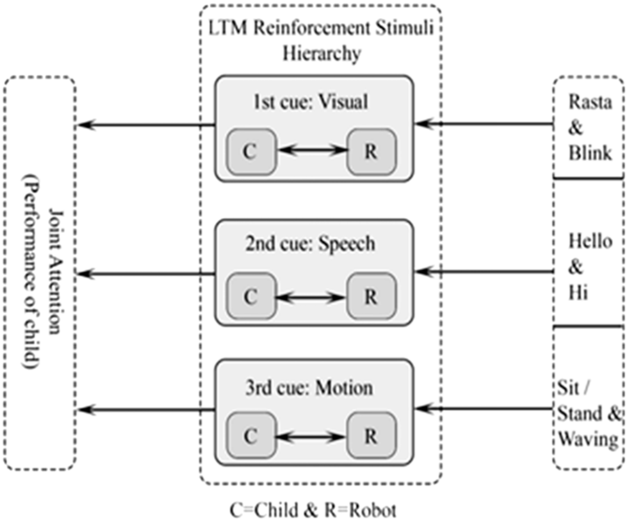

FIGURE 1. The architecture of the therapy conducted for comparing three different stimuli in a robotic intervention.

category. 4 out of 12 children had a medium spectrum, while the other eight had a severe autism spectrum. Each participant was given three different types of reinforcement stimuli. The maximum length of the experiment was 2 months, during which 8 experiments were carried out. Visual cues (color variation) includes rasta and blink, auditor cues include hi and hello by the robot and motion cues are represented by standing up and sitting down along with the waving.

The proposed therapy uses a NAO humanoid robot for ASD children. NAO is widely used for therapies in autism because of its anthropomorphic appearance [35], [36]. The robot is programmed to give three different kinds of stimuli to categorize the most effective stimulus for a particular level of autism.

Figure 1 explains about the intervention room which was divided into two parts using a wood partition. The networking protocol of this architecture includes a TCP server and corresponding two TCP clients. These TCP clients have been integrated with reinforcement stimuli module. All devices were communicating with each other using a WIFI network. Reinforcement stimuli module consists of three different types of stimuli i.e. visual, speech and motion stimulus. They were ordered from least to most i.e. color stimulus to motion stimulus to compare the effectiveness when presented to an ASD child in a robotic intervention as shown in Figure 2. In this research, the concept of least to most (LTM) refers to investigate the behavior of children with ASD by increasing the level of stimulus to observe the response with each type of stimulus presented. However, the effectiveness of particular type of stimulus was not known before hand. The experiments were conducted in order to investigate this concept.

II. SYSTEM ARCHITECTURE

A. FINITE STATE MACHINE MODEL

This Finite State Machine (FSM) diagram is representing three different states of the designed intervention system. These states are as follow:

1) Initialization
2) Execution (parallel modules joint attention and reinforcement module)
3) Termination

With the start of the intervention, the system gets into the initialization stage. The execution is started where two independent modules are running in parallel. These modules are joint attention module and TCP client integrated reinforcement stimulus module. Both of these modules are running on a NAO robot to notice the joint attention of ASD child. The information is written in a text file. After the execution

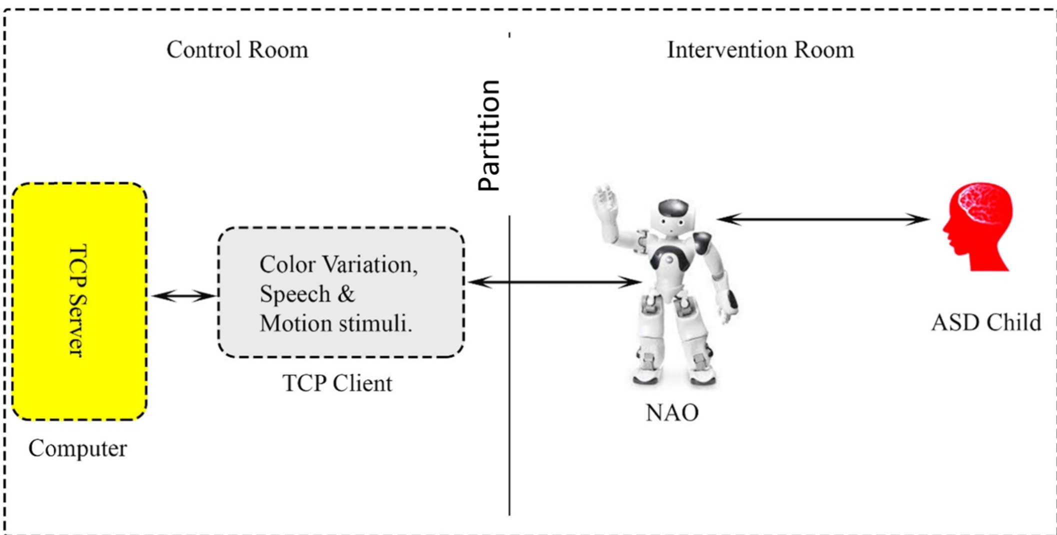

FIGURE 2. Least-to-most (LTM) hierarchy model for stimuli of the therapy.

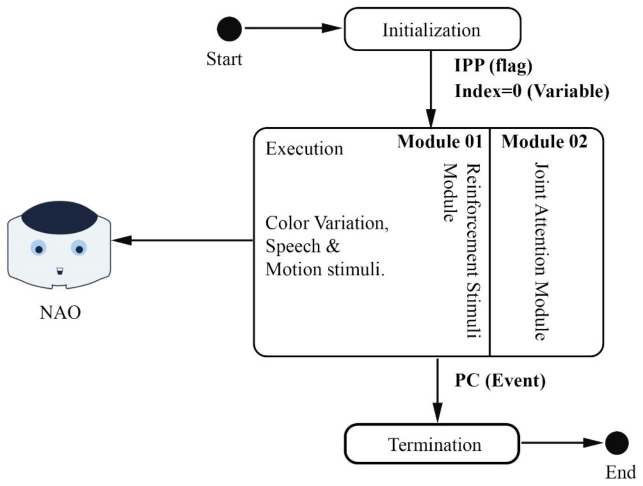

FIGURE 3. Finite State Machine (FSM) model for the therapy conducted to compare the effectiveness of different stimuli.

TABLE 1. Allowed state combinations.

U	Initialization	Execution	Termination
1	1	0	0
1	0	1	0
1	0	0	1

state is completed, the system goes in termination state, where the intervention is terminated. The discussed FSM model is shown in Figure 3 where IPP is the flag for person present and PC as an event called process completed.

B. MATHEMATICAL MODEL

The designed system can be at only one state at a given instant of time. XOR gate can represent the function of the complete system.

$$U = XOR\{Initialization,\ Execution,\ Termination\} \quad (1)$$

The binary variable U will only be 1 if any of the states of the 0parallel manner is not possible so following are the allowed combinations of bits of states as shown in Table 1. Rest all other combinations are not valid for this system. The joint attention module will be used to capture the information of gaze (eye contact) of the participant. It can be represented as:

$$JAM = \sum\nolimits_{i=1}^{n} \left(\int_{j=0}^{m} dt \right); \quad m, n \in \Re \quad (2)$$

The integral term, $\int_{J=0}^{m} dt$ is used to measure the time of eye contact while the summation term, $\sum_{i=1}^{n} (x)$ is used to add all the duration of each eye contact and tells about the total time of eye contact. The reinforcement stimuli module is responsible for different stimulus to be executed. It can be represented as,

$$RSM = \sum\nolimits_{y=1}^{n} \left(RS_y\right); \quad n \in \Re \wedge n \leq 3 \quad (3)$$

RS_y represents different reinforcement stimulus. It can be represented as,

$$RS_y = \begin{cases} Visual; & y = 1 \\ Speech; & y = 2 \\ Motion; & y = 3 \end{cases} \quad (4)$$

The execution state consists of two different modules. These modules run in a parallel manner. So, this operation can be represented by an "AND" operation.

$$Exe\_State = AND\,(JAM, RSM) \quad (5)$$

where, JAM is an abbreviation of joint attention module and RSM is an abbreviation of reinforcement stimulus module. The inputs to equation 5 are condition of modules in Boolean form (working / not working).

C. PSEUDO CODE

Where Present_Stimulus(): extracts the information of the current stimulus to be executed. Robot_Behavior(): defines the behavior of the robot using any type of stimulus.Participant_Joint_Attention(): extracts the information of the participant's joint attention during the intervention when a particular stimulus is given. Push(): appends data at the end of the list (Person_Joint_Attention).Write_File(): write the file and extracts information. Terminate(): close/terminate all the processes running i.e. threads.

III. MATERIALS AND METHODS

```
Robot_Stimuli_List={ "Visual", "Speech", "Motion"};
Person_Joint_Attention [3];
Initialization:
Is_Person_Present, Index;
Execution:
Step 01:
If(Is_Person_Present)
        Sumulus = Presenl_Stimulus
(Robot_Stimuli_List (Index));
        Robot_Behavior (Stimulus),
        While(Robot_Behavior)
        {
          JA=Participant_Joint_Anention ();
          Person_Joint_Attention[Index]_push(JA),
        }
        If (index—length(Robot_Stimuli_List)−l)
        Go To Step03;
Step 02:
Index++;
Go To Step01;
Termination:
Step 03:
Write_Fite (Robot_Stimuh_List, Partici-
pant_Joint_Attention);
Terminate ();
```

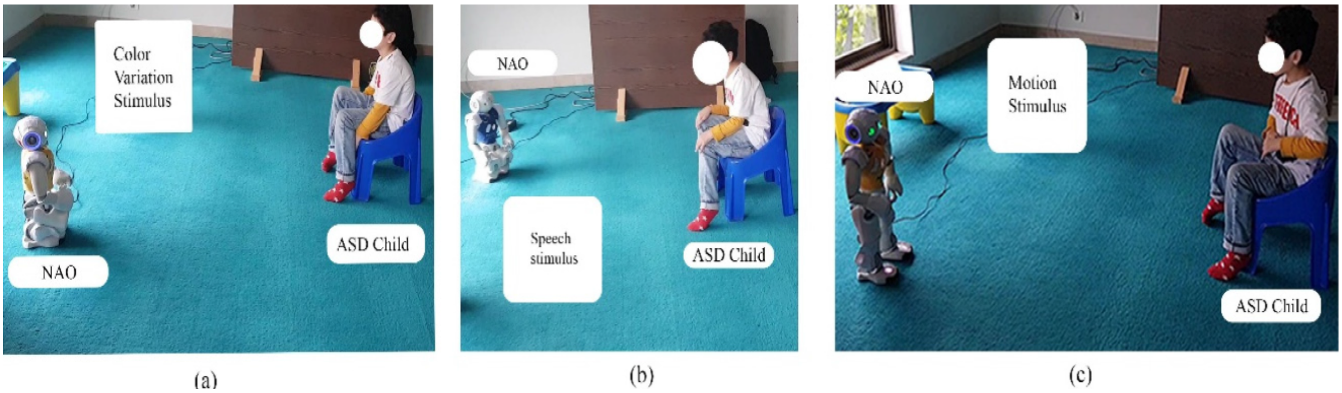

FIGURE 4. **Intervention pictures (a) Visual stimuli (b) Auditory stimuli (c) Motion stimuli.**

A. PARTICIPANTS

12 ASD children (11 males and 1 female) ranging from age of 4.1 to 10.10 years participated in the therapy. The mean age for mild category is 7.73 years and for the minimal category mean age is 8.42 years. These participants were recruited from the Autism Resource Center (ARC), Islamabad, Pakistan. The participants are already accessed on a clinical scale childhood autism rating scale score (CARS). The therapy was approved by the specialist and director board of Autism Resource Center.

B. ETHICS STATEMENT

The present study was approved by the ethics committee of the Autism Resource Center (ARC). All participants were recruited from the Autism Resource Center (ARC), Islamabad, Pakistan. This study involves human participants and all the experimentation was conducted according to the ethical standards of the institutional and/or national research committee and the 1964 Helsinki Declaration and its subsequent amendments or comparable ethical standards. All the subjects participated voluntarily and written consent was provided by their parents before the experimental procedures.

C. EXPERIMENTAL SETUP AND PROCEDURE

Figure 4 shows the environmental setup for the proposed therapy. The robot was placed in front of the child at a distance of 1m. Before the start of the module, the child sits on a comfortable plastic chair to attain an appropriate height for making eye contact with the robot.

The proposed architecture and mathematical model of this therapy are discussed above. Before the start of intervention, the ASD child is taken to the intervention room for some reinforcement activity. For this, the child sits on a comfortable chair and counts from 1 to 10. After that, the child is familiarized with the robot. The robot stands up and says ''hello'' along with the waving action of the robot. During these experiments, no data is recorded as it was to familiarize the ASD child with the robot. After a gap to this introductory session, the robot starts with the proposed intervention. The robot presents three different reinforcement stimuli in the therapy i.e., visual (color variation), auditory and motion cues. The reinforcement stimulus presented by the robot is in least-to-most (LTM) order to check the effectiveness of each cue based on the joint attention of a child. For each participant, 12 cues (4 for each category) were given to the ASD child in a single experiment and the response was reported for each signal in the form of joint attention and time for which the eye contact was created. The treatment was administered for a span of 2 months on 12 children with ASD. Eight experiments, i.e. 1 experiment per week, were carried out. Average time was approved for each session was approximately 15 minutes excluding the time consumed in reinforcement activity during the introductory session. There were instances during the therapy when an ASD child would not be feeling comfortable to participate in the intervention or was absent. In such case, the same session was held on any other day of the week to make sure that 8 sessions per child have been completed. This strategy for ensuring full participation in experiments was followed from [37].

IV. RESULT

The results obtained from the therapy shows that among visual (color-based), auditory and motion-based reinforcement stimuli, visual stimulus is the most effective and speech is the least effective one. Table 2 shows the average accuracies of all subjects against each type of stimulus and their sensitivities. Moreover, average eye contact time given to each stimulus by different subjects is shown in Table 3. The joint attention is measured on the basis of number of times the eye contact is made with the robot when a stimulus was given. The average success rate of each subject against all stimuli is shown in Figure 5. Figure 5 represents the performance of all subjects against three different categories of reinforcement stimuli. It can be seen that visual stimulus is dominating as compared to speech and motion-based reinforcement stimuli. If we further move on, we can also see the motion is more sensitive as compare to speech-based reinforcement stimulus.

TABLE 2. Average accuracies of all subjects against each type of stimuli and their sensitivities.

Subjects	Age (YY-MM)	Autism case	Total cues	Accuracies			Most sensitive towards
				Visual	Auditory	Motion	
S1	7.11	Mild	12	66.30	56.32	68.23	Motion stimuli
S2	8.6	Minimal	12	77.34	67.94	61.25	Visual stimuli
S3	9.6	Minimal	12	66.93	59.18	52.73	Visual stimuli
S4	10.6	Minimal	12	59.64	37.60	43.75	Visual stimuli
S5	5.6	Mild	12	65.63	68.20	69.92	Motion stimuli
S6	8.11	Mild	12	65.84	65.52	66.88	Motion stimuli
S7	4.9	Minimal	12	69.05	57.68	62.50	Visual stimuli
S8	4.1	Minimal	12	93.23	83.34	78.97	Visual stimuli
S9	10.3	Minimal	12	90.23	81.34	74.97	Visual stimuli
S10	10.2	Minimal	12	83.85	70.99	61.72	Visual stimuli
S11	10.10	Mild	12	88.98	73.52	65.94	Visual stimuli
S12	9.10	Minimal	12	82.81	45.70	74.22	Visual stimuli

TABLE 3. Average eye contact time given to each stimulus by different subjects.

Subjects	Visual stimulus time (seconds)	Speech stimulus time (seconds)	Motion-based stimulus time (seconds)	Highest time	Lowest time
S1	76.69	98.81	47.63	Speech	Motion
S2	70.50	104.81	53.19	-do-	-do-
S3	84.25	117.75	54.13	-do-	-do-
S4	72.13	78.75	38.50	-do-	-do-
S5	66.50	94.19	49.31	-do-	-do-
S6	92.13	129.88	74.44	-do-	-do-
S7	66.93	92.93	48.64	-do-	-do-
S8	69.00	95.63	45.88	-do-	-do-
S9	63.07	87.03	42.04	-do-	-do-
S10	54.25	54.25	24.25	-do-	-do-
S11	70.00	93.50	42.50	-do-	-do-
S12	77.31	119.38	51.38	-do-	-do-

The relationship between different categories of reinforcement stimuli is shown in Figure 6. In these three subplots, we can see that most of the data points are present on the extreme top right corner which is the indication that ASD subjects are performing well in different types of reinforcement stimuli with small changes. If we compare the autism category wise performance, we find that ASD children with minimal autism are performing well as compared to ASD children with the mild category. The highest and lowest performance against each type of reinforcement stimulus has been shown by minimal autism case while mild autism cases cannot be generalized. However, the performance of mild cases is above average.

V. STATISTICAL ANALYSIS

ANOVA (single factor) was used as a statistical analysis technique. The chosen level of alpha is 0.05 and p-value (which comes out) is 0.0342 which is less than the set value of alpha. Moreover, the F value is 3.7456 and F critical value is 3.2834.i.e., F value obtained is also greater than F critical

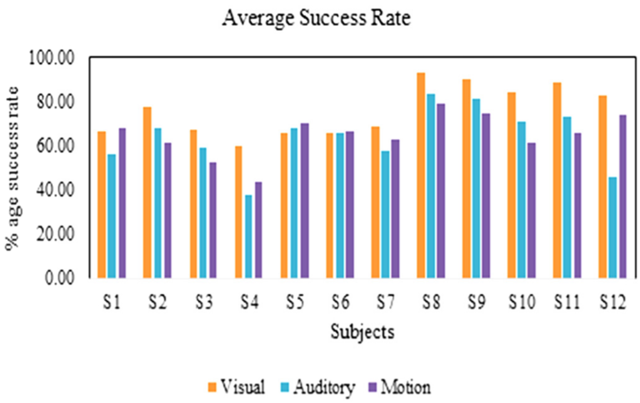

FIGURE 5. Average success rate of each subject against all stimuli.

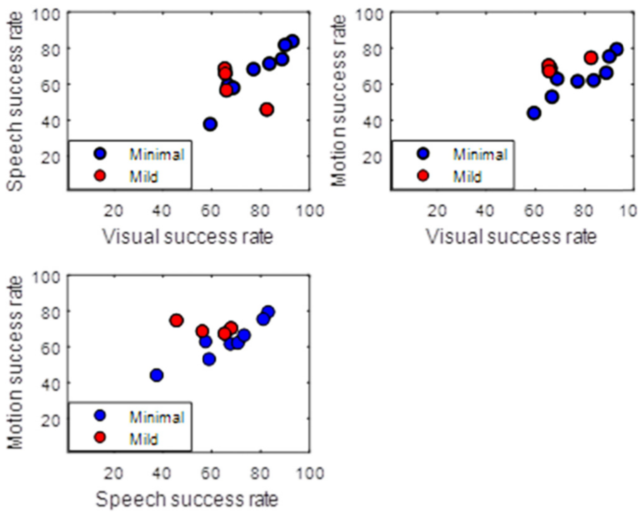

FIGURE 6. Intra stimulus comparisons for ASD children representing relationship among different reinforcement stimuli of each subject.

value therefore results/reading obtained are statistically significant.

The single factor ANOVA was used as statistical analysis technique for average accuracy of 8 experiments for each of the 12 subjects. Therefore the values written represent 12* 8 = 96 experiments in total. The average accuracy for each stimulus by subjects is discussed in Table 2 and is shown in Figure 7.

Furthermore, post-hoc test (ANOVA single factor for each combination) has been performed to find the significant difference between different categories. From post-hoc test, it was found that the difference between visual vs speech ($p = 0.030 < 0.05$), and visual vs motion ($p = 0.022 < 0.05$) was significant.

We conducted the two factor ANOVA without replication. The two factors considered in this case are type of stimulus and category of autism. It was found that types of stimuli are statistically significant (p-value = 0.00016). Furthermore, type of autism/category of autism are also statistically significant (p-value = 0.00076). Moreover, power analysis test has

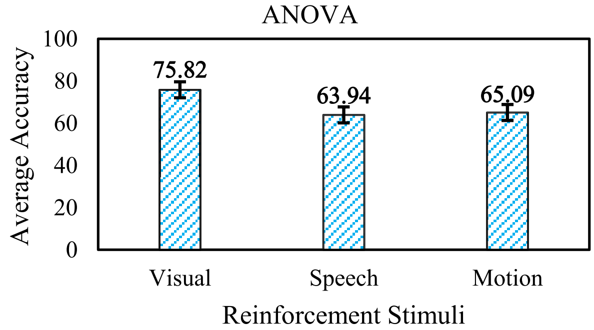

FIGURE 7. ANOVA (single factor) results for the intervention.

also been performed to know the type II (beta) error. In this case probability of type II (beta) error is 0.089 and power is 0.9101.

VI. DISCUSSION

As discussed in the literature review, various studies have been done working on effective communication of interactive robotic therapies. Research has been done on robot-animal interaction that can be used as a test bench for human-robot interaction in future [38]. Moreover, the robots are also used as demonstrators in social learning experiments [39]. Moreover, some animals resulted to have similar features in different neural circuit organization, making them valuable models to test neurological diseases in humans [40], [41], [42]. However, these therapies do not focus on checking the effectiveness of different types of stimuli that can be generated by a robot during the therapy. Unlike previous researches, our proposed therapy checks the effectiveness of three different stimuli i.e., visual (color variation), auditory and motion stimuli on 12 ASD children for a period of 2 months.

Comparing the two columns of Table 2 i.e., autism case and sensitivity column, there can be seen a general trend. Almost all minimal autism cases were deviated or receptive to visual stimulus (color variation) and all other mild cases were inclined towards physical motion stimulus except the S11 case. The results obtained from the therapy shows that among visual (color-based), auditory and motion-based reinforcement stimuli, visual stimulus is the most effective and speech stimulus is the least effective one. Although the color based variation i.e., visual reinforcement cue seems not so prominent but it has been found that often the concentration of children with ASD is on very small details rather than seeing the whole situation [43].

Some advantage of the proposed models includes: 1) no sensor that touches the body of the child during the intervention to make the child uncomfortable. 2) Chances of error been reduced as the behavior of the child is recorded using sensors such as joint attention of the child is recorded using NAO cameras, ensuring the correctness of results. 3) Another advantage of this model is that it does not require the continuous involvement of a human therapist. Unlike robots, for any person, it is impossible to work for extended hours continuously. Moreover, these robotic therapies can also be conducted at home however affordability of the robot is a factor that should be kept in mind for these therapies. However keeping in view the non-human participation, it has certain disadvantages specifically if the child gets frustrated, how to situation will be managed?

Robot-mediated therapies have some drawbacks e.g. trust issues of parents with these robots, the adaptation of activities to each child as this can complicate the use of robots in schools and institutes. However, there are some open-ended questions e.g. what is the best way to integrate a robot in a therapy [17]? 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. This research is a step toward this concept in which the focus is to investigate the simulation type that a particular child is more responsive to so that it can be incorporated in the adaptive therapies. A solution towards this can be making therapies that have levels for each of the specific core impairment.

VII. CONCLUSION

In this article, we have proposed a therapy to find the effective stimulus given by the robot to improve the efficiency of communication for robotic interventions. Based on the results the main contribution of this research is to find the most effective stimulus among three i.e., visual (color variation), auditory and motion stimuli based on the level of autism. The purpose of this research is enhancing the communication effectiveness of robotic therapy for children with autism spectrum disorder. The therapy was conducted on 12 ASD children ranging from minimal to mild on the spectrum of autism as indicated by the Autism Resource Center (ARC). Out of 12 ASD children, 4 were on mild category whereas the remaining 8 of them were under minimal cases. The reinforcement stimuli used for comparison were visual stimulus (color variation): rasta and blink, auditory stimulus: hi and hello and motion stimulus: stand up and sit down along with waving action by the robot. The experimentation was conducted for 2 months. Total 8 experiments were conducted with 1 trial per week so to ensure the participation of every subject in each experiment. Each trial was conducted with 12 cues corresponding to 4 cues per reinforcement stimulus.

The results show that there is a general trend of choosing the effective stimulus that is linked with the autism category. It is seen that the minimal cases of autism are mostly responsive towards visual stimulus (color variation) whereas the mild category for autism is inclined towards physical motion stimulus except for one case i.e., S11. The parameters used to find the most effective stimulus in this research are the joint attention of the child (recorded by NAO cameras) and time given to each stimulus. Based on the results it can be concluded that the response to a certain stimulus is depended on the category of autism.

The advantage of this model is that it does not require any body-worn sensors during intervention therefore the children are comfortable during the intervention. Moreover, the results are based on values recorded by sensors rather than manual recording, therefore, reducing the chance of error and ensuring correctness of results.

REFERENCES

[1] R. S. Kirby, M. S. Wingate, K. Van Naarden Braun, N. S. Doernberg, C. L. Arneson, R. E. Benedict, B. Mulvihill, M. S. Durkin, R. T. Fitzgerald, M. J. Maenner, J. A. Patz, and M. Yeargin-Allsopp, "Prevalence and functioning of children with cerebral palsy in four areas of the United States in 2006: A report from the Autism and Developmental Disabilities Monitoring Network," *Res. Develop. Disabilities*, vol. 32, no. 2, pp. 462–469, Mar. 2011.

[2] Z. Zheng, E. M. Young, A. R. Swanson, A. S. Weitlauf, Z. E. Warren, and N. Sarkar, "Robot-mediated imitation skill training for children with autism," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 24, no. 6, pp. 682–691, Jun. 2016.

[3] American Psychiatric Association, "Diagnostic and statistical manual of mental disorders," *BMC Med.*, vol. 17, pp. 133–137, 2013.

[4] C. Lord, M. Rutter, P. C. DiLavore, and S. Risi, *Autism Diagnostic Observation Schedule*. Los Angeles, CA, USA: Western Psychological Services, 2002.

[5] C. Lord, "The autism diagnostic observation schedule–generic: A standard measure of social and communication deficits associated with the spectrum of autism," *J. Autism Develop. Disorders*, vol. 30, no. 3, pp. 205–223, 2000.

[6] M. Begum, R. W. Serna, and H. A. Yanco, "Are robots ready to deliver autism interventions? A comprehensive review," *Int. J. Soc. Robot.*, vol. 8, no. 2, pp. 157–181, Apr. 2016.

[7] B. Scassellati, H. Admoni, and M. Matarić, "Robots for use in autism research," *Annu. Rev. Biomed. Eng.*, vol. 14, no. 1, pp. 275–294, Aug. 2012.

[8] B. Robins, E. Ferrari, K. Dautenhahn, G. Kronreif, B. Prazak-Aram, G.-J. Gelderblom, B. Tanja, F. Caprino, E. Laudanna, and P. Marti, "Human-centred design methods: Developing scenarios for robot assisted play informed by user panels and field trials," *Int. J. Hum.-Comput. Stud.*, vol. 68, no. 12, pp. 873–898, Dec. 2010.

[9] F. Petric, K. Hrvatinic, A. Babic, L. Malovan, D. Miklic, Z. Kovacic, M. Cepanec, J. Stosic, and S. Simlesa, "Four tasks of a robot-assisted autism spectrum disorder diagnostic protocol: First clinical tests," in *Proc. IEEE Global Humanitarian Technol. Conf. (GHTC)*, Oct. 2014, pp. 510–517.

[10] S. V. Wass and K. Porayska-Pomsta, "The uses of cognitive training technologies in the treatment of autism spectrum disorders," *Autism*, vol. 18, no. 8, pp. 851–871, Nov. 2014.

[11] E. R. Lorah, A. Parnell, P. S. Whitby, and D. Hantula, "A systematic review of tablet computers and portable media players as speech generating devices for individuals with autism spectrum disorder," *J. Autism Develop. Disorders*, vol. 45, no. 12, pp. 3792–3804, Dec. 2015.

[12] K. Logan, T. Iacono, and D. Trembath, "A systematic review of research into aided AAC to increase social-communication functions in children with autism spectrum disorder," *Augmentative Alternative Commun.*, vol. 33, no. 1, pp. 51–64, Jan. 2017.

[13] J. Dipietro, A. Kelemen, Y. Liang, and C. Sik-Lanyi, "Computer- and robot-assisted therapies to aid social and intellectual functioning of children with autism spectrum disorder," *Medicina*, vol. 55, no. 8, p. 440, Aug. 2019.

[14] A. J. Esbensen, M. M. Seltzer, K. S. L. Lam, and J. W. Bodfish, "Age-related differences in restricted repetitive behaviors in autism spectrum disorders," *J. Autism Develop. Disorders*, vol. 39, no. 1, pp. 57–66, Jan. 2009.

[15] S. B. Sial, M. B. Sial, Y. Ayaz, S. I. A. Shah, and A. Zivanovic, "Interaction of robot with humans by communicating simulated emotional states through expressive movements," *Intell. Service Robot.*, vol. 9, no. 3, pp. 231–255, Jul. 2016.

[16] J. Wainer, B. Robins, F. Amirabdollahian, and K. Dautenhahn, "Using the humanoid robot KASPAR to autonomously play triadic games and facilitate collaborative play among children with autism," *IEEE Trans. Auton. Mental Develop.*, vol. 6, no. 3, pp. 183–199, Sep. 2014.

[17] J. J. Diehl, L. M. Schmitt, M. Villano, and C. R. Crowell, "The clinical use of robots for individuals with autism spectrum disorders: A critical review," *Res. Autism Spectr. Disorders*, vol. 6, no. 1, pp. 249–262, Jan. 2012.
[18] M. Wolf, T. Risley, and H. Mees, "Application of operant conditioning procedures to the behaviour problems of an autistic child," *Behav. Res. Therapy*, vol. 1, nos. 2–4, pp. 305–312, 1963.
[19] G. C. Davison, "A social learning therapy programme with an autistic child," *Behav. Res. Therapy*, vol. 2, nos. 2–4, pp. 149–159, 1964.
[20] G. Martin, G. England, E. Kaprowy, K. Kilgour, and V. Pilek, "Operant conditioning of kindergarten-class behavior in autistic children," *Behav. Res. Therapy*, vol. 6, no. 3, pp. 281–294, Aug. 1968.
[21] J. Richard Metz, "Conditioning generalized imitation in autistic children," *J. Experim. Child Psychol.*, vol. 2, no. 4, pp. 389–399, Dec. 1965.
[22] O. Bartra, J. T. Mcguire, and J. W. Kable, "The valuation system: A coordinate-based meta-analysis of BOLD fMRI experiments examining neural correlates of subjective value," *NeuroImage*, vol. 76, pp. 412–427, Aug. 2013.
[23] J. Lee, H. Takehashi, C. Nagai, G. Obinata, and D. Stefanov, "Enhancement of the communication effectiveness of interactive robots for autism therapy by using touch and colour feedback," *Paladyn., J. Behav. Robot.*, vol. 5, no. 1, pp. 53–63, 2014.
[24] J. H. Foss-Feig, J. L. Heacock, and C. J. Cascio, "Tactile responsiveness patterns and their association with core features in autism spectrum disorders," *Res. Autism Spectr. Disorders*, vol. 6, no. 1, pp. 337–344, Jan. 2012.
[25] E. G. Carr and V. M. Durand, "Reducing behavior problems through functional communication training.," *J. Appl. Behav. Anal.*, vol. 18, no. 2, pp. 111–126, 1985.
[26] J.-P. Leung and K.-I. Wu, "Teaching receptive naming of chinese characters to children with autism by incorporating echolalia," *J. Appl. Behav. Anal.*, vol. 30, no. 1, pp. 59–68, Mar. 1997.
[27] R. Stromer, H. A. Mackay, and B. Remington, "Naming, the formation of stimulus classes, and applied behavior analysis," *J. Appl. Behav. Anal.*, vol. 29, no. 3, pp. 409–431, Sep. 1996.
[28] M. Chesnut, P. N. Williamson, and J. E. Morrow, "The use of visual cues to teach receptive skills to children with severe auditory discrimination deficits.," *Behav. Anal. Today*, vol. 4, no. 2, pp. 212–224, Dec. 2014.
[29] J. L. Wilbarger, D. N. Mcintosh, and P. Winkielman, "Startle modulation in autism: Positive affective stimuli enhance startle response," *Neuropsychologia*, vol. 47, no. 5, pp. 1323–1331, Apr. 2009.
[30] B. Hubert, B. Wicker, E. Monfardini, and C. Deruelle, "Electrodermal reactivity to emotion processing in adults with autistic spectrum disorders," *Autism*, vol. 13, no. 1, pp. 9–19, Jan. 2009.
[31] J. Lee, H. Takehashi, C. Nagai, G. Obinata, and D. Stefanov, "Which robot features can stimulate better responses from children with autism in robot-assisted therapy?" *Int. J. Adv. Robotic Syst.*, vol. 9, no. 3, p. 72, Sep. 2012.
[32] C. M. Gale, S. Eikeseth, and L. Klintwall, "Children with autism show atypical preference for non-social stimuli," *Sci. Rep.*, vol. 9, no. 1, 2019, Art. no. 10355.
[33] N. M. Hanney, J. E. Carr, and L. A. Leblanc, "Teaching children with autism spectrum disorder to tact auditory stimuli," *J. Appl. Behav. Anal.*, vol. 52, no. 3, pp. 733–738, Jul. 2019.
[34] S. M. Srinivasan, I. K. Park, L. B. Neelly, and A. N. Bhat, "A comparison of the effects of rhythm and robotic interventions on repetitive behaviors and affective states of children with Autism Spectrum Disorder (ASD)," *Res. Autism Spectr. Disorders*, vol. 18, pp. 51–63, Oct. 2015.
[35] S. Ali, F. Mehmood, D. Dancey, Y. Ayaz, M. J. Khan, N. Naseer, R. D. C. Amadeu, H. Sadia, and R. Nawaz, "An adaptive multi-robot therapy for improving joint attention and imitation of ASD children," *IEEE Access*, vol. 7, pp. 81808–81825, 2019.
[36] F. Mehmood, Y. Ayaz, S. Ali, R. De Cassia Amadeu, and H. Sadia, "Dominance in visual space of ASD children using multi-robot joint attention integrated distributed imitation system," *IEEE Access*, vol. 7, pp. 168815–168827, 2019.
[37] E. T. Bekele, U. Lahiri, A. R. Swanson, J. A. Crittendon, Z. E. Warren, and N. Sarkar, "A step towards developing adaptive robot-mediated intervention architecture (ARIA) for children with autism," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 21, no. 2, pp. 289–299, Mar. 2013.
[38] D. Romano, E. Donati, G. Benelli, and C. Stefanini, "A review on animal–robot interaction: From bio-hybrid organisms to mixed societies," *Biol. Cybern.*, vol. 113, no. 3, pp. 201–225, Jun. 2019.
[39] J. Krause, A. F. Winfield, and J.-L. Deneubourg, "Interactive robots in experimental biology," *Trends Ecol. Evol.*, vol. 26, no. 7, pp. 369–375, Jul. 2011.
[40] D. Romano, G. Benelli, and C. Stefanini, "Encoding lateralization of jump kinematics and eye use in a locust via bio-robotic artifacts," *J. Exp. Biol.*, vol. 222, no. 2, Jan. 2019, Art. no. jeb187427.
[41] R. J. Clément, S. Macrì, and M. Porfiri, "Design and development of a robotic predator as a stimulus in conditioned place aversion for the study of the effect of ethanol and citalopram in zebrafish," *Behav. Brain Res.*, vol. 378, Jan. 2020, Art. no. 112256.
[42] G. Polverino, M. Karakaya, C. Spinello, V. R. Soman, and M. Porfiri, "Behavioural and life-history responses of mosquitofish to biologically inspired and interactive robotic predators," *J. Roy. Soc. Interface*, vol. 16, no. 158, Sep. 2019, Art. no. 20190359.
[43] F. J. Scott and S. Baron-Cohen, "Imagining real and unreal things: Evidence of a dissociation in autism," *J. Cognit. Neurosci.*, vol. 8, no. 4, pp. 371–382, Oct. 1996.

SARA ALI received the M.Sc. degree in robotics from Middlesex University London. She is currently pursuing the Ph.D. degree in robotics and intelligent machine engineering with the National University of Sciences and Technology (NUST), Pakistan. She is working as an Assistant Professor with the School of Mechanical and Manufacturing Engineering (SMME), NUST, Pakistan. Her research interests include human–robot interaction and brain computer interface (BCI).

FAISAL MEHMOOD received the B.Eng. degree in electrical engineering from the COMSATS Institute of Information Technology and the M.Eng. degree in robotics and intelligent machine engineering from the National University of Sciences and Technology (NUST), Pakistan, in 2016 and 2018, respectively. He is currently pursuing the Ph.D. degree with Osaka University, Japan. He worked as a Research Engineer with the School of Mechanical and Manufacturing Engineering (SMME), NUST, Islamabad, Pakistan. His research interests include human–robot interaction (HRI), therapeutic robotics (TR), and brain computer interface (BCI).

YASAR AYAZ (Senior Member, IEEE) received the Ph.D. degree in robotics and machine intelligence from Tohoku University, Japan, in 2009. He is currently the Chairman and Central Project Director of the National Center of Artificial Intelligence (NCAI), Pakistan, and also the Head of the Department of Robotics and Intelligent Machine Engineering, NUST, Pakistan. He is also a Specially-Appointed Associate Professor at the Graduate School of Engineering, Tohoku University, Sendai, Japan. His research interests include human–machine interaction, humanoids, and motion planning.

MUHAMMAD JAWAD KHAN received the B.E. and M.S. degrees in mechatronics engineering from Air University, Pakistan, in 2007 and 2010, respectively, and the Ph.D. degree in mechanical engineering from Pusan National University, South Korea, in 2018. He worked on hybrid EEG-fNIRS-based BCI for rehabilitation during his Ph.D. He is currently working as an Assistant Professor with SMME, NUST, Pakistan. His research interests include hybrid brain-computer interfacing, rehabilitation, and machine learning.

HALEEMA SADIA received the M.A. degree in special education, mental retardation from the Department of Special Education, in 2008, and the M.Ed. degree in autism (children) from the University of Birmingham, U.K., in 2012. She has also worked with the Human Development Research Foundation (HDRF), London, U.K., and Oasis Trust, Sharif Medical Complex, Pakistan. She is currently working as the Director of the Autism Resource Centre, Islamabad. Pakistan.

RAHEEL NAWAZ is currently the Director of Digital Technology Solutions and Reader in Analytics and Digital Education with Manchester Metropolitan University (MMU). Before becoming a full-time academic, he served in various senior leadership positions in the private higher and further education sector, and he was an army officer before that. He has founded and/or headed several research units specializing in artificial intelligence, digital transformations, data science, digital education, and apprenticeships in higher education. He has led on numerous funded research projects in the U.K., EU, South Asia, and Middle East. He holds adjunct or honorary positions with several research, higher education, and policy organizations, both in the U.K. and overseas. He regularly makes media appearances and speaks on a range of topics including digital technologies, artificial intelligence, digital literacy, and higher education.