Multi-Robot Interactive Therapy for Children with Autism Spectrum Disorder

By

Sara Ali

(Registration No: 00000238671)

Thesis Supervisor: Dr. Yasar Ayaz

Department of Robotics and Intelligent Machine Engineering

School of Mechanical and Manufacturing Engineering

National University of Sciences and Technology

Islamabad, Pakistan

(2020)

Multi-Robot Interactive Therapy for Children with Autism Spectrum Disorder

By

Sara Ali

(Registration No: 00000238671)

A thesis submitted to the National University of Sciences and Technology, Islamabad,

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy in

Robotics and Intelligent Machine Engineering

Thesis Supervisor: Dr. Yasar Ayaz

Department of Robotics and Intelligent Machine Engineering

School of Mechanical and Manufacturing Engineering

National University of Sciences & Technology (NUST)

Islamabad, Pakistan

(2020)

THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of PhD Thesis written by Ms Sara Ali, (Registration No. 00000238671), of School of Mechanical and Manufacturing Engineering has been vetted by undersigned, found complete in all respects as per NUST Statutes / Regulations / PhD Policy, is free of plagiarism, errors, and mistakes and is accepted as partial fulfillment for award of PhD degree. It is further certified that necessary amendments as pointed out by GEC members and foreign/local evaluators of the scholar have also been incorporated in the said thesis.

Signature: ______________________________

Name of Supervisor: Dr. Yasar Ayaz______________

Date: ______________________________

Signature (HOD): ______________________________

Date: ______________________________

Signature (Dean/Principal): ______________________

Date: ______________________________

Annex L
Form PhD-7
DOCTORAL PROGRAM
OF STUDY
(Must be type written)

National University of Sciences & Technology, Islamabad

REPORT OF DOCTORAL THESIS DEFENCE

Name: **Sara Ali** NUST Regn No: **00000238671**

School/College/Center: School of Mechanical and Manufacturing Engineering (SMME)

Title: "Multi-Robot Interactive Therapy for Children with Autism Spectrum Disorder".

DOCTORAL DEFENSE COMMITTEE

Doctoral Defense Held on: 14th September 2020

Member	QUALIFIED		NOT QUALIFIED		Signature
GEC Member 1: Dr. Hasan Sajid	QUALIFIED		NOT QUALIFIED		Signature ____________
GEC Member 2: Dr. Muhammad Jawad Khan	QUALIFIED		NOT QUALIFIED		Signature ____________
GEC Member (Ext): Dr. Noman Naseer	QUALIFIED		NOT QUALIFIED		Signature ____________
Supervisor: Dr. YasarAyaz	QUALIFIED		NOT QUALIFIED		Signature ____________
External Evaluator 1: Dr. Adeel Mehmood (Local Expert)	QUALIFIED	✓	NOT QUALIFIED		Signature ____________
External Evaluator 2: Dr. Muhammad Uzair Khan (Local Expert)	QUALIFIED	✓	NOT QUALIFIED		Signature ____________
External Evaluator 3: Dr.Mannan Saeed Muhammad (Foreign Expert*)	QUALIFIED	✓	NOT QUALIFIED		Signature ____________
External Evaluator 4: Dr. Muhammad Raheel Afzal (Foreign Expert*)	QUALIFIED	✓	NOT QUALIFIED		Signature ____________

FINAL RESULT OF THE DOCTORAL DEFENSE
(Approximate box to be signed by HOD)

☐ **PASS** ☐ **FAIL**

The student Sara Ali Regn No: 00000238671 is accepted for Doctor of Philosophy Degree.

Dated: ____________

____
Dean/Commandant/Principal

Distribution:

1 x copy each for Director PGP, Registrar Directorate (Examination Branch), Director Research, Director Academics at Main Office, NUST, HoD, Supervisor, Co-Supervisor (if appointed), one for student's dossier at the Institution and copy each for members of GEC.

Note:* Decision of External Evaluators (Foreign Experts) will be sought through video conference, if possible, on the same date and their decision will be intimated (on paper) to Main Office, NUST at a later date.

Certificate of Approval

This is to certify that the research work presented in this thesis titled "Multi-Robot Interactive Therapy for Children with Autism Spectrum Disorder" was conducted by Ms. Sara Ali under the supervision of Dr. Yasar Ayaz.

No part of this thesis has been submitted anywhere else for any degree. This thesis is submitted to the School of Mechanical and Manufacturing Engineering in partial fulfillment of the requirements for the degree of **Doctor of Philosophy** in the field of Robotics and Intelligent Machine Engineering, Department of Robotics and Intelligent Machine Engineering, School of Mechanical and Manufacturing Engineering (SMME).

Student Name: **Ms. Sara Ali** Signature: _______________

Examination Committee:

(a) External Examiner 1:Dr. Adeel Mehmood Signature: _______________
(Designation and Official Address)
Assistant Professor, Department of Electrical and Computer Engineering, COMSATS University, Islamabad, Pakistan.

(b) External Examiner 2: Dr. Muhammad Uzair Khan Signature: _______________
(Designation and Official Address)
Assistant Professor, Software Quality Assurance and Testing Laboratory (QUEST), National University of Computer and Emerging Sciences, Islamabad, Pakistan.

(c) Internal Examiner: Dr. Muhammad Jawad Khan Signature:______________
(Designation and Official Address)
Assistant Professor, School of Mechanical and Manufacturing Engineering, National University of Sciences and Technology, Islamabad, Pakistan

Supervisor Name: Dr. Yasar Ayaz Signature: ________________

Name of Dean/ HoD: Dr. Shahid Ikramullah Butt Signature: ________________

Author’s Declaration

I, Sara Ali here by state that my PhD thesis titled “Multi-Robot Interactive Therapy for Children with Autism Spectrum Disorder” is my own work and has not been submitted previously by me for taking any degree from National University of Sciences and Technology (NUST) Or anywhere else in the country/world.

At any time if my statement is found to be incorrect even after my graduation, the university has right to withdraw my PhD degree.

.

Name of Student: Sara Ali

Date: ________________

Plagiarism Undertaking

I solemnly declare that research work presented in the thesis titled "Multi-Robot Interactive Therapy for Children with Autism Spectrum Disorder" is solely my research work with no significant contribution from any other person. Small contribution / help wherever taken has been duly acknowledged and that complete thesis has been written by me.

I understand the zero tolerance policy of the HEC and National University of Sciences and Technology towards plagiarism. Therefore, I as an Author of the above titled thesis declare that no portion of my thesis has been plagiarized and any material used as reference is properly referred/cited.

I undertake that if I am found guilty of any formal plagiarism in the above titled thesis even after award of PhD degree, the University reserves the rights to withdraw/revoke my PhD degree and that HEC and the University has the right to publish my name on the HEC/University Website on which names of students are placed who submitted plagiarized thesis.

Student/ Author Signature: _______________

Name: Sara Ali

Dedicated to my parents, husband and my children

Acknowledgement

I am deeply in debt to my supervisor Dr.Yasar Ayaz for his guidance, suggestions, constructive criticism and encouragement. He helped me sail through the hard times. I would also like to thank Prof. Raheel Nawaz and Dr. Muhammad Jawad Khan for his inputs at various stages of the research.

Special thanks are due to Mr. Faisal Mehmood for his help in conducting the experimentation, especially at Autism Resource Center (ARC).

Thanks are also due to the staff of the School of Mechanical and Manufacturing Engineering (SMME) and Autism Resource Center (ARC) for their support and help. I appreciate the guidance provided by psychologist and therapists during the experimentation phases of the research.

List of Abbreviations

RAT	Robot Assisted Therapies
ASD	Autism Spectrum Disorder
EEG	Electroencephalogram
CARS	Childhood Autism Rating Scale
TD	Typically developed
AOSI	Autism Observation Scale for Infants
HRI	Human Robot Interaction
ABA	Adaptive Behavior Analysis
CDC	Centers for Disease Control
EBP	Evidence Based Practice
MRIS	Multi-Robot-Mediated Intervention System
ADDM	Autism and Developmental Disabilities Monitoring
AS	Asperger Syndrome
PDD-NOS	Pervasive Developmental Disorder
ADOS-G	Autism Diagnostic Observation Schedule General
CBT	Cognitive Behavioral Therapy
ESDM	Early Start Denver Model
TEACCH	Treatment and Education of Autistic and Related Communication Handicapped Children
VMM	Variable-order Markov Model
HFA	High Functioning Autism
TUI	Tangible User Interface
GUI	Graphical User Interface
SAR	Socially Assisted Robot
LTM	Least to Most
RMIs	Robot Mediated Interventions
TCP	Transmission Control Protocol

S	TCP Server
C	TCP client
CD	Client Descriptor
OS	Operating System
LTM	Least to Most
PQ	Priority Queue
FSM	Finite State Machine
TO	Time Out
TH	Target Hit
JA	Joint Attention
ARC	Autism Resource Center
HHI-S1	Human-Human Interaction, Stage 1
HHI-S2	Human-Robot Interaction, Stage 2
HHI-S3	Human-Human Interaction, Stage 3
ANOVA	Analysis of Variance

List of Nomenclature

O_{JA}	Joint attention and stimulus module
ST_j	Stimulus number
RS_y	Different reinforcement stimuli
R_i	Robot number
i	Number
j	Type of reinforcement stimulus
k	Number of gaze shifts
n, m	Real numbers
JAM	Joint attention module
RSM	Reinforcement stimuli module

Abstract

Robot-Assisted Therapies (RAT) is an emerging field and has shown promising results. Recently, one of the prominent applications of robots is assistive therapy is for Autism Spectrum Disorder (ASD). Autism Spectrum Disorder is a set of neurodevelopment disorder affecting 7.5 million people around the world. Children with ASD lack social and communication skills which affects their ability in schools as well as in community. Recently, humanoid robots are used for the treatment of children with autism spectrum disorder to improve the development of communicational, behavioral, motor movements, joint attention, and physical behaviors. These interactive interventions that use robots for children with ASD, is one of the favorable tools for improving the behavior of children. In particular, the area of robotics is helping a lot in the treatment of ASD as the robot acts as a mediator as well as measures the response of an autistic child. However, the research aiming that the treatment of children with autism is limited, these therapies introduced by robots are successful in establishing basic communication skills. This research has proposed a novel mathematical model for an adaptive therapy of children with Autism Spectrum Disorder called Multi-robot-mediated Intervention System (MRIS). Three different therapies related to improvement in joint attention and imitation skills, effective human-human interaction and comparison of effective stimulus are introduced under this mathematical model. This research aims to introduce multi-sensory data that provides the quantitative support for improvement in social skills of children with autism, replacing the current techniques of measuring the improvement from physically observing the ASD child and with video analysis. Besides ensuring the accuracy in results, this method also introduces consistency as robots are immune to fatigue, unlike humans. The effectiveness of the model has been validated using cognitive brain state of the children with Electroencephalogram (EEG) neuroheadsets. Moreover, the effectiveness of the results has been validated using statistical analysis and the Childhood Autism Rating Scale (CARS).

Table of Contents

List of Figures

List of Tables

List of Publications

<u>Total Publications</u>: 20

Journal Publications: 7

Conference Publications: 13

<u>Impact Factor Journal Publications (as first author):</u>

1. **S. Ali** et al., “A Preliminary Study on Effectiveness of a Standardized Multi-Robot Therapy for Improvement in Collaborative Multi-Human Interaction of Children with ASD,” IEEE Access, pp. 1–1, 2020, doi: 10.1109/ACCESS.2020.3001365.
2. **S. Ali**, F. Mehmood, Y. Ayaz, M. J. Khan, H. Sadia and R. Nawaz, "Comparing the Effectiveness of Different Reinforcement Stimuli in a Robotic Therapy for Children With ASD," in IEEE Access, vol. 8, pp. 13128-13137, 2020. (IF: 4.098)
3. **Ali, S**., Mehmood, F., Dancey, D., Ayaz, Y., Khan, M.J., Naseer, N., Amadeu, R.D.C., Sadia, H., Nawaz, R., 2019. An Adaptive Multi-Robot Therapy for Improving Joint Attention and Imitation of ASD Children. IEEE Access 7, 81808–81825. https://doi.org/10.1109/ACCESS.2019.2923678. (IF=4.098)

<u>Impact Factor Journal Publications (as co-author):</u>

4. Mehmood, Ayaz, Y., **Ali, S**, Amadeu, R.D.C., Sadia, H., 2019. Dominance in Visual Space of ASD children using multi-robot joint attention integrated distributed imitation system. IEEE Access, 10.1109/ACCESS.2019.2951366. (IF=4.098)
5. Yunus, R., **Ali, S**., Ayaz, Y., Khan, M., Kanwal, S., Akhlaque, U., Nawaz, R., 2020. Development and Testing of a Wearable Vibrotactile Haptic Feedback System for Proprioceptive Rehabilitation. IEEE Access 8, 35172–35184. https://doi.org/10.1109/ACCESS.2020.2975149 .(IF=4.098).

Non-ISI Journal Publications:

6. **Ali S**, Yunus R, Arif A,Ayaz Y, Sial MB, Asif R, et al., "Hand Gestures Based Emotion Identification Using Flex Sensors," International Journal of Industrial and Systems Engineering, vol. 12, no. 9, p. 5, 2018.
7. **Sara Ali**, YasarAyaz, Muhammad Jawad Khan. "Use of Latest Robots for Autism Spectrum Disorder," ARME, vol. 1, no. 2, Oct. 2018.

Conference Publication (as first author)

8. **Sara Ali**, Faisal Mehmood, Yasar Ayaz, Umer Asgher, Muhammad Jawad Khan. "Effect of Different Visual Stimuli on Joint attention of ASD Children Using NAO Robot". AHFE 2019 10th International Conference on Applied Human Factors and Ergonomics and the Affiliated Conferences 24-28, July, 2019, Washington Hilton, Washington D.C, United States of America.
9. **Sara Ali,** Mohammad Samad, Faisal Mehmood, Yasar Ayaz, Wajahat Mehmood Qazi, Muhammad Jawad Khan , Umer Asgher. "Hand Gesture Based Control of NAO Robot Using Myo Armband". AHFE 2019 10th International Conference on Applied Human Factors and Ergonomics and the Affiliated Conferences 24-28, July, 2019, Washington Hilton, Washington D.C, United States of America.
10. **Sara Ali**, Yasar Ayaz, Muhammad Jawad Khan, et al, 2018, Therapy for Autsim Using Robots as Virtual Agents, International Conference on Virtual Reality Technology.
11. **Sara Ali**, Faisal Mehmood, Yasar Ayaz, Noman Naseer, Umer Asgher, Muhammad Jahangeer Qureshi and M. Jawad Khan. Cognitive assessment for autistic children using robotic therapy: an fNIRS study fNRIS conference 2018. III-46, p.276. https://fnirs2018.org/wp-content/uploads/2018/09/fNIRS2018_program.pdf.

12. **Sara Ali**, Muhammad Sajid, Yasar Ayaz, Umer Asgher. “A Methodology for Integrating Project Based Learning Outcomes and Attributes via Questionnaire”. AHFE 2020, 11th International Conference on Applied Human Factors and Ergonomics and the Affiliated Conferences, 16-20, July, 2020, Virtual Conference, United States of America.
13. **Sara Ali**, Faisal Mehmood, Yasar Ayaz, Muhammad Jawad Khan, Umer Asgher. “Effect of Paired Stimuli on Joint Attention of Children with ASD”. AHFE 2020, 11th International Conference on Applied Human Factors and Ergonomics and the Affiliated Conferences, 16-20, July, 2020, Virtual Conference, United States of America.

Conference Publication (as co-author)

14. Faisal Mehmood, **Sara Ali**, Yasar Ayaz, Muhammad Jawad Khan, Umer Asgher. “Comparing Effect of Active vs. Passive Robotic Interaction on Joint Attention of Children with ASD”. AHFE 2020, 11th International Conference on Applied Human Factors and Ergonomics and the Affiliated Conferences, 16-20, July, 2020, Virtual Conference, United States of America.
15. Umer Asgher, José Arzola-Ruiz, Riaz Ahmad, Osmel Martínez-Valdés, Yasar Ayaz**, Sara Ali**. Modeling and multi-objective optimization of insulating lining using Heuristic technique “Exploration of Variable Codes (EVC)”. AHFE 2019 10^{th} International Conference on Applied Human Factors and Ergonomics and the Affiliated Conferences 24-28, July, 2019, Washington Hilton, Washington D.C, United States of America.
16. Khurram Khalil, Umer Asgher, Yasar Ayaz, Riaz Ahmad, Salman Nazir, **Sara Ali**, Sofia Scataglini, Noriyuki Oka. “Efficient Extreme Learning Machine (ELM) Based Algorithm for Electrocardiogram (ECG) Heartbeat Classification”. AHFE 2020, 11th International

Conference on Applied Human Factors and Ergonomics and the Affiliated Conferences, 16-20, July, 2020, Virtual Conference, United States of America.

17. Khurram Khalil, Umer Asgher, Yasar Ayaz, Riaz Ahmad, Jose Arzola Ruiz, Noriyuki Oka, **Sara Ali**. "Cognitive Computing for Human-Machine Interaction: An IBM Watson Implementation". AHFE 2020, 11th International Conference on Applied Human Factors and Ergonomics and the Affiliated Conferences, 16-20, July, 2020, Virtual Conference, United States of America.

18. Umer Asgher, Jose Arzola Ruiz, Gutiérrez-Gualotuña E R , Yasar Ayaz, Muhammad sajid, Khurram Khalil, **Sara Ali**. "Mathematical Modeling and Optimization of Downdraft Gasifiers using Artificial Neural Networks (ANN) and Stochastic Programming Techniques". AHFE 2020, 11th International Conference on Applied Human Factors and Ergonomics and the Affiliated Conferences, 16-20, July, 2020, Virtual Conference, United States of America.

19. Umer Asgher, Jose Arzola Ruiz, Yasar Ayaz, Muhammad sajid, Khurram Khalil, **Sara Ali**. "Multi-level Optimization of Reactive Power Compensation in Industrial Nets with Heuristic Modelling Techniques". AHFE 2020, 11th International Conference on Applied Human Factors and Ergonomics and the Affiliated Conferences, 16-20, July, 2020, Virtual Conference, United States of America.

20. Jawad Khan, Yasar Ayaz , Faisal Mehmood, **Sara Ali**, Noman Naseer , Umer Asgher , and Muhammad Jahangeer Qureshi . Enhanced classification accuracy using deep learning for mental math: an fNIRS study. fNIRS conference 2018. III-43, p.273. https://fnirs2018.org/wp content/uploads/2018/09/fNIRS2018_program.pdf

CHAPTER 1

INTRODUCTION

In 2014, the estimated prevalence of Autism Spectrum Disorder (ASD) in the United States was 1 out of 68 children [1]. It was noticed that the trend from 2010 to 2014 was an increase of 52% in Autism patients where is other diseases were reduced by 1% during the same period. Centers for Disease Control and Prevention (CDC)update in 2018 on increases in the estimate of autism's prevalence by 15 percent, to 1 in 59 children [2]. Because of lack of communication skills and social cues [3], children with autism spectrum disorder have low rates of employment as compared to Typically Developed (TD) children [4]. Social and communication skills including verbal as well as non-verbal communication are important in employment, relationships and many other aspects of life [5]. It has been observed that the effect of early intervention is considerably more on a younger autistic child in improving his/her communication abilities [6]. These deficits are there in early childhood, however recent research shows that the symptoms are not faded with time and therefore require proper treatment [7-9]. Along with the communication skills and social issues, these children also have delayed language development skills as compared to typically developed child. A typically developed (TD) child establishes the joint attention even before saying his/her first word [10]. From the age of 1 to 4 years, in a normal development process, a TD child shows a drastic change in language development skills [11] and[10]. However, for children with neuro-developmental disorders, communication as well as language skills, are not fully developed [12]. In second phase of National Standards project, National Autism Center (2015) identifies following for the treatment of autism: (1) Behavioral Interventions, (2) Cognitive Behavioral Interventions, (3) Language Training, (4) Modeling, (5) Naturalistic Teaching, (6) Parent Training, (7) Peer Training, (8) Pivotal Response Treatment (PRT), (9) Schedules, (10) Scripting, (11) Self-Management, (12) Social Skills Package, and (13) Story-Based Interventions. Many of these can be pitched based on technology interventions that are recently introduced for the improvement of the social and communication skills of ASD children.

With the increase in autism over the years, the aim is to develop more intervention opportunities for children with ASD. For this purpose, technology-driven interventions are proposed and evaluated for their effectiveness. Recently robots are used for cognitive-behavioral therapies to catch the interest of ASD children. The robots used for this purpose are usually humanoid [13] as well as mobile robots [6] for improving the social skills of the child. Joint attention [14], ability to imitate [15], verbal communication [16] and social activities [17] are the targeted areas for the interventions to be performed by Socially Assistive Robots (SAR).

Research conducted using SAR shows that children with autism are more inclined towards the robots rather than human therapist [18-19]. There are many advantages of using robots as a therapist for the treatment of autism. Beside mood lift of the child, consistency, reliability, standardized stimuli production along with the controllability, low cost and adaptability with the environment are the key factors for preferring the use of robots over a human therapist [20]. Anthropomorphic, [21] as well as zoomorphic robots [16], [22] both are used for therapy of children with autism. However anthropomorphic robots are preferred over zoomorphic robots because of their appearance as they are closer to humans [23], [13].

However, along with the advantages of using these robots for interventions, several concerns are also associated. The major concern is the "novelty effect" and "uncanny valley". The novelty effect states that the child will be highly attracted by the robot initially and then will gradually lose the interest [24]. This can be addressed by changing the stimuli, the appearance of the robot, length of interventions, the order of the intervention, changing the intervention itself and many more [25]. The "Uncanny valley" theory describes the negative response of human while interacting with the robots. This factor should be kept in mind while designing the intervention and can be controlled while designing the intervention application for autistic children.

1.1 Problem Statement

At present, there is a lot of research focusing on the improvement of autism using robots. However, the concept of multi-person communication is never introduced using robotic therapies. Moreover, there is limited research that focuses on adaptive therapies for children with autism. Another major concern of the end-users is about Evidence-Based Practice (EBP) while making application-based systems. At present, this is not generally satisfied with solutions provided by robotic therapies [26].

1.2 Research Aim

This research focuses on the multi-robot adaptive therapy along with the evidence-based practice (EBP). The research aims to develop an original adaptive mathematical model based on multi-robot therapy of children with autism spectrum disorder. This therapy focuses on two main deficiencies in autism i.e., a) Joint attention and b) Imitation. The proposed therapy uses a multi-robot system to improve the multi-communication skills of an ASD child, which to the best of author's knowledge is a novel work.

Along with this adaptive multi-robot therapy, various other therapies are also introduced including the measurement of different motion stimuli on ASD child, prominent improvement in multi-person interaction of the child before and after therapy.

1.3 Research Objectives

The objectives set for this research are as follows:

1. Therapy-1: Design and development of a single mathematical adaptive model that addresses joint attention as well as imitation module called MRIS (Multi-robot-mediated Intervention System)
    a. Validation and effectiveness of MRIS system using CARS
    b. Validation of MRIS by analyzing the cognitive state of the brain using EEG
2. Therapy-2: Design and development of robotic therapy for multi-human interaction for noticing the improvement in multi-person interaction of ASD children
3. Therapy-3: Effectiveness of different stimuli in a therapy. This therapy aims to check the most effective stimulus for interaction of the robot with autistic children to facilitate better human-robot communication. Three different stimuli i.e. visual (color variation), speech and motion stimuli are tested to check the level of engagement of autistic child based on stimuli. The goal of this research was to have a quantitative measure for the effectiveness of the given stimulus.

1.4 Research Methodology

Keeping in view the inclination of autistic children, the MRIS system uses NAO humanoid robot for all the three therapies [21]. This robot is widely used for performing intervention with ASD children [27]. An adaptive closed-loop supervisory control has been established using NAO robots. MRIS system performs experimentation as 1) human-robot interaction (without any inter robots' interaction) and 2) human-robot interaction along with the inter robot communication.

1.5 Thesis Organization

This thesis is organized into seven chapters based on the research work carried out during the course of this PhD.

Chapter 1 is about **“Introduction”** that establishes the wider importance of robotic therapies for children with autism spectrum disorder. Chapter 2 is about “**Robots as Social Mediators-Literature Review”**. This chapter presents the comparison of current research with the previous intervention models using robots. Chapter 3 is **“Design and Development of Adaptive MRIS System (Therapy-1)”**. This chapter explains in detail the experimental setup for therapy-1, introducing multi-robot for improvement in joint attention and imitation skills. Chapter 4is on **“Robotic Therapy for Multi-human Interaction (Therapy-2)”**. This chapter explains in detail the experimental setup for therapy-2 by introducing the concept of multi-human interaction using the multi-robot system. Chapter 5 **“Effectiveness of different stimuli in a robotic intervention (Therapy-3)”** explains in detail the experimental setup for therapy-3. This compares different stimuli to find the most effective one in the intervention. Chapter 6 refers to the **“Experimental Results and Statistical Analysis”.** This chapter presents the results for all the three therapies performed using multi-robot. Chapter 7 is about “**Conclusions and Recommendations for Future Research”**. This chapter summarizes the work done and proposes future work.

CHAPTER 2

ROBOTS AS SOCIAL MEDIATORS - LITERATURE REVIEW

2.1 Autism Spectrum Disorder

ASD is a developmental syndrome that implies impairment in language as well as restricted/repeated stereotyped behaviors along with the above-mentioned symptoms [28]. This developmental disorder starts at an early age and lasts through out the life affecting the ability to communicate, learn and interact with others. People affected by ASD have a range on symptoms and therefore it is called as a “spectrum” disorder [29]. There is no difference between the looks of an ASD and a typically developed child, however the things that show the symptoms of autism in a child include, way of communication, interaction, learning capabilities. The possible red flags for autism can be no name recognition till 12 months, no eye contact, delayed speech, repetition of words and phrases (echolalia), obsessive interests, flapping hands, spinning in circles, unusual reaction to sounds, smells, looks etc.

Estimation of the ratio for autism is 1 in 68 children by the Centers for Disease Control and Prevention (CDC)'s Autism and Developmental Disabilities Monitoring (ADDM) Network [30]. In South Asia, this developmental neuro-disorder has affected more than 5 million children [31]. The concept of early intervention is not present in middle class and low-middle class (LMICs) effected by ASD. In Pakistan, unfortunately, the awareness about autism and other early childhood developmental disorders has not received proper attention [32].

There are three different types of autism: 1) Asperger Syndrome (AS), 2) Autistic disorder and 3) Pervasive Development Disorder (PDD-NOS). Individuals with Asperger Syndrome have slighter symptoms of autistic disorder without having any language issues. For individuals with autistic disorder, they have language delay issues, social problems and lack of communication skills. This is also known as “classic autism”. Pervasive Development Disorder also called “atypical autism” is possessed by individuals with some of the symptoms of autistic disorder or AS. There are different methods for early detection of autism. The most common one is to approach the therapist or psychologist. For early identification of autism a scale called Autism Observation Scale of Infants, abbreviated as AOSI has been established [33]. Three major categories according to the scale are Asperger syndrome, Low functioning autistic, and Hi functioning autistic. Major core deficit of children with ASD are social skill and language impairments for lifetime [34], [8], [35]. These core deficits prohibit the students from participating in classrooms, therefore, effecting their output. Because of the large number of increase in autistic children, schools need to develop a strategy for effective and evidence-based intervention and treatment of children with ASD [36]. Researchers have been working on the methods that should be labeled as “evidence-based practices” and can be used by teachers and policymakers for children with ASD in schools [37]. With the fast pace of growing technology that is becoming part of everyday life, it is important to integrate the technology with evidence-based practices in the classroom. This is because individuals with ASD show more inclination towards the tasks based on technology [38], [39].

2.2 Diagnosis and Treatment for ASD

Although, the diagnosis of ASD is not the part of, this research, however, there are two renowned methods for diagnosis of ASD are: 1) Autism Diagnostic Inventory-Revised (ADI-R) developed by Lord et al. [40]. This is a survey questionnaire to be filled by parents or guardians of the autistic child. The second technique for diagnosis is: 2) Autism Diagnostic Observation Schedule General (ADOS-G), developed by Lord et al. [41]. This is related to the autistic person directly in whom the therapist takes his/her interview directly. Moreover, there are different observation scales for autism that can demonstrate inter-rater reliability of autism such as CARS, BOS, BRIAAC, AOS, ABC, ASIEP. Childhood autism rating scale (CARS) is one of the most widely used scales for diagnosis and treatment of children with ASD [42], [43]. This scale has 14 domains that assess the behaviors associated with autistic children, whereas a 15th domain is for rating general impressions of autism. Each domain is scored on a scale ranging from one to four; the more the score obtained, the higher is the level of impairment. Total scores can range from a low of 15 to a high of 60; scores below 30 indicate that the individual is in the non-autistic range, scores between 30 and 36.5 indicate mild to moderate autism, and scores from 37 to 60 indicate severe autism[40]. Information regarding psychometrics of the CARS is well documented [44], [45], [46] and [47]. We have used CARS in our research to check the effectiveness of our therapy and compare the results of the robotic intervention.

Regarding the treatments of autism, in the second phase of the National Standards Project, the National Autism Center (2015) recognized the following as established treatments(a) Behavioral Interventions, (b) Cognitive Behavioral Interventions, (c) Language Training, (d) Modeling, (e) Naturalistic Teaching, (f) Parent Training, (g) Peer Training, (h) Pivotal Response Treatment (PRT), (i) Schedules, (j) Scripting, (k) Self-Management, (l) Social Skills Package, and (m) Story-Based Interventions.

2.3 Intervention strategies for ASD

One of the main goals of ASD interventions is to motivate and reward the social behavior and experience sharing [48]. Therefore to encourage this social behavior in children with autism, a research direction is always given to the caretakers/guardian and therapist of children [49], [50] and [51]. This could motivate them to engage the children with autism and improve their social behavior tremendously.

For this purpose, several methods are available for intervention depending upon the abilities lacking in each autistic children. These interventions include social stories, verbal and nonverbal social skills training, interactions with typical peers, cognitive behavioral therapy (CBT) and computer face processing games as treatments [52], [53], [54] and [55]. Some other therapies include Parents education and training, social skills training and speech-language therapy, Applied Behavior Analysis (ABA), sensory integration/Occupational Therapy (OT), medication, Early Start Denver Model (ESDM) Therapy, Treatment and Education of Autistic and Related Communication Handicapped Children (TEACCH).

2.4 Applied Behavior Analysis (ABA)

One of the most famous intervention types is Applied Behavior Analysis (ABA). There is a lot of research in favor of applying ABA intervention for the improvement in the behavior of autistic child [56]. ABA is based on the belief that most social behaviors acquired by humans are learned throughout history of interaction between the individual and his/her environment and environmental cues and stimuli can influence how a person diagnosed with ASD behaves [57]. ABA includes cognition and speech-language therapy. ABA therapy is highly structured and curriculum is divided into small parts, each part is removed as the child learns it. As the child masters the skill, he/she gets an award. ABA therapy works on step by step learning. Therapy includes sports and other interesting features. As the child learns a skill or progresses, the results are noted by direct observation but if the results are not satisfactory or are negative then changes are made.

2.4.1 Why ABA?

One of the most effective and oldest therapies for autism is Applied Behavior Analysis (ABA). This intervention technique is preferred all over the world. Some of the prominent research on ABA therapies include: Lovaas O. applied intensive ABA therapy on 19 children for 40 hours a week for the duration of 2 years. 9 in 19 children performed better in school with minimum support while 1 in 40 children in control group had significant improvement [58]. Landa et al., applied ABA on 48 children above 2 years for 6 months and they got significant improvement in IQ, social skills and reduction in severity level of autism [59]. Cohen et al., [60] analyzed 21 children who got ABA therapy for 35-40 hours/week and 21 children who were in the control group. After 3 years 17/21 children who got ABA therapy were fully included in regular education with no or limited support while only 1/21 children were included in regular education from the control group. Children who got ABA had better IQ and social skills than control group children [60]. Most studies compare children on the spectrum with a "control group" of typically developing children. The definition of "typically developing" can vary according to the age, IQ, and some by other measures.

ABA Therapy methods are scientific based treatment as these therapies are based upon research derived from behavioral analysis that includes the study of human behavior and effects of environmental condition in ASD children. The principles and techniques applied in ABA therapies for Behavioral Analysis is to reinforce positive behaviors and promote the development of new communication skills in children with ASD.

The reason for using ABA therapies is that it addresses the cognitive shortages in ASD children such as social communication skills, verbal communication skills, social development, emotional skills, motor skills and adaptive behavior. The ABA therapy has no particular rule, as it depends and differs from child to child. There is no “one size fits all” concept for ABA therapies. Moreover, the therapy can look differ throughout the treatment as ABA therapies addresses wide range of cognitive deficiencies during the therapy session.

ABA therapy helps us understand 1) how the behavior of the child works, 2) how the environment affects the child’s behavior, and 3) process of learning. These therapies help in improving mainly following skills of ASD children 1) improves language and communication skills, 2) it can help improve memory, attention and focus therefore improving the academics of an ASD child and 3) reduces the problems associated with the behavior.

One of the main strategies of ABA therapy is positive reinforcement. When an improved behavior is followed by some reward, the person is most likely to improve further. This is the key to develop positive behavior over the time using the concept of positive reinforcement in ABA therapy after the identification of goal behavior by the therapist. Another concept of ABA analysis is A-B-Cs that stands for Antecedent, Behavior and Consequence, is an important three step process that helps us to teach and understand the behavior of children with autism. Antecedents (that occurs before the behavior) and consequence (that occurs after the behavior) are important to understand as a part of ABA program.

1. Antecedent: occurs in verbal form as command or request just before the target behavior. It can also be any physical effect such as toy, sound, object, lights or anything else in the environment. It can come from environment, can be internal (such as thoughts and feeling of a person) or from another person.

2. Resulting Behavior: this step is basically the person response either positive or negative as a result of antecedent. This can be in the form of verbal response, an action or can be anything else.

3. A Consequence: this comes directly after the behavior. It can a positive reinforcement of the desired behavior or can include no response or even negative response.

Keeping in view the above strengths of ABA therapy, this research is based on the intervention that uses this concept for the improvement of social, verbal, imitation, joint attention and communication skills of children with ASD.

2.4.2 Robotic Interventions for ASD

It has been observed in the research that the individualized capabilities of intelligent machines enable to capitalize on the effect of interventions of ASD. Socially Assistive Robots (SAR) is used for Human-Robot Interaction (HRI). The task of these SAR’s varies from bomb disposal [61] to multi-modal sensing [62], roles of robots in society [63] and their work [64], [65], etc. Robots are now used for elderly care, education, rehabilitation, people who require social and cognitive assistance and many more. The goal of these socially interactive robots is to assist the people [66]. The application of SAR’s involves social interaction rather than physical interaction facilitated by Human-Robot Interaction [67-69].

These socially assistive robots have been widely used for diagnosis [70] and [71], treatment and socialization of children with ASD [72-75]. In diagnostics, robots can observe the improvement in a way human cannot e.g. eye-tracking using robot’s sensors is much more accurate. For socialization, robots tend to a more comfortable partner for ASD children than humans.

The focus of robot-based interventions is usually because of the physical features of the robot [24], control architecture [24], variety of assessment criteria [70], and different human-robot interaction-based algorithms [76]. The latest research also focuses on the perception of autism using robots. Using different animate and inanimate entities based on the theory of mind [77]. Visual processing of autistic children is compared with typically developed children [78]. In perception, a prominent effect is of human-like nature of the robot [79]. Important features to increase the child-robot interaction are presented in [80]. Different occipital therapies are used to measure the response of ASD children [81]. A robot acting as a physical mediator has a positive effect on the gaze and physical contact behavior of child [74].

Mobile robots are also been used widely for HRI and treating autism. The European AURORA project uses simple mobile robots to help children with autism to guide through complex interactions by incorporating eye gaze and turn-taking aspects of human communication [82]. A robot as a social mediator was shown to have a positive effect on gaze and physical contact behavior [83]. Another project on autism using robots is a DREAM. This project focuses on the study and development of artificial cognitive robotic systems to support psychotherapy for children with mental disorders, in particular children with Autism Spectrum Disorders (ASD) [84].

2.4.3 Interventions for Joint Attention

Joint attention is also referred to as shared attention. This is achieved when one individual alerts another to an object using eye-gazing, pointing or other verbal or non-verbal indications [85].

Joint attention is one of the core impairments in children with ASD. Transfer of eye gaze is mandatory to successfully interact and communicate in the social circle. Usually, autistic children have a lack of joint attention and therefore it is one of the biggest hints for diagnosis of autism [86]. Esubalew et al. presented an intervention for joint attention improvement with setup consist of a room comprising three LCD monitors at two different walls of room and NAO humanoid robot in front of a child [28]. Petric et al. presented the work which is an up-gradation of this work [87]. In Human-Robot Interaction (HRI), joint attention holds great importance as the interaction can be improved by improving the visual feedbacks. Mavadati et al. designed different modules for the recording of initial responses of ASD children and then highly concentrate on joint attention or eye gaze maintenance during the whole therapy [88]. Gaze analysis of autistic and typically developed kids are also modelled with the help of Variable-order Markov Model (VMM) [89]. These robotic interventions can be used to improve the gaze/eye contact among children with High Functioning Autism (HFA) [90]. In this concept, researchers made a game that consists of verbal communication and then ask for eye contact from the child. The shifting of gaze and duration of concentration are measured as parameters. Joint attention is therefore considered to be a vital building block for social-communication skills for language and social skills development.

2.4.4 Intervention for Verbal and Non-Verbal Communication Skill

Children with ASD lack verbal communication skills that affect their communication with the people around them. Several researchers have developed robotic interventions to improve verbal communication skills to learners with ASD. Kim et al. compared the verbal utterances of 24 children with ASD with dinosaur robot, human, and touch screen computer game [16]. Frequency of utterance was also recorded during the experimentation. There were three sessions each of them lasted for 3 minutes. It was observed that the participants engaged in more verbal communication with the robot than with the human or the touch screen computer game. Robotic interventions are also used to increase the verbal communication of ASD children via obeying orders.

Ende et al. have designed a robot that is programmed uses tag-based word recognition in a sentence and then performs actions accordingly [91]. Huskens et al. performed an experiment in which ABA-based interventions were implemented on human-robot interaction for self-initiated questions for six ASD children, ages 8-14 years old [92].They also performed the robot-mediated interventions to check the effect on initiations, responses, and "play together" of 3 pairs of children [93].

Srinivasan et al. experimented to observe the effect of verbal communication by comparing three interventions on 36 ASD students with the age ranging from 5 to 12. The observed factors were traditional instruction, rhythm and movement-based instruction, and robotics-based instruction. It was observed that the social verbalization was improved in the rhythm and robot conditions as compared to the traditional instructions of social verbalization [94-95]. Non-verbal communication issues are also prevalent in children with ASD. Non-verbal communication usually includes gestures. There are different gesture-based therapies to improve the non-verbal communication skills of autistic child [96-98].

2.4.5 Interventions for Imitation

Imitation is one of the core impairments of children with ASD. Several robotic interventions are used to improve the imitation skills of these children. In these interventions, the child has to imitate the behavior of the robot and then the robot evaluates the performance of the child using various parameters usually based on gestures [99] and [100]. ASD children repeat the movement, again and again, called stereotyped movements. These stereotyped movements are used as biomarker for the detection of ASD. Muty et al. conducted the intervention in which these stereotyped movements were recorded using Kinect sensor[100]. Moreover, human pose estimation and skeletonizing algorithms are also used to detect arm flipping behavior in ASD children [101].

Pop et al. studied the impact of a robot-mediated intervention on the frequency of imitation gestures, physical interaction, and attention two subjects of ASD. It was observed that imitation skills were not improved but there was an increase in physical interaction and attentiveness of the child [102].

Kaburlasos, Vassilis G., et al. has done a preliminary research on multi-robot engagement in special education in autism [103]. This research has implemented multi-robot engagement to circumvent the ethical issues that can be raised during therapeutic interventions. Whereas the current research presented in this thesis uses multi-robot to introduce the concept of multi-human interaction to ASD children. Moreover, this research uses robots as the therapists as this is particularly useful as, unlike humans, robots can be more consistent and relatively immune to fatigue.

Research done by Kaburlasos, Vassilis G., focuses on developing customized behavioral treatment(s) in special education where R1 is passively trained to mimic/simulate the behavior of child. The second robot R2 is tele-operated by humans used to operate on R1 towards developing an effective treatment for autistic children keeping in view the ethical concerns. Therefore, the robots in this proposed preliminary research are not directly interacting with the children with ASD so not to raise any ethical issues. However, in the present proposed research of this thesis, both the robots are actively communicating with the children and improvement in communication skills is directly recorded by the robots.

The experimentation proposed in research presented by [103], was done on two children with mild ASD whereas the present research was done on 12 ASD children ranging from mild-low ASD. Moreover, the experimentation involved in research presented by [103] only the basic imitation skills copied passively by R1 unlike the present research in which imitation as well as joint attention of ASD children were improved during the intervention.

2.4.6 Interventions for Physical Play Skills

To increase the social interaction and play skills of children with ASD, intervention in which robots play with the children are also designed. Suzuki et al. presented a physical play game where two levels are involved: touch my body and dance with me [101]. Saima et al. also introduced physical play ABA therapy for ASD children using soccer-playing game. Social interaction, joint attention, turn-taking, communication, and eye gaze were the parameters used for evaluation of improvement [27]. Robots can also be used to teach along with improvement in play skills. Costa et al. performed this task using KASPAR robot in which a child was taught about different body parts and then was evaluated by touching the robot for a particular body part when asked [103].

2.4.7 Facial Expression Based Interventions

Facial expression can lead to various parameters that can tell about the emotions of a person while performing a particular task. During a human-robot interaction, the facial expression of ASD children can tell a lot about the adaptability and interest level of the child during the interaction. Guha et al. used this approach of observing the facial expression for sadness, happiness, fear, anger, and neutral moods [104]. For more useful interaction between robots and humans, the therapy can be made adaptive depending upon these emotions. In research, researchers divided the face into eight different parts to perform a comparison between ASD and TD children under different facial expressions/emotions [105]. A research was conducted based on a game based emotions learning for ASD children [106]. In this study, the child has to present few emotions to the robot using rackets, which will be shown by the robot previously, and then upon correct presentation of emotions, he/she will be rewarded accordingly.

2.4.8 Games Based Interventions

Depending upon the event-based occurrence concept, various games based interventions have also been developed by the researchers for improvement of response to events. Few people introduced the concept of virtual reality in games as well which is used to evaluate problem handling ability of autistic child and increases adaptive behavior skills [107]. Various hardware along with the robots are utilized in such interventions e.g. computers, laptops, tablets and even mobile phones along with auxiliary hardware. These are used to award autistic child according to his/her performance. In a research game with a Tangible User Interface (TUI) was developed for autistic children, with Graphical User Interface (GUI) in computer. The child was given a task to draw a pattern on TUI by showing them a figure, initially provided on paper and then later on via computer GUI [108].

Due to the lack of visual perception in children with ASD, they have a problem with their joint attention skills and transferring the eye gaze. Researchers have designed different video-based therapies to notice the expressions and feelings of ASD children [109]. In this regard, video for accessing the smell sense of ASD child was presented and it was proved that ASD child cannot correctly identify the odor of fruits and flowers as compare to TD children. In this, a video was presented to the child that comprised of any fruit or flower. Later the child has to sniff the smell being given to him/her by fragrance and then he/she has to answer the question.

2.4.9 Interventions Based on EEG Signals

There is multiple numbers of interventions for ASD children that can be integrated with EEG signals of ASD children. These signals can be used for observing the results with some processing. In research, a technique to remove eye blink and muscular artifacts from EEG signals of ASD child was studied [110]. A researcher studied about brain activity in ASD children in which eye-opening and closing was compared with TD child using EEG [111].

2.5 Effect of Robotic Embodiment

The research conducted on designing the therapies for children with ASD shows that these children are more inclined towards the robots rather than therapists [112]. Research has proved that use of robots for designing clinical interventions, is helpful towards stimulating the positive social behavior of a child with autism spectrum disorder [18]. Moreover, the robotic therapies are gaining attention as the environment using them is controllable, predictable and accurate [113] and [114]. Moreover, repeatability and fatigue-free interaction with a child is prominent factors of robotic interventions [115]. Recently, related research is focusing on the implementation of adaptive robotic interventions due to the inquisition of ASD children in robots [116] and [15]. Engagement of children in interventions is a prerequisite for such therapies [17]. Physical features of the robot are of great importance in robotic therapeutic interventions [114]. The behavior of autistic children may vary according to the size, shape, and looks of the robots, therefore the appearance of robot matters [24].

The clinical use of anthropomorphic as well as zoomorphic robots shows promising development in the light of the research. Using these robots, research has shown that children with ASD exhibits the perception of physical world, children become more responsive towards physical as well as social feedback when interaction is done using technology rather than a human involvement and that the children are more interested in therapy if robots or any other electronic gadgets are used. For this purpose, there are different types of non-humanoid, partially humanoid, and humanoid robots available in Autism Spectrum Disorder.

The different types of robotic embodiments involved in therapeutic intervention for children with autism are 1) Anthropomorphic robots: these robots look like humans. Social interaction and collaborative play are the key features of these robots [117] and [21]. An example of such robots is “KASPAR” [16] and “NAO” [15]. These robots are preferred because of their appearance despite having physical limitations as they play an important role in significant improvement of a child’s behavior[27] and [13]. In the perception of robots, human-like nature holds great importance [24]. Several features can even increase the human-robot interaction [81]. The second type of robotic embodiment used for interaction with ASD children is zoomorphic robots. These are the robots that look like animals and are used for interacting with children with ASD. “Keepon” is one of the famous robots that is used for positive social interaction in therapies[80].Other famous zoomorphic robots include Pleo, Charlie, Roball, Muu, Aibo. A long term study with one of the famous zoomorphic robot called Paro shows a positive improvement in human interaction, showing a prominent factor of performance in therapy [118]. There are some other famous non-humanoid robots such as Robota Doll and Tito etc. One of the main concerns for robotic therapies of children with ASD is whether they will prefer a humanoid or a non-humanoid robot. In literature this question has been given a considerable importance. It has been argued that non-humanoid robots will be initially more appealing towards ASD children, however if they generalization of skills are considered, a humanoid robot shall be preferred.

Previously it has been reported that children with ASD show both positive as well as negative effects while interacting with the robots. In a research [119], a child with an ASD is compared with a typically developed child on their behavioral and physiological response. The response of both the children was measured in terms of increase in heart rate. It was observed that the child with ASD did not show an increase in the heart rate while when exposed to the robotic face whereas the typically developed child felt uncomfortable and the heart rate increased. However a follow up study to this initial experimentation showed the variance of results for ASD children when a robotic face was shown to them such as increase in the social communication because of the robotic face, decrease in communication or no wither showing no communication [120]. Another experimentation was performed on group of 8 ASD children using a mobile robot (non-humanoid robot) [121]. The results showed tremendous variability on valence of effective response was observed were a robot was shown. Outside the therapeutic context, a research was done studying the long-term interaction between a human and a robot. It was observed that they children considered the robot QRIO as a peer rather than a toy[122]. A study was done showing impact of robot in imitation games using robot Tito to elicit shared focused attention [123].

Researchers have studied about the perception of children for these robots. It has been observed that most of the children perceive these robots as toys [124]. Few of the robots used in therapies for autism are shown in Figure 2.1 and Figure 2.2 [125].

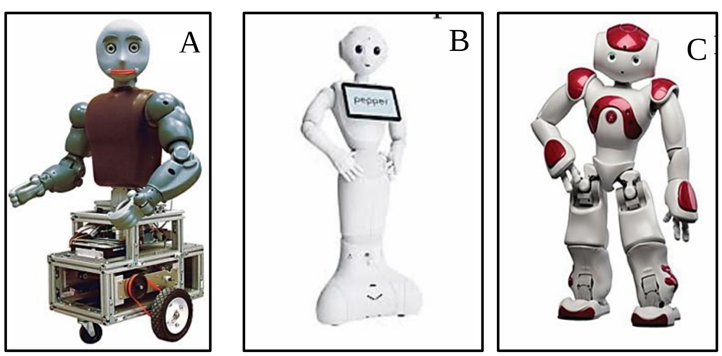


Figure 2.1 Anthropomorphic robots Bandit, Pepper and NAO used in therapies for Autism Spectrum Disorder.

Figure 2.2 Zoomorphic robots Keepon, Charlie and Pleo used in therapies for Autism Spectrum Disorder.

2.6 Summary

Children with ASD have deficits in social-communication skills that affect their ability to communicate effectively as well as affect their education at the school level. These social skills deficits are frequently cited as barriers to improved employment outcomes [13] and [126]. There is a critical need to make the therapies effective looking at the increase in number of students with ASD in schools to have a quality social skills instruction in schools for this population [127]. For this purpose, different types of robotic embodiments available can help in treating the social behavior and improve the language skills of children with ASD. Also some robots are specifically designed to deliver a social curriculum [128].

This chapter explicitly discusses the need for therapeutic interventions for treating autism. It is also discussed that why we have chosen ABA interventions for our therapies. Moreover, the literature review of already existing therapies for improving joint attention, verbal and non-verbal skills, imitation, physical play skills, facial expressions based intervention, use of EEG in interventions, are also discussed. Lastly, it discusses the effect of robotic embodiment on children with autism by explaining how they perceive the particular type of robot that includes humanoid and non-humanoid robots.

The focus of current research includes a humanoid robot NAO. This humanoid robot is used for improving the joint attention and imitation skills of children with ASD. The current work focuses of an adaptive mathematical model for the improvement in multi-human interaction. Previous research done using humanoid robots have not introduced an adaptive mathematical model for multi-human interaction that is considered as one of the main social skills in communication. The proposed model represents an adaptive therapy using multi-robot system for improvement in joint attention and imitation of an ASD child. Table 2.3 shows the differences between current research and previously work done

Table 2.1 Comparison of existing and proposed model

Existing research models	Proposed model
Presented robot assisted autism therapy for diagnosis of autism using joint attention and imitation tasks	Presenting robots assisted therapy for improvement of joint attention and imitation
Non-adaptive	Completely adaptive
Diagnosing autism	Improving social impairments of Autism
Uses Autism Diagnostic Observation Schedule (ADOS)	Uses Childhood Autism Rating Score (CARS)
ALFaceDetection: Uses face detection for gaze detection of child- a major drawback	Used ALGazeAnalysis: Eye gaze detection along with face detection. Moreover KINECT was integrated for head / face tracking ensuring direction of the face
In case of no response from ASD child, robot simply increases sentences to get attention	In our proposed therapy is based on increasing the effectiveness of stimuli i.e. LTM based approach
Two robots are used one active and one passive, Order of stimuli: Waving, flashing leds, and sounds making (neither LTM nor MTL)	Both are active robots and continuously noticing the responses. Order of stimuli: Rasta cues, speaking and waving (LTM model)

Offline tracking of object to estimate the moves of the ASD child	Online / real time tracking of joints of ASD child's skeleton to estimate the accuracy of the action in imitation.
4 ASD children, number of experiments not specified	12 ASD children. Multiple sessions done for each experiment
Vocal recognition- Reduced performance	Vocalization not used because of such issues.
Used vocalization utterances for classification based on voice	Used joint attention to measure the response to vocalization (speech task of robot)
Dealing in believe space (3D, no ASD, HF ASD, LF ASD)	Dealing with minimal and mild cases of autism

CHAPTER 3

DESIGN AND DEVELOPMENT OF ADAPTIVE MRIS SYSTEM

(Therapy-1)

3.1 Introduction

Robotic interventions have proved to have a high impact on social skills especially using robots that closely resemble with human beings [129] and [24]. Moreover, various sensors are used in this intervention that shows the improvement in communication skills before and after the interventions [130]. These sensors are also used to compare the improvement using humanoid robots when compared to other robots [131]. These robots can be used as a therapeutic playmate, social mediator, and model social agent [130] along with different controlling schemes [132] so that human-robot interaction can become more collaborative and independent and that it can resemble human behavior. NAO robot developed by French robotics company, Aldebaran Robotics, which was acquired by SoftBank Group is used in these interventions [133]. NAO Special Ed curriculum is launched that supports the Applied Behavior Analysis (ABA) principles [129], [130]. Sensors integrated with NAO are Emotiv EPOC EEG Headset, Kinect for Windows and Firefly MV 0.3 MP Camera is used for recording purpose.

This chapter explains the design and architecture of the design and development of a multi-robot based adaptive model for the improvement of joint attention and imitation of children with ASD. This model is called MRIS (Multi-robot-mediated Intervention System) and it also satisfies the EBP concern. This intervention has two parts: 1) Improvement of joint attention and 2) Improvement in imitation skills based on joint attention. In these therapies, robots act as non-human therapists to develop social skills and imitation without the use of any sensor that touches the body. The experimentation has proved this therapy as a successful robot-mediated intervention (RMI) as an evidence-based practice (EBP) in autism. This process is done using integration of several sensors. The integration of sensors ensures accuracy of data by avoiding human error in results. The results of therapies were also supported by EEG results recorded before and after the experimentation. The ultimate aim of this adaptive multi-robot based therapy is to find the parameters for joint attention and imitation that can increase the multi-communication of ASD children. The model is tested on 12 children with autism in which there were 8 sessions for each intervention for a total time of approximately 6 months.

Important contributions of this therapy are: 1) design and development of adaptive mathematical model that addresses that concern for the improvement of joint attention as well as imitation module. 2) Validation and effectiveness of MRIS system using CARS 3) Prominent progress in multi-human interaction skills of ASD children using multi-robot modeling.

3.2 MRIS Architecture (Therapy-1)

The proposed architecture of MRIS architecture is based on Zheng et al proposed model [134]. In the research done by Zheng et al., have proposed an adaptive joint attention (JA) model only and that for a single robot. The previous model did not focus on the concept of multi-person interaction of an ASD child in the proposed model. This research proposes a new adaptive model for both joint attention as well as imitation to improve the multi-communication of an ASD child using 2 NAO robots in the intervention simultaneously. This architecture is explained in two parts: 1) Least to most (LTM) based joint attention protocol and 2) Imitation protocol. The system architecture diagram is shown in Figure 3.1. The experimentation has been performed for both with/without inter-robot communication. These two modules are explained in the next sections.

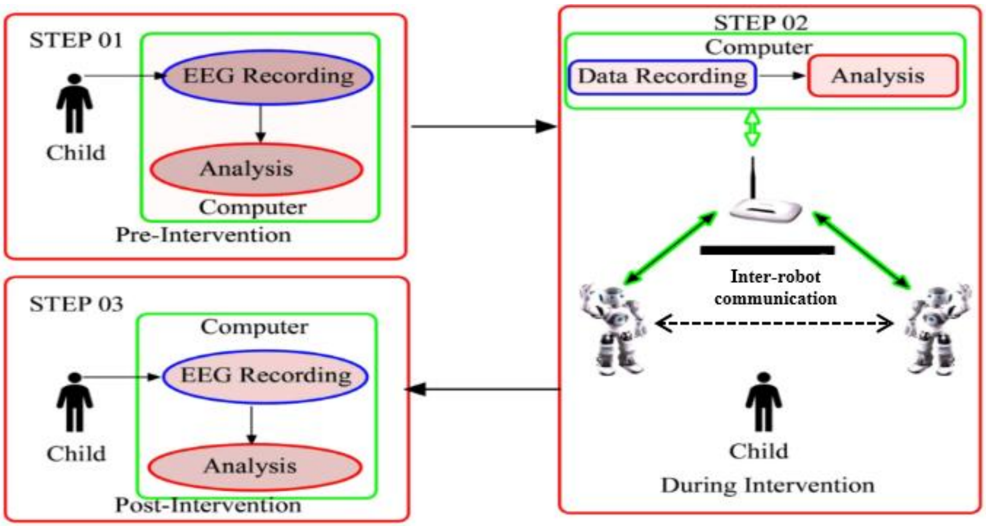


Figure 3.1 The three step system architecture explaining the intervention step

There are two main types of attention while measuring the joint attention of ASD child: overt Attention and covert attention. The focus of this research is on overt attention as for children

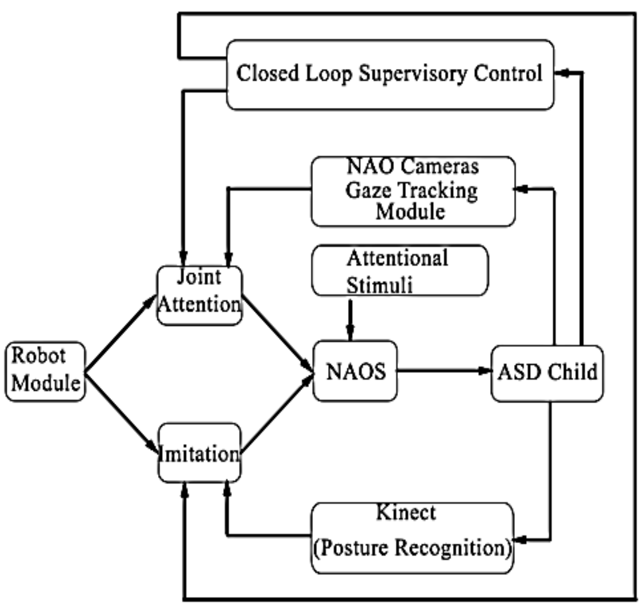


Figure 3.2 Supervisory closed loop adaptive module for both joint attention and imitation tasks using LTM cues.

with autism, head movement is considered the most important parameter while measuring joint attention [135-139]. This research uses NaoqiPeoplesPerception module from Naoqi SDK. The API offers the module ALGazeDetection which provides information about the human's gaze behavior [140-146]. ALGazeDetection allows you to analyze the direction of the gaze of a detected person, in order to know if he/she is looking at the robot. It also detects whether the person's eyes are open or close.

Following steps are followed in the designed algorithm for eye gaze detection using head movement.

1. Enabling the face detection module: By detecting the face of a person using ALFaceDetection module and studying its orientation, it is possible to detect whether or not this person is looking at the robot.

2. Calculating the score: First the scoring value called "lookingattherobot" is computed for the person. Scores between 0-1, describes the confidence in the fact that the person is looking at the robot

3. Memory key: This score is stored in memory key PeoplePerception/Person/<ID>/LookingAtRobotScore.

4. Comparison with threshold value: This is then compared with the threshold value.

   Score > threshold value, the person is characterized as looking at the robot.

   Score < threshold value, the person is characterized as not looking at the robot.

   The threshold value can be changed by setting up the tolerance. The threshold value was set to 0.7 for all the experiments.

5. This result is added to the description of the people in the ALMemory by filling the key

   "GazeAnalysis/PersonStartsLookingAtRobot",

   "GazeAnalysis/PersonStopsLookingAtRobot".

Regarding Kinect posture recognition module, imitation is measured using Kinect V2 sensor whose depth camera is used. The imitation of the child was recorded and evaluated by Kinect based on the joint movement. For measuring the imitation action i.e., hand raised, hands down, moving forward and moving backward, 4- joints were taken in account, namely: Right wrist, Left wrist, Neck joint, Spine mid, Start point. Improvement in imitation for this research is based on criteria of attempt and perception of action rather than accurate muscle movement.

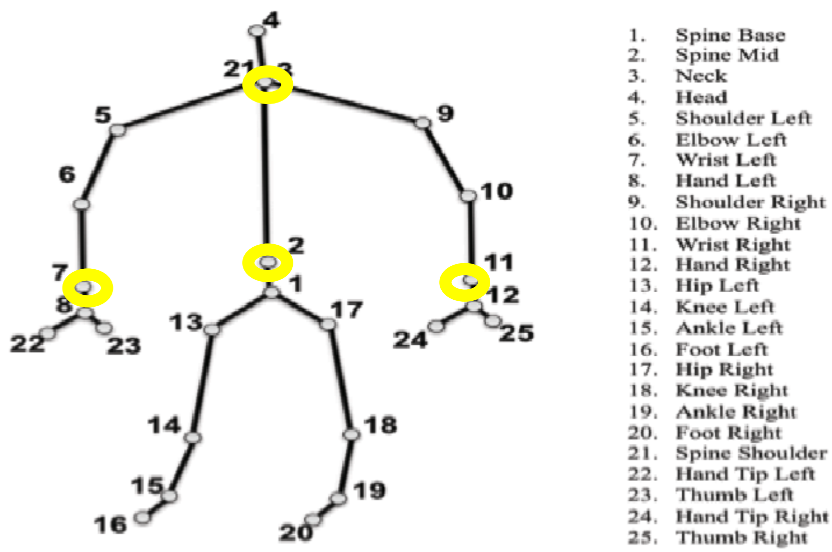


Figure 3.3 Skeleton tracking using Kinect sensor.

There are two types of evaluation criteria: Binary evaluation, Triad or 3-point score evaluation as per medical research [147-151] as well as robotic intervention for imitation [152-154]. This module is evaluated on the basis of binary assessment of imitated actions. The imitation accuracy was calculated by Kinect based on joints movement.

Regarding measuring the action of the child, the imitation of the child was recorded and evaluated by Kinect based on the joint movement as shown in Fig. 3.3. The child's imitation (by Kinect) and robot's imitation (recorded by file writing) was compared to see if the child has imitated the action or not. Later, the file stitching was done using time stamps. Real-time tracking of joints of ASD child is done using Kinect however the comparison of child and robot's action is done offline to estimate the score of ASD child.

3.3 LTM Based Joint Attention Protocol

MRIS system introduces an LTM based protocol for joint attention using (LTM) cues as shown in Figure 3.2. One of the most frequent tools used for screening and diagnosis of ASD is LTM based cues methods [155]. In this method, the child is first introduced with the cue that is least intruding and if required i.e. in case of no response, he/she is moved to the next level pertaining more prominent cue [156] and [157]. Robot mediated interventions (RMIs) have been extensively used in teaching skills for children with ASD [158].

There are three steps for the designed protocol: 1) Visual Cues based on "Rasta" (cyclically changing eye color of robot) and "Blinking". This is the least intruding stimulus as a cue. 2) In the second protocol, along with the visual cues, speech cues are added. Speech cues added in the intervention are "Hi" and "Hello". As the speech cues are to more prominent hint and are therefore added as the second level of LTM based cues for the ASD child [157]. The last and most prominent cue is motion cues. This comprises of visual, speech and motion cues all combined. The motion cues added are "Move forward", "Move backward", "Stand-up", and "Sit-down". These LTM based prompt cues are only used when required. Previous models have used the LTM based concept only for the imitation module while in the proposed intervention both JA as well as imitation are adaptive and can be improved using one therapy.

3.3.1 Networking Protocol

LTM-based joint attention has a networking protocol as shown in Figure 3.4. In these two transmission control protocol (TCP) servers, denoted by S1and S2, both NAO robots have joint attention as well as imitation module. Both modules are thread-safe and running in a parallel fashion. These modules are integrated with TCP clients, which are represented by Cij. The communication follows the protocol where Si denotes ith server number, Cij: i is server number, to whom this client must be connected, and j is client number connected to server i.

There are two transmission control protocol (TCP) servers implemented in the main control computer. The two control modules i.e. eye contact module (measuring the eye-gaze) and reinforcement stimuli module are used for recording the gaze contact duration of child and use of LTM cues for JA module respectively. Stimuli activation and feedback of data through the TCP servers during the experiment is done using the communication of control computer and NAO robots. Figure3.5 represents these modules reinforcement stimuli module by C11 and C12 whereas

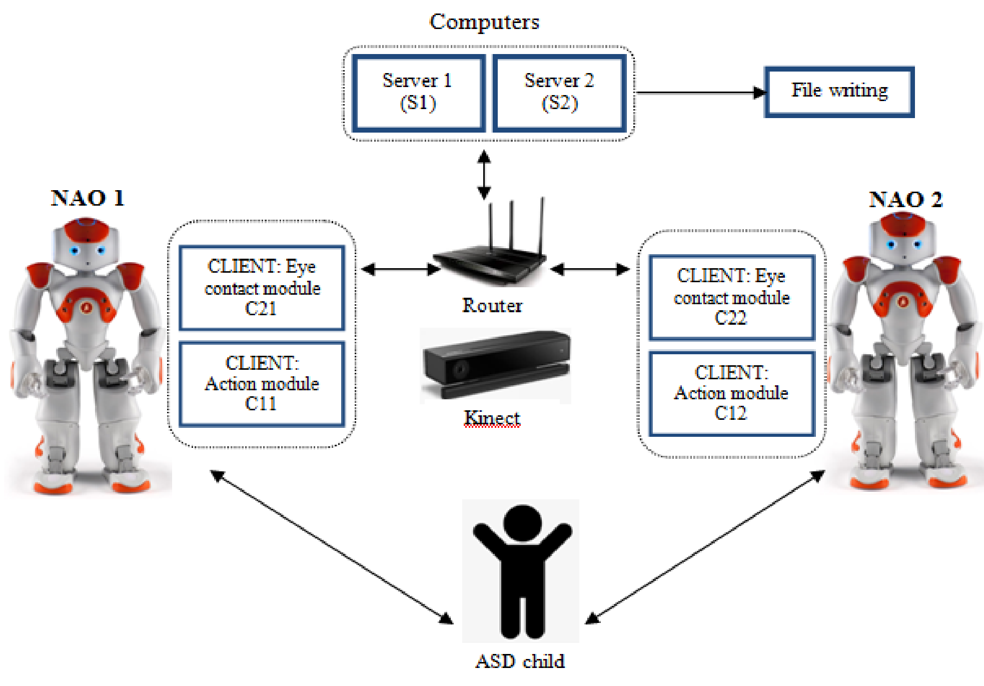


Figure 3.4 Networking protocol of MRIS system with two NAO robots as clients.

eye contact modules (measuring the gaze shift) are represented by C21 and C22. The server sends commands to both NAO robots as clients simultaneously via router and feedback is received during the experiment. The networking protocol is shown in Figure 3.4.

3.3.2 Mathematical Model for Joint Attention

MRIS-LTM mathematical model for joint attention is shown below in equations (3.1), (3.2), (3.3) and (3.4).

$$S_1 = XOR\ \{Initialization, Execution, Termination, Reward\} \quad (3.1)$$

$$S_2 = AND\ \{Robot1, Robot2, Gaze\ Module\} \quad (3.2)$$

$$S_3 = OR\ \{V, V + S, V + S + M\} \quad (3.3)$$

Here "Si" denotes the output from different hierarchy levels. Hierarchical level of states is mentioned as: S_1 is the top level state or parental state. S_2 is intermediate state and S_3 is the leaf node state. Control operators are indicated in Equation (1), (2) and (3). S_1, S_2, S_3 triggers the level respective to that once it meets the conditions.

$$O_{JA} = f_c\{Joint\mathrm{int}attention, Reinforcement\ Stimulus\} \quad (3.4)$$

$$O_{JA} = f_c\ (\mathrm{p(t)}, \mathrm{s(t)}) \quad (3.5)$$

Where,

$$\mathrm{P(t)} = f_{hr}\ (R_i, t_{sec}) \quad (3.6)$$

Where, f_{hr} is a complex function of human response and depends on:

1. R_i – robot number
2. t_{sec} – time to maintain eye gaze contact/gaze concentration

Where, p(t) gives information about:

1. Response time
2. Attention duration

And s(t) is a robot reinforcement stimulus variable:

$$\mathrm{s(t)} = f_R\left(R_i, q_i(\mathrm{t}), ST_j\right) \tag{3.7}$$

Where, i is the robot number, ST_j is the type of reinforcement stimulus and q_i(t) is the robot joint trajectories (in case of any robot motion).

The joint attention module of this MRIS architecture is explained in detail using mathematical equations (3.4) - (3.7). Using the reinforcement stimuli; the joint attention of the ASD child is measured in this module. O_{JA} is a module to measure joint attention and stimulus module. In execution state, the two modules are running in a parallel manner. The joint attention of the child is recorded by both robots using first operand deals while the second operand deals with reinforcement stimulus given by the robots as shown in equation (3.4). Further explanation of this mathematical model is in equation (3.5) – (3.7).

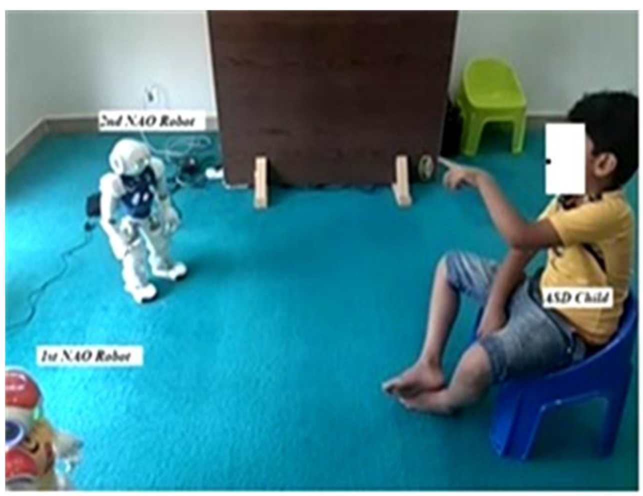


Figure 3.5 ASD child interacting with multi-robots for the improvement of joint attention.

3.3.3 Pseudo Code for Joint Attention

Where load Priority Queue List will give the list of ASD participants, Robotic actions () generates the details of actions to be performed by the robot, $R_{behavior}$ represents current robot's behavior, JA_child () represents the gaze tracking module evaluating joint attention of the participant. Higher_Stimulus defines the next action of the next robot to be handled.

Reinforcement_stimulus = [“V”, “V+S”, “V+S+M”]

Initialization

n=1, C=0, I=1;

Load Priority queue (ASD participants.xlsx)

Step 1:

R_{action}(n)=***Robotic actions*** (List (Index))

$R_{behavior}$(n)= R_{action}(n)

Current_gaze(n) = ***JA_child*** ();

If

Current_gaze(n)= Expected_JA

Reward

INSERT (***Priority queue***, Current_gaze(n), I)

Write (***SORT*** (priority queue), ASD participants)

Terminate

Else

I=***Higher_Stimulus*** (Current_gaze(n), Priority queue)

n++;

Go to step 1

In Step 1: As the index is passed to Reinforcement_stimulus, the robot performs an action and therefore defines a behavior of the robot, R_{action}. Then a function is initiated that collects the data for JA and gives the Current_gaze(n)= Expected_JA, a reward is given. If the current response is not equal to the expected response, then the loop goes to increasing the intensity of reinforcement stimulus. Figure 3.5 shows the interaction of ASD children during LTM-based joint attention module for multi-agent communication to develop multi-person communication skills.

3.3.4 Harel Statechart Model of MRIS Joint Attention

Figure 3.6 shows the Harel Statechart model for the joint attention of the MRIS system. Whether the system will be shifted to the next cue or not is decided with the help of two signals i.e. timeout (TO) and target hit (TH) along with threshold values. This model places two checks in regard with the joint attention module: 1) Time during which eye gaze of the child should get engaged towards the robot and 2) the minimum time duration for which the gaze contact is established therefore considering it as (TH) target hit. The joint attention module is activated by the minimum gaze duration of at least 5 secs. However, if there is no action by ASD child then TO triggers. To represent module 1 and 2 in execution stage i.e. the second stage in this model.

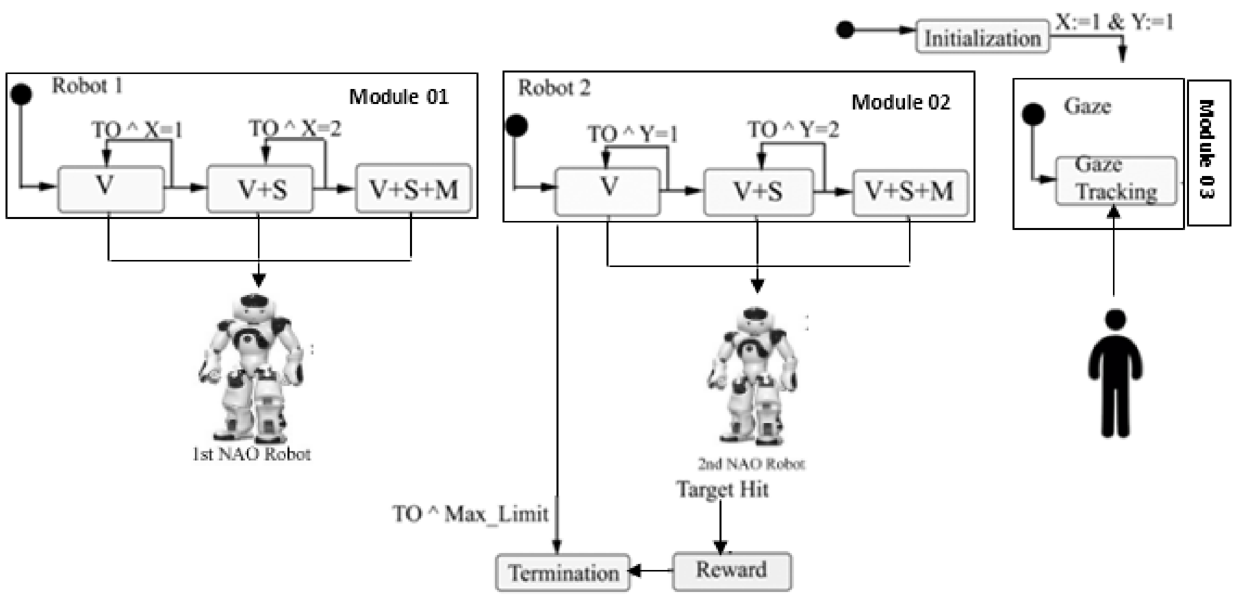


Figure 3.6 Harel Statechart model for joint attention module

This is represented by {V}. In case of no response or a value less than the threshold value for joint attention, it moves to the next level represented as {V+S}. If the threshold requirement for second cue is also not met, the therapy is moved to the third stage i.e. the highest level {S+V+M}. Both the robots are working in parallel manner in the execution stage. The reward of the child is given at the end of the therapy. One of the hyper-parameter of this model is the threshold value. The threshold value for this research is 50%.

3.3.5 Electrode Placement Criterion

Pre and post-intervention assessment of cognitive state of brain of ASD child was done to detect the change in the state of brain due to intervention. During the assessment of the cognitive state of brain, the child is asked to count or speak English alphabets. After the reinforcement activity is finished, the EEG neuro-headset is used to measure the child's brain state.

The ASD child was made to sit on a comfortable chair where the researcher from the NUST was standing in front of the child and the child's therapist was standing beside the child. First the researcher measured the CMS and DRL at A1 and A2 and then electrodes were placed on child on marked locations. If the child resisted, the data was not collected for him/her. The data collection in this case was done after a break.

Figure 3.7 Headband adjustment on child's head.

The procedure for headband adjustment on child's head includes: moist the electrode pad with saline water, following the initial hydration steps, each of the inserts (sensor unit with moist pad) must be removed from the pack and securely mounted in the EPOC neuroheadset. For headset placement use both hands, slide the headset down from the top of the head. Place the arms approximately as depicted in Fig. 3.7, being careful to place the sensors with the black rubber insert on the bone just behind each ear lobe. Correct placement of the rubber sensor is critical for correct operation. The 2 front sensors should be approximately at the hairline or about the width of 3 fingers above your eyebrows. After the headset is in position, press and hold the 2 reference sensors (located just above and behind your ears) for about 5-10 seconds. Good contact of reference sensors is the key for a good signal.

These EEG readings were recorded for two minutes. For the assessment of ASD child's attention, frontal channels of neuro-headset were processed. For the time when child was feeling uncomfortable, the headset was removed and data was collected again after any reinforcement activity and interaction with therapist. The processing of the EEG signal is described in section 3.5.5.

3.3.6 Evaluation of Parameters for Joint Attention

Following parameters were evaluated for measuring the improvement in joint attention of the child with ASD: Gaze shift is recorded by NAO, duration of each gaze contact, latency in shifting the gaze when a stimulus is given, number of gaze contact with 1st robot, number of gaze contacts with 2nd robot, maximum and minimum duration of gaze contact, average gaze duration, time for intervention, time series vector, vector of deviation angles, total number of attention diversion recorded by Kinect, total number of attention diversion towards left robot recorded by Kinect, total number of attention diversion towards right robot recorded by Kinect, numbered of missed reinforcement stimuli

3.4 Imitation Protocol Using Joint Attention

The supervisory closed-loop adaptive module for both joint attention and imitation tasks using LTM cues is shown already in Figure 3.2. The central module i.e., the supervisory control module of MRIS is the one that controls the cues based on the child's response and therefore adaptively changes the command of the robot with the child's behavior. The adaptive algorithm decides whether the child is following the command or not. If the child performs the imitation task correctly, the algorithm shifts to the next level. In the joint attention module, NAO camera gives the adaptive closed-loop supervisory control feedback whereas Kinect is used for correct posture information useful for evaluation of imitation module.

The networking protocol of the MRIS-imitation module is the same as the joint attention module, shown in Figure 3.4. The gaze contact is responsible for an action module that makes the imitation module adaptive.

3.4.1 Mathematical Model for Imitation Module

This module of the MRIS system is adaptive as it uses the JA of the child to activate the imitation tasks. After the joint attention is established for at least 5sec the imitation intervention starts. This concept for allotting a threshold time makes sure that only one robot is activated at a time and there is no overlap in robot's activation. The imitation tasks performed by the robot are: Move Forward, Move Backward, Raise Hands, Hands Down. These motion gestures are imitated by the child and are measured using Kinect to calculate the success rate. Figure 3.8 shows the engagement of autistic child during imitation tasks activated by the joint attention module.

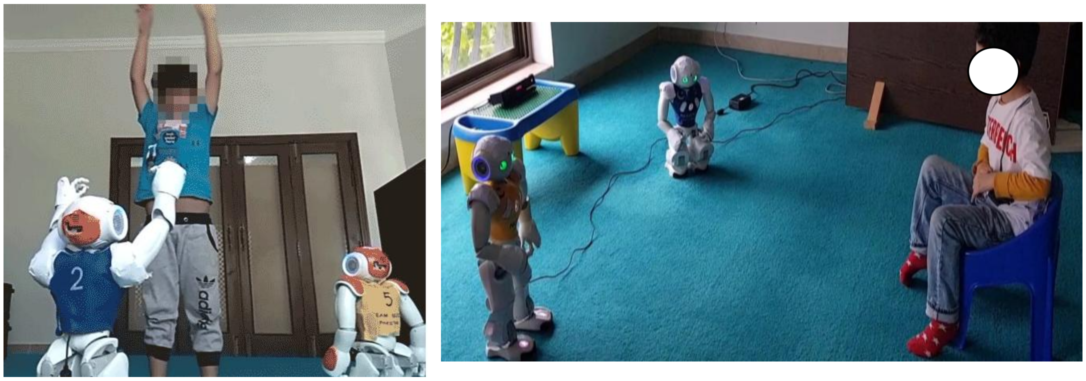


Figure 3.8 MRIS- Imitation module activated by joint attention of the child.

MRIS-LTM mathematical model for imitation based on joint attention is shown in equations (3.8), (3.9), (3.10) and (3.11). "Si": output from different hierarchy levels. "i: hierarchy number. All the states are mentioned in a hierarchical level i.e. S1 is the top-level state or parental state. S2 is the intermediate state and S3 is the leaf node states the same as for joint attention module. The difference from the joint attention module is that in this case leaf node S3, only one robot will execute and perform imitation tasks

$$S_1 = \text{XOR}\left\{\text{Initialization, Execution, Termination, Reward}\right\} \tag{3.8}$$

$$S_2 = \text{AND}\ \{\text{Robot1, Robot2, Gaze Module}\} \tag{3.9}$$

$$S_3 = \text{OR}\ \{\text{OR}\{\text{Forward, Backward}\}, \text{OR}\{\text{Raise hands, Hands down}\}\} \tag{3.10}$$

$$O_{JA\rightarrow IM} = f\{Joint attention, imitation\} \tag{3.11}$$

$$O_{JA\rightarrow IM} = f\left(\text{p(t)}, \text{IM(t)}\right) \tag{3.12}$$

Where,

$$\text{P(t)} = f_{hr}\ (R_i, t_{sec}) \tag{3.13}$$

Where, f_{hr} is a complex function of human response and depends on:

1. R_i – robot number

2. t_{sec} – time to maintain gaze contact

Where, p(t) gives information about:

1. Response time

2. Attention duration

And IM(t) is a robot reinforcement stimulus variable:

$$\text{IM(t)} = f_R\left(R_i, IM_j\right) \tag{3.14}$$

Where R_i is the duration of gaze contact noted by the robot and IM_j denotes the imitation task sequence executed by the robot and j denotes the type of imitation. The iterations continue till completion of the therapy session.

3.4.2 Pseudo Code for Imitation Module

Where, ***Robot$_{actions}$ ():*** Gives details of actions to be performed by the robot, ***JA_child():*** noticing and evaluating joint attention of an ASD subject. In initialization, different variables and Priority queue list is loaded.

In step 1 of pseudo code, the child's joint attention is captured with an eye gaze tracking module and its current response is compared with the expected response. If the current response is the same as expected response, then robot performs an action which must be imitated by the child. If actions are performed by child successfully, a reward is given as "*Good Job*".

Robot actions = ["Move Forward", "Move Backward", "Raise Hands", "Hands Down"]

Initialization:

N = 1, C = 0, t_d = 10;

Load priority queue (subjects);

Step 1:

Current_response = ***JA_child*** ();

IF (Current_response == Expected_response)

R_actions = ***Robot Actions*** (List(index))

Delay (t_d)

n++

Reward (Good job)

Terminate

3.4.3 Harel Statechart for Imitation Module

The state machine diagram shown in Figure 3.9, it has three variables: X, Y, and Max_Limit along with two events: TO (time out) and TH (target hit). “X” and “Y” variables' values range from 1 to 2 only, where “X” deals with robot one's second hierarchy level states and

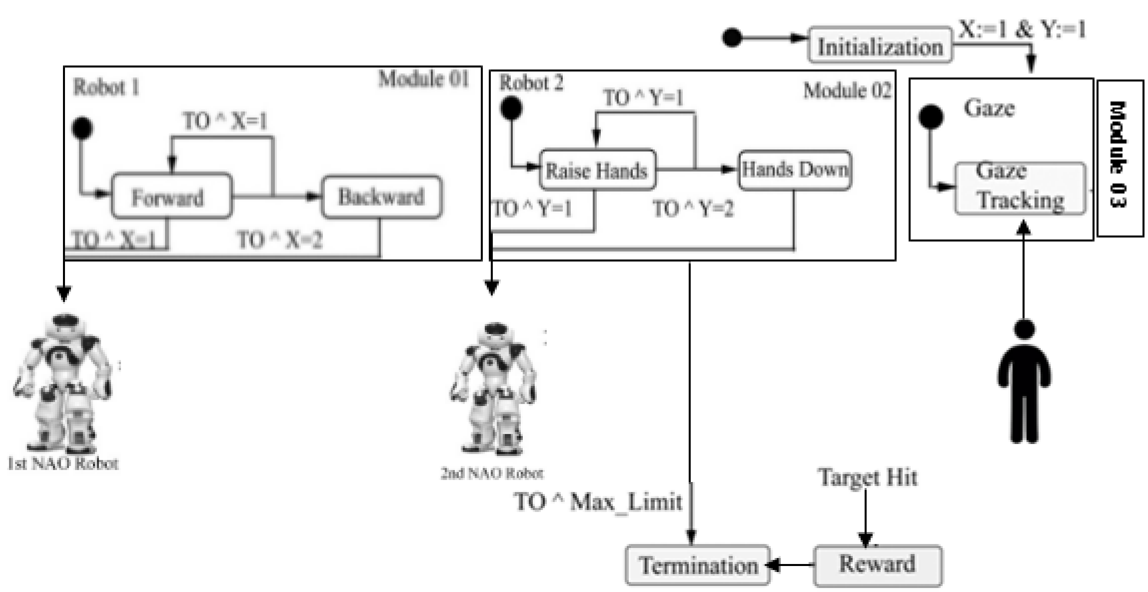


Figure 3.9 Harel Statechart model for imitation module.

“Y” deals with robot two’s second hierarchy level states. “Max_Limit” variable is set to 3 that means the intervention will be given 3 chances if failed. “TO” is an event that occurs only no response is there for 10 seconds. While “TH” is another event which occurs only if the current response of ASD child matches with expected response. In that case, a reward is given to the child by waving hand and saying, “Good job! You tried very well”.

3.5 Materials and Methods

3.5.1 Experimental Setup and Design

Figure 3.5 and Figure 3.8 show the environmental setup for the above-discussed therapy. A comfortable plastic chair is used for the child in front of the two NAO robots. The robots are at a distance of 1m from each other. The placement of robots and children was in an arc-like manner. However, for the imitation module, the child is supposed to stand in front of the robots.

MRIS follows the experiment architecture explained above in Figure 3.1 showing that two sets of interventions were performed i.e. 1) human-robot interaction (without any inter robots’ interaction) and 2) human-robot interaction along with the inter robot communication. However, the focus of this research was not to inter-compare the two strategies. This is because the two experiments were not done in parallel therefore the CARS score for later experimentation was improved because of the first experimentation that was done without inter-robot communication. The aim was to observe the improvement over the time in both strategies rather than which therapy is better than another as the protocol of both the therapies are different and depends on the intervention to be conducted. Also the parameters observed for improvement in both of the interventions are different and therefore cannot be compared.

3.5.2 Subjects

12 ASD children including 11 males and 1 female participated in this therapy. The ASD children were recruited from the Autism Resource Center (ARC). The approval of this study was taken from autism specialist and director board of ARC. The recruited participants were already evaluated clinically based on the Childhood Autism Rating Scale Schedule (CARS) criteria by the experts. A written consent from parents of these children was also signed consent before the therapy. The statistical characteristics provided by ARC about the participants are presented in Table 3.1.

It should be noted that the children for both experimentation i.e. Human-robot interaction (without any inter robots' interaction) and human-robot interaction along with the inter robot communication was done on same set of children, however the intervention for human-robot interaction along with the inter robot communication started after the intervention of human-robot interaction (without any inter robots' interaction) ended. Therefore, for the same reason the CARS after for the first therapy became CARS before for the second therapy. Moreover, the experimental design for both the interventions is different therefore these two therapies were independent in regards of results and analysis also.

Table 3.1 Statistical characteristics of ASD children involved in therapy

Subjects	Age (YEARS)	Type of eye gaze contact
1	7.5	Immediate
S2	8	Immediate
S3	9	Immediate
S4	10	Delayed
S5	5	Immediate
S6	8.5	Immediate

S7	4.3	Immediate
S8	3.7	Immediate
S9	9.9	Immediate
S10	9.8	Immediate
S11	10.4	Immediate
S12	9.4	Immediate

3.5.3 Human-Robot Interaction without Inter-Robot Communication

The cognitive brain activity of the ASD child is measured before the experimentation. The child is taken to the EEG area to measure the attentiveness of the brain. This process starts by reinforcement activity in which a child is asked to count from 1 to 10 and after a delay of 30s, he/she is asked to read the alphabets. After the reinforcement activity is finished, the EEG neuro-headset is used to measure the child's brain state. Following that, the robotic intervention begins in which a child is seated on a chair towards the robots in the intervention area. The child is introduced to the robots with their first intervention therapy i.e. LTM-based adaptive joint attention module. The eye gaze response is recorded using NAO cameras. After the robotic intervention, the child is again taken to EEG room to measure the cognitive brain state of the child after therapy is recorded as shown in Figure 3.1. After the intervention of joint attention is completed, the ASD child is introduced to second intervention i.e., imitation. The same protocol is followed for this part of the intervention also. The therapy starts as the child enters the intervention area. At the arrival of a child in the room, the robots give stimuli by flashing their eyes with the same color. After this attention gaining stimuli, both the robots wait for 5sec so that a child can make eye gaze contact. Once eye gaze contact is established, the robot is activated for imitation tasks. This is how the intervention for the imitation task is utilizing the joint attention module.

3.5.4 Human-Robot Interaction with Inter-robot Communication

In this part of the therapy, the concept of inter-robot communication along with the human-robot interaction of ASD children is introduced. The main reason for inter-robot communication is that there is a situation where a person might have to listen/ watch the conversation done by others in daily life. At the start of experimentation, both the robots are sitting and facing each other. The therapy starts with one of the robots that stands up and says “hello” along with waving action to the partner robot. The partner robot shows the response by standing up, saying “hello/hi” coupled with a waving action.

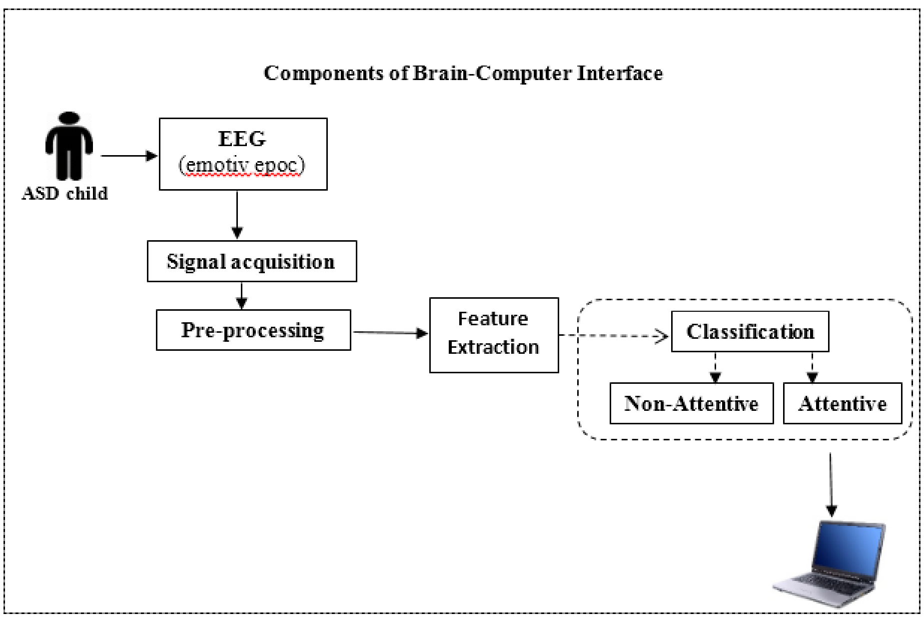


Figure 3.10 EEG protocol for measuring the cognitive brain state before and after intervention.

During this time of inter-robot communication, the response of child is recorded. This is done by noticing the JA of the child towards the robot giving the stimuli or not. Once done with the inter-robot communication, the robot turns and starts communicating with the child similarly. The robot involved in communication with the child is selected randomly. In return the child’s response is recorded in terms of joint attention (child's gaze contact), imitation (waving of hand) and speech.

3.5.5 EEG Signal Processing

The EEG signal processing for pre/post-intervention is done as shown in Figure 3.10. The dotted line for classification shows that the band comparison of alpha with others will be done in future research. Fig 3.11 shows the time series data for each modality for one subject in single intervention.

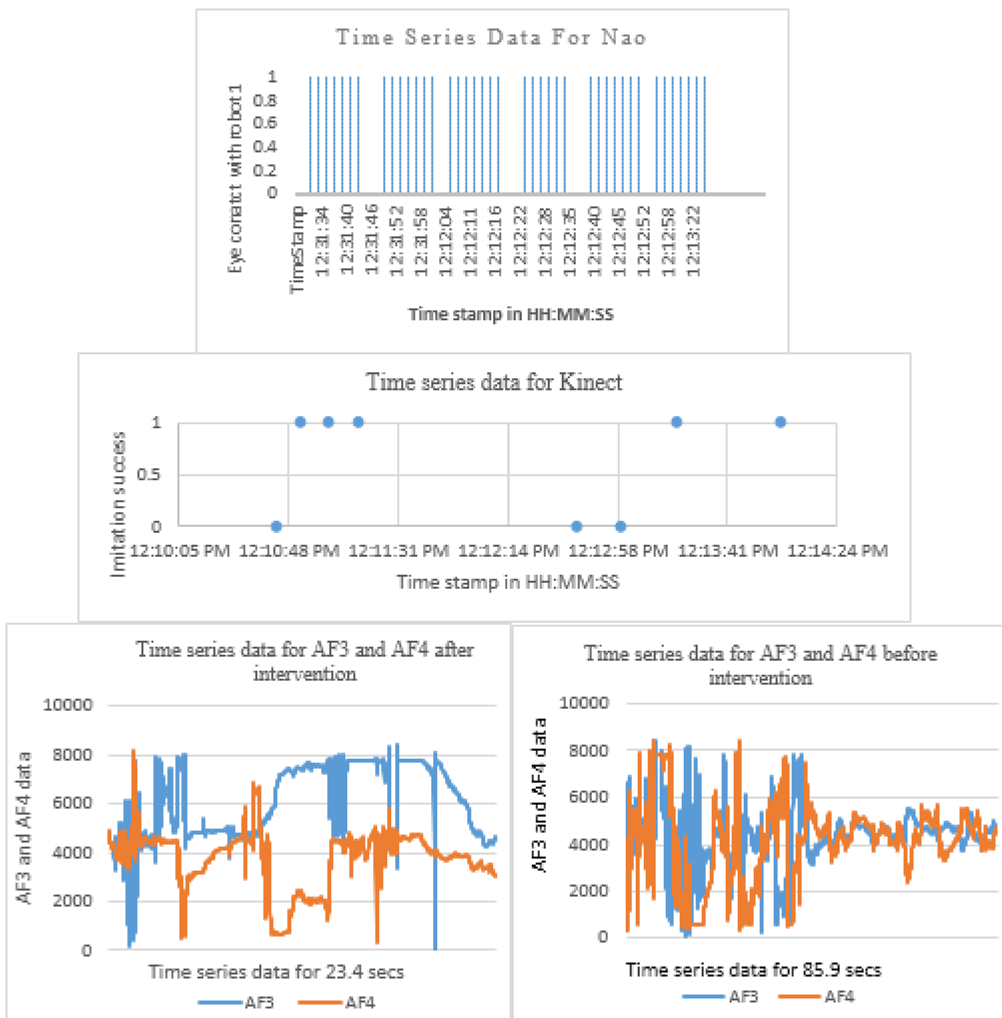


Figure 3.11 Time series data for each modality i.e., NAO, Kinect and EEG (before and after intervention).

The sampling rate for Emotive Epoc is 128 Hz. As the task was based on attention so the selected channels were 1 and 14. i.e., AF3 and AF4. For handling the artifacts, channel averaging was done using averaging on the selected channels i.e., AF3 and AF4, for artifacts attenuation, as artifacts usually have much larger amplitudes than the signals of interest. By averaging the EEG time-courses of all trials, only the stimulus-related EEG activity survives while the unrelated random background noise is attenuated. Now for extraction of signal in alpha band, band pass filter is applied. The range of band pass filter corresponds to the alpha band. Discrete time filter, Infinite Impulse Response (IIR), second order Butterworth filter with Fc1 is 8 and Fc2 is 13hz. PSD/peak analysis was used to classify whether the child was attentive or not. This was done using Welch's power spectral density estimate. For power spectral density (PSD), Welch method was applied and for peak extraction the minimum peak prominence was set to be 7 as shown in Fig. 3.12. Average SNR calculated before and after were 1.06 and -11.28.

However, the criteria for improvement in attention for this research is if (highest peak in alpha band after intervention) – (highest peak in alpha band before intervention) is positive, the child has an improved attention after intervention. Moreover, the channels that refer to the alpha cognitive band were AF3 and AF4. As these channels are related with the working memory that counts for the attention [159-161]. Frontal channels were targeted keeping in view the comfort of child. Moreover, because of no/less hair, the signal quality for frontal electrodes (aiming at cognitive activity) were good. Alpha, beta and theta estimates (difference of alpha with theta and beta bands) for false positives is not the focus of current research. Relationship between different bands for autistic children is not the scope of current research. This will be evaluated in future research articles.

For this research only alpha band has been compared for peak values as literature has reported it to be the most significant for cognitive activity [162-164]. For experimental results, statistical analysis and validation of therapy-1 please refer to chapter 6: section 6.2.

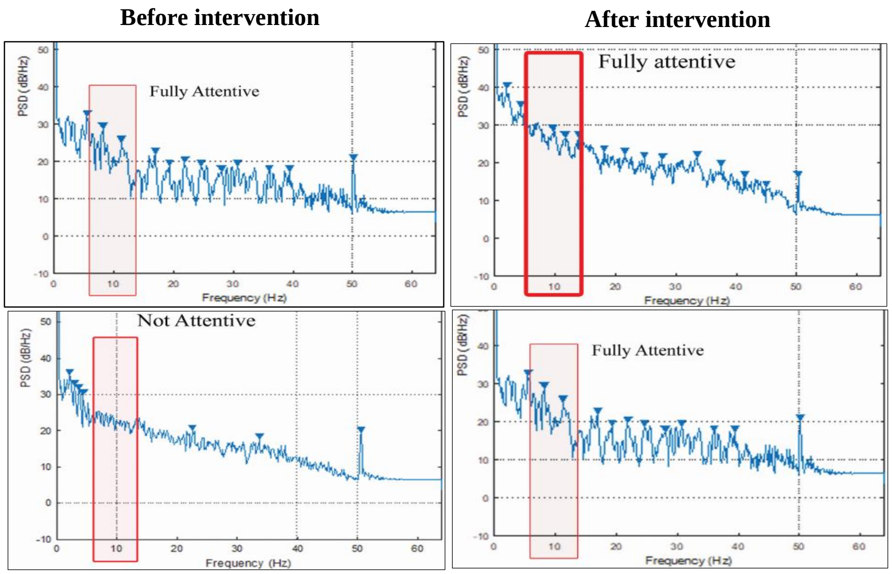


Figure 3.12 Power Spectrum Density using Welch method of EEG signal for two sample subjects.

3.6 Summary

This chapter explains the details about first adaptive therapy i.e. MRIS architecture in detail. It explains the MRIS system architecture that has two modules within itself i.e. 1) LTM-based joint attention module and 2) Imitation protocol based on JA. For both the sub-modules, mathematical model, networking, state-machine diagram and pseudo code are explained in detail. Eye gaze tracking using NAO cameras is done for joint attention module and posture recognition by kinect is done for imitation module. Parameters recorded during the joint attention module are: 1) Delay in making gaze shift with the robot. 2) The time duration for which eye gaze contact is made. Kinect measures the child's posture and matches that with the posture of the robot during the imitation module. This chapter also discusses the parameters that are evaluated to show the improvement in the ASD child'. Moreover, the results of this experimentation were obtained for both with/without inter-robot communication during the intervention. The advantage of this therapy is that it does not use any body-worn sensor during the intervention and the sensor integration ensures the correctness and reliability of data.

CHAPTER 4

ROBOTIC THERAPY FOR MULTI-HUMAN INTERACTION (Therapy-2)

4.1 Introduction

Several methodologies have been implemented for using robots as tools for improving communication skills and social interaction of ASD children. Research shows that pre-school and school-aged ASD children had improved social communication with adults because of these robotic therapies as compared to having a therapy session with adults.

This chapter focuses on the interventions for improvement in inter-human communication. This is done by noticing the multi-human communication of ASD child before and after the robotic intervention. This will help to check if the robotic therapy can practically improve the multi-human communication in ASD child or not. This research aims at developing a new 3-step framework for improving multi-human interaction by observing parameters of joint attention, imitation and command following for both visual as well as auditory commands. The framework has been tested on eight ASD subjects with 10 sessions over a period of two and a half months (around 75) days. Each session consisted of 18 cues presented by a single robot. Therefore 36 cues were presented in total by both robots.

Therapy-1 was introduced in order to improve the multi-human interaction skills of children with ASD using multi-robot concept. The improvement in therapy-1 was observed by recording data over a period of time. However, there was no actual observation in therapy-1 regarding tangible real-world interaction of those children with ASD in a normal environment. Therefore, the extension of therapy-1 focuses on therapy-2, in which the same set of children were exposed to real-world multi-human interaction in order to observe the improvement in multi-human interaction unlike the improvement observed in therapy -1 that recorded improvement in multi-robot interaction.

4.2 System Architecture

In this therapy, the aim is to present a multi-robot-based therapy focusing on the improvement of the social interaction skills of an ASD child. The reason for introducing multi-robot is to familiarize the children with multi-human communication, a social trend. The therapies have done so far focused on one-to-one communication of a child and a robot. Therefore, we introduced the therapy that measures improvement in multi-human communication by using multi-robot therapy.

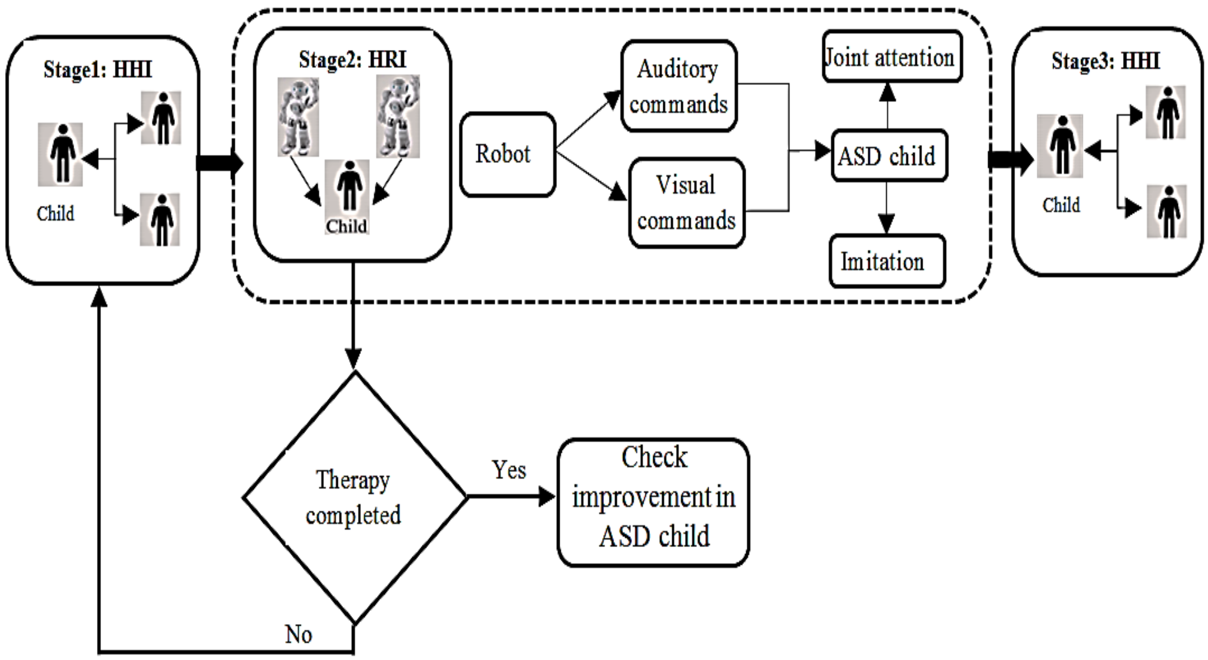


Figure 4.1 System architecture explaining the 3 step therapy for improvement in multi-human interaction skills of children with ASD

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 interaction of an ASD child are done in Stage 1 and 3, 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 improve multi-human communication in daily life scenario or not. Figure4.1 shows the architecture of this three-stage research for multi-robot therapy to improve a multi-human communication in ASD children. The two sets of commands given in therapy were control commands and auditory, visual and visual + auditory commands. Control commands were initiated to gain the initial attention of an ASD child and therefore were not included in the evaluation process. The control commands were: calling the child's name and high five. In the evaluation process, auditory, visual and visual + auditory commands were included. The set of auditory commands consisted of directing commands such as asking a child to stand up, sit down, jump, etc. Whereas the visual command set consists of give/ take of a ball (any color) from the child. The last command is a waving gesture along with speech comprising auditory and visual simultaneously.

4.3 Networking Protocol

The architecture for human-robot interaction is shown in Figure 4.1. The networking protocol for this therapy is shown in Figure 4.2. Each robot was running an eye contact module (measuring gaze movement) along with auditory and visual commands. Two transmission control protocol (TCP) servers are implemented in computers represented by C11, C12, C21, and C22. The modules running on the robot were TCP client integrated and they were sharing real-time data to the laptop which was running corresponding TCP servers. This information was being written in a file via file writing process. The server modules are S1 and S2.

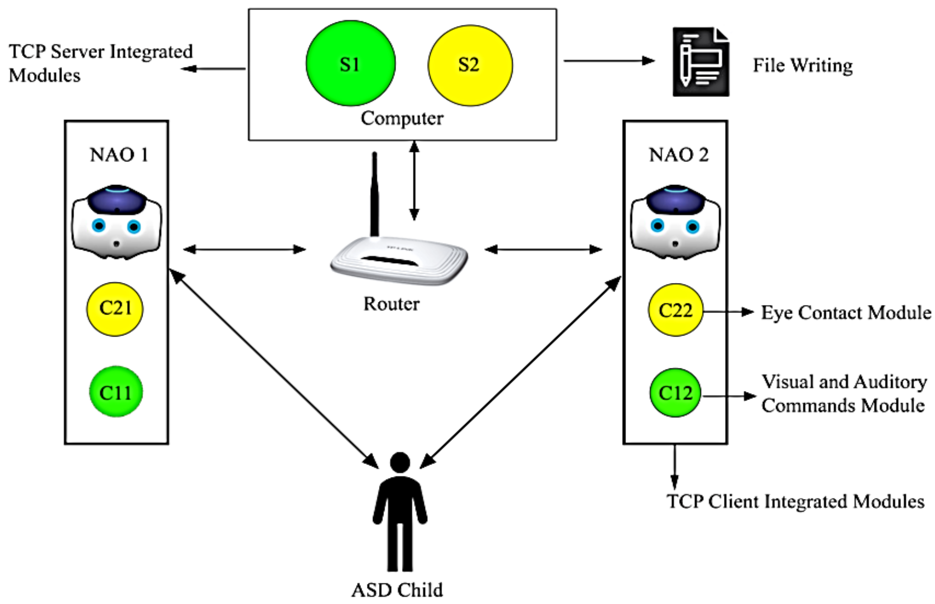


Figure 4.2 Networking protocol of the therapy for improvement of multi-human interaction in children with ASD.

4.4 Materials and Methods

4.4.1 Human-Robot Interaction without Inter-robot Communication Subjects

Eight ASD children (7 males and 1 female) participated were recruited in the therapy. 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.

4.4.2 Ethical Statement

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

4.4.3 Experimental Setup and Design

Experimental setup of the therapy is shown in Figure 4.3 for all the three stages of multi human-robot interaction for improving the multi-communication skills of children with ASD. 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 so that there is no biasness introduced in the therapy towards any of the robots.

In Stage 1 and Stage 3, the child interacted with two persons as shown in Figure 4.3. The reason for introducing multiple people was to check improvement in the multi-communication skills of an ASD child. Both the persons were sitting 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. The control command session was followed by auditory, visual and combination of both commands for an ASD child. An evaluation was done based on commands followed by an ASD child. A total of 14 commands were given on the basis of based on which an ASD child was evaluated. These include 6 auditory, 6 visual and 2 auditory + visual commands. Command set for auditory includes: stand up, sit down and jump. The command set for visual includes: passing the ball of a specific color, taking the ball of a specific color from any person during communication and pointing the ball of specific color. Form a combination of auditory and visual commands the child was asked to wave along with the speech. These command set for auditory, visual and auditory and visual was repeated twice. Therefore, the child was evaluated for total of 14 commands. Each command took approximately 60 secs. Therefore, the total time for human-human interaction in Stage 1 and

Stage 3 was approximately 14 minutes. The commands were given in random order and the response for each specific command category was recorded.

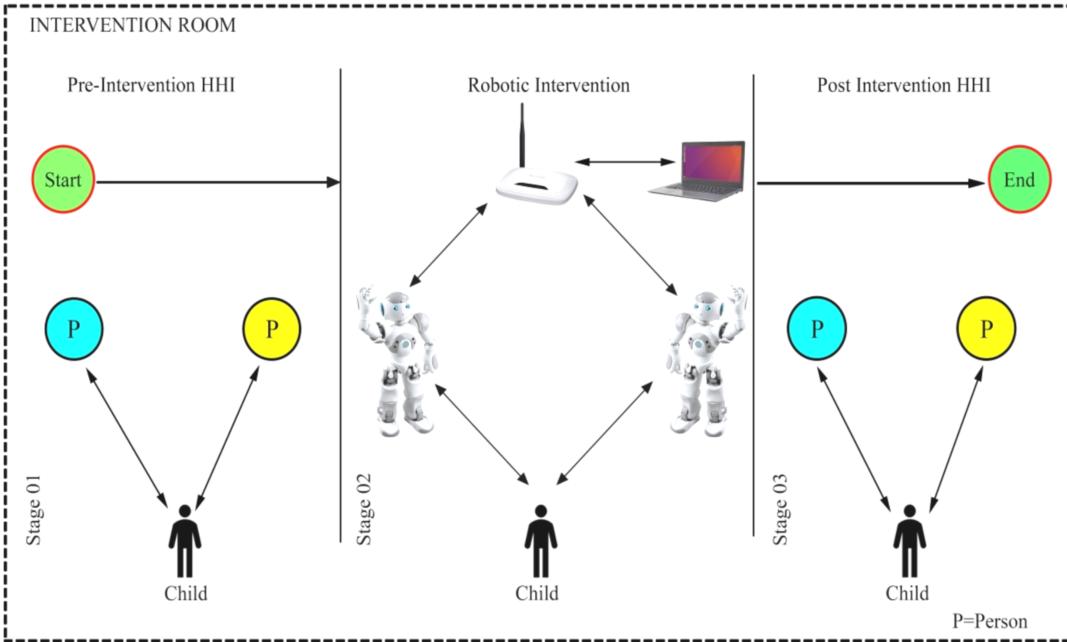


Figure 4.3 Experimental design of three-stage therapy for improvement in multi-human interaction of children with ASD.

In Stage 2 of 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 and Stage 3. Lighting conditions for both 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 waving gesture of the robot. A combination of auditory and visual command includes waving along with speech “Hello nice to meet you”. This set of command action was repeated 18 times by each robot. The total number of times actions performed (trials) by both robots were 36. 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. In this stage post-therapy, multi-communication effect is observed. The total time for this session was 15 minutes. The number of sessions given to each subject was 10. The experiment was 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.

Figure 4.4 Interaction of ASD child in three-stage therapy for improvement in multi-human interaction of children with ASD.

However, for an incorrect or no response, the therapy was conducted without any change. Figure 4.4 represents the interaction of ASD children in the three-stage therapy for improvement in the multi-human interaction of children with ASD. For experimental results, statistical analysis and validation of therapy-2, please refer to chapter 6: section 6.3.

4.5 Summary

This chapter discusses a new proposed therapy that focuses on the pioneer multi-robot intervention for improving the multi-communication and social interaction skills of ASD children in common social scenarios. The proposed intervention is a three-stage therapy. In Stage 1, the child interacts with more than one person creating a usual multi-communication scenario. In Stage 2 of the proposed intervention, two robots are introduced prompting various audio and visual cues along with combinations of both. In Stage 3, the child again interacts with humans as in Stage 1. The effect of the therapy is measured by noticing the difference of command following in Stage 1 and Stage 3.

This therapy 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. The estimated time for each session is 6 minutes. We measured the command following the child for pre-HHI and post-HHI.

The advantage of the proposed therapy of multi-robot interaction is that it does not require human/therapist involvement during the robotic therapy at stage 2. Moreover, for this suggested therapy, the main focus is on promoting their social skills and interaction by multi-communication scenario, therefore, eliminating the isolation effects.

However, robot-mediated therapies have some drawbacks e.g. trust issue of parents with these robots, the adaptation of activities to each child as this can complicate the use of robots in schools and institutes [117]. However, there are some open-ended questions e.g. what is the best way to integrate a robot in a therapy? 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.

CHAPTER 5

COMPARISON OF EFFECTIVENESS OF DIFFERENT STIMULI IN ROBOTIC THERAPY (Therapy-3)

5.1 Introduction

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 [18], [13] and [165]. This is because the behavior of a robot is predictable and consistent, unlike humans.

Recent research has shown reliability on robotic therapies for improvement in core impairments of autism unlike low inter-rater reliability among clinical experts on this matter. To facilitate the improvement using robots, this study evaluated the effectiveness of three different stimuli in robotic intervention for children with autism spectrum disorder. This chapter explains a new therapy that compares three different stimuli given in a robotic intervention using NAO robot. The focus of this therapy is to look into the effectiveness of each stimulus and compare the three different reinforcement stimuli introduced in the therapy using NAO robot i.e., visual, auditory and motion cues. The reinforcement stimuli were presented in least-to-most (LTM) order by the robot to check the effectiveness of each cue based on the joint attention of a child. 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 beforehand. The experiments were conducted in order to investigate this concept. The therapy was conducted on 12 ASD children, each with 8 trials over a period of 2 months. Average time was approved for each session was approximately 15 minutes excluding the time consumed in reinforcement activity during the introductory session. The results indicate that visual cue is the most effective reinforcement stimuli whereas speech is least effective in the entire given stimulus for the robotic therapy based on joint attention and time eye gaze contact is maintained. The results of the robotic therapy help in selecting suitable reinforcement stimuli for robotic interventions to be used in the future for improvement of autism spectrum disorder.

This study aims to identify the most effective stimulus interaction of the robot with autistic children to facilitate better human-robot communication. 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 autistic child based on stimuli.

5.2 System Architecture

Figure 5.1 explains the intervention room which is divided into two parts using a wood partition. The networking protocol of this architecture includes a TCP server and corresponding

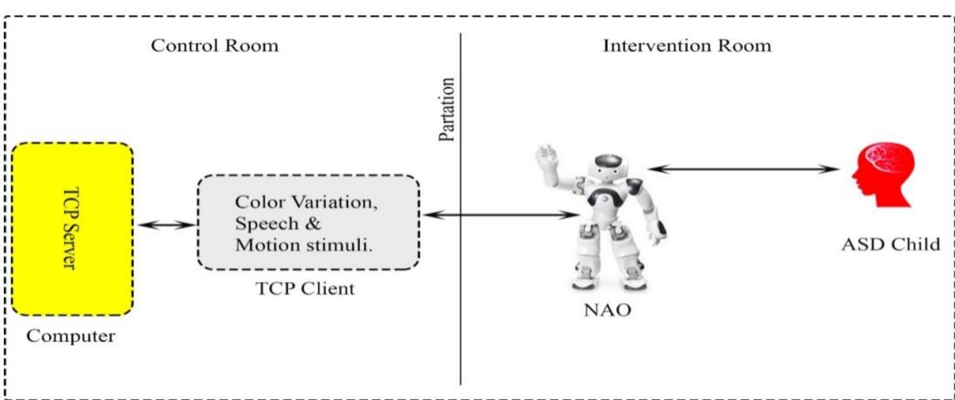


Figure 5.1 Architecture of the therapy conducted for comparing three different stimuli.

two TCP clients. These TCP clients have been integrated with reinforcement stimuli modules. Reinforcement stimuli modules consist of three different types of stimuli i.e. visual, speech and motion stimuli. They were ordered from least to most i.e. color stimuli to motion stimuli to compare the effectiveness when presented to an ASD child in a robotic intervention as shown in Figure 5.2. All devices were communicating with each other using a WIFI network.

5.2.1 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:

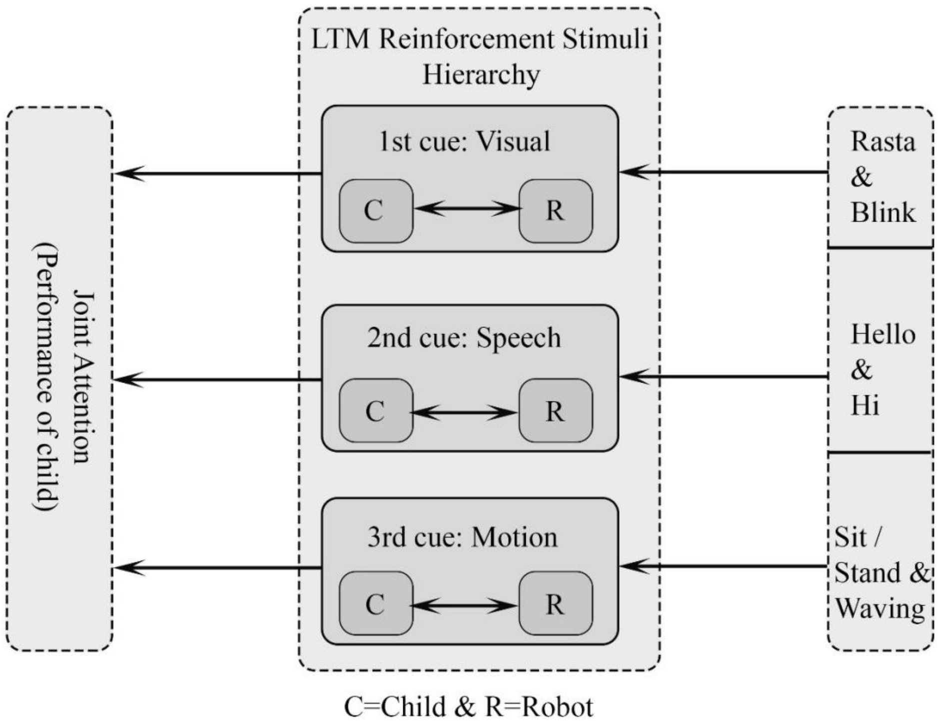


Figure 5.2 Least-to-most (LTM) hierarchy model for stimuli of the therapy.

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

With the start of the intervention, the system gets into the initialization stage. Then execution is started were two independent modules are running in parallel. These modules are joint attention module and TCP client integrated reinforcement stimuli module. Both of these modules are running on NAO robot to notice the joint attention of ASD child. The information is written in a text file. After the execution state is completed, the system goes in termination state, where the intervention is terminated. The discussed FSM model is shown in Figure 5.3.

5.3 Mathematical Model and Pseudo Code

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

$$U = XOR\{ Initialization , Execution , Ter\min ation \} \tag{5.1}$$

The binary variable U will only be 1 if any of the state of the whole system is functional. Execution of these three states in a parallel manner is not possible so following are the allowed combinations of bits of states.

Table 5.1 Allowed state combinations

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

Rest all other combinations are not valid for this system. A joint attention module will be used to capture the information of gaze (eye gaze contact) of the participant. It can be represented as:

$$JAM = \sum_{i=1}^{n} \left(\int_{j=0}^{m} dt \right); \quad m, n \in \Re \tag{5.2}$$

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

$$RSM = \sum_{y=1}^{n}(RS_y); \quad n \in \Re \wedge n \leq 3 \tag{5.3}$$

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

$$RS_y = \begin{cases} Visual & ; \quad y=1 \\ Speech & ; \quad y=2 \\ Motion & ; \quad y=3 \end{cases} \tag{5.4}$$

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.

$$Exe\_State = AND \ (JAM \ , \ RSM) \tag{5.5}$$

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

5.4 Materials and Methods

5.4.1 Subjects

12 ASD children participated in this therapy in which there were 4 mild and 8 minimal cases. Each child had been exposed to three different types of reinforcement stimuli. The duration of this therapy was 2 months in which 8 experiments, 1 trial per week was conducted.

Pseudo Code

```
Robot_Stimuli_List = {"Visual", "Speech", "Motion"};
Person_Joint_Attention [3];
Initialization:
Is_Person_Present, Index;
Execution:
Step 01:
If(Is_Person_Present)
        Stimulus=Present_Stimulus (Robot_Stimuli_List (Index));
        Robot_Behavior (Stimulus);
        While (Robot_Behavior)
        {
                JA=Participant_Joint_Attention ();
                Person_Joint_Attention[Index].Push(JA);
        }
        If (index == length(Robot_Stimuli_List)-1)
        Go To Step 03;
Step 02:
Index ++;
Go To Step 01;
Termination:
Step 03:
Write_File (Robot_Stimuli_List, Participant_Joint_Attention);
Terminate ();
```

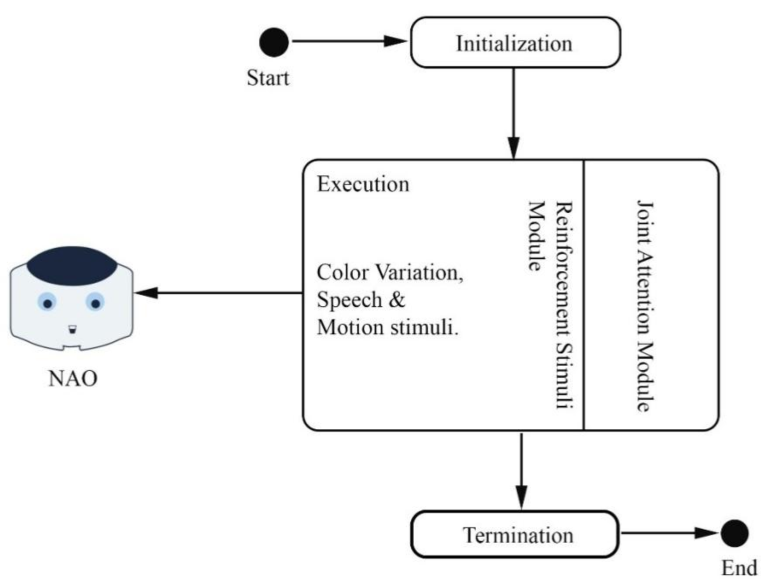


Figure 5.3 Finite State Machine (FSM) model for the therapy conducted to compare the effectiveness of different stimuli.

5.4.2 Ethical Statement

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

5.4.3 Experimental Setup and Design

The main aim of this therapy is to check the effectiveness of different reinforcement stimuli in a robotic intervention presented to ASD children. The cues given in this therapy are presented in Table 5.2.

Table 5. 2 Cues presented to ASD children in the therapy

Total cues	Visual cues	Auditory cues	Motion cues
12	4	4	4

In experimentation, the child was sitting in front of NAO robot. The robot was 1 meter away from the child. The robot starts with giving the reinforcement stimuli. The reinforcement stimuli follow the Least-to-most (LTM) model. No biasness was introduced in any of the 8 experiments/trials as lightning conditions, cues, time for each cue, etc. were the same. During the intervention, the robot was presenting reinforcement stimuli to ASD child and the joint attention of the child was recorded during experimentation as shown in Figure 5.4.

For experimental results, statistical analysis and validation of therapy-III, please refer to section 6.3 of chapter 6.

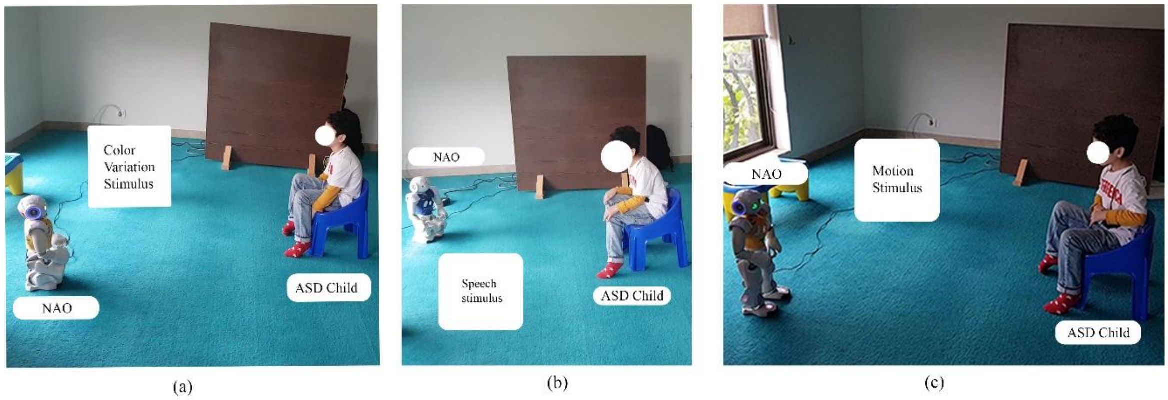


Figure 5.4 Intervention pictures (a) Visual stimuli (b) Auditory stimuli (c) Motion stimuli

5.5 Summary

This chapter discusses a new proposed therapy that focuses on the comparison of three different stimuli. The three stimuli presented in this therapy are visual cues (color based variation), speech cues and motion cues. The experimentation was conducted for a period of 2 months with 8 trials. In this proposed intervention, the child interacts with the robot sitting at a distance of 1m. This experimentation led to the comparison of different stimuli based on the time given to each stimulus by an ASD child. The effectiveness was therefore noted in terms of joint attention. Therefore, the performance of all subjects against three different categories of reinforcement stimuli was recorded. The variation of the effectiveness of stimuli was recorded based on the autism category of the ASD child. This therapy led to the identification of the most effective stimuli for each category of autism.

CHAPTER 6

EXPERIMENTAL RESULTS AND STATISTICAL ANALYSIS OF THERAPIES

6.1 Introduction

This chapter focuses on experimental results of all the three therapies explained in previous chapters. The purpose of these therapies was to develop joint attention and imitation skills (therapy-1), multi-human social interaction (therapy-2) and comparison of most effective stimuli for an ASD child during the intervention. The results for these therapies are explained in detail in this chapter.

6.2 Experimental Results and Statistical Analysis of Therapy-1

6.2.1 Human-Robot Interaction without Inter-Robot Communication

There were two modules in this intervention i.e. joint attention and imitation actuated by JA. The parameters used to measure the improvement in joint attention of ASD children were as follow:

1. The joint attention or attentiveness was recorded by the gaze contact of ASD children using the robot's stimulus as shown in Figure 6.1.

2. The delay in shifting the eye gaze when a stimulus was given to the child as shown in Figure 6.2. This figure represents the pulse plot of eye gaze. It is showing the visual attention of the subject representing the total number of 12 cues including 6 Blinks and 6 Rasta in which the duration of each cue was 4 seconds. The second plot represents the

speech recognition of the subject in which total number of cues are 12 comprising of6 Hello and 6 Hi cues. The duration of each cue is 2 seconds and third plot deals with the motion-based cues given to ASD subject. In total 12 cues including 6 standing &waving and 6 sitting cues were given. Duration of each cue is standing & waving=10 seconds; sitting=5.

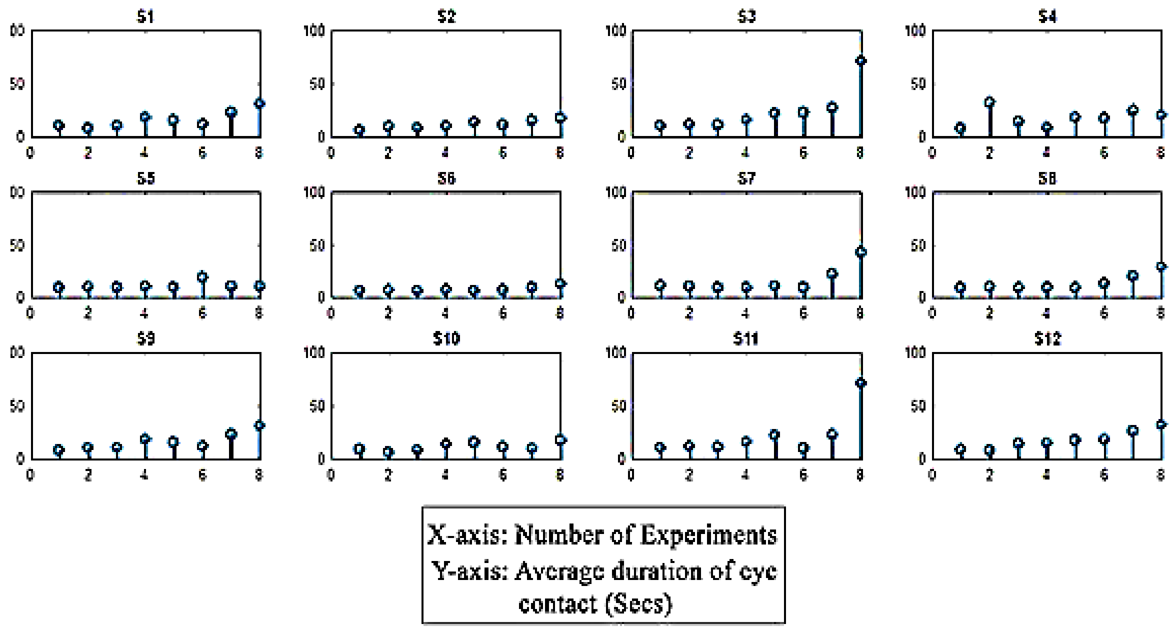


Figure 6.1 Improvement in eye gaze contact/joint attention of each ASD subject over the experiments.

3. The interest level of the participants in joint attention module was measured before and after the intervention using EEG as shown in Figure 6.4.

These parameters were used to access the improvement in the behavior of ASD children for therapy-1 as shown in Table 6.1. This table clearly shows the improvement in JA of each ASD child.

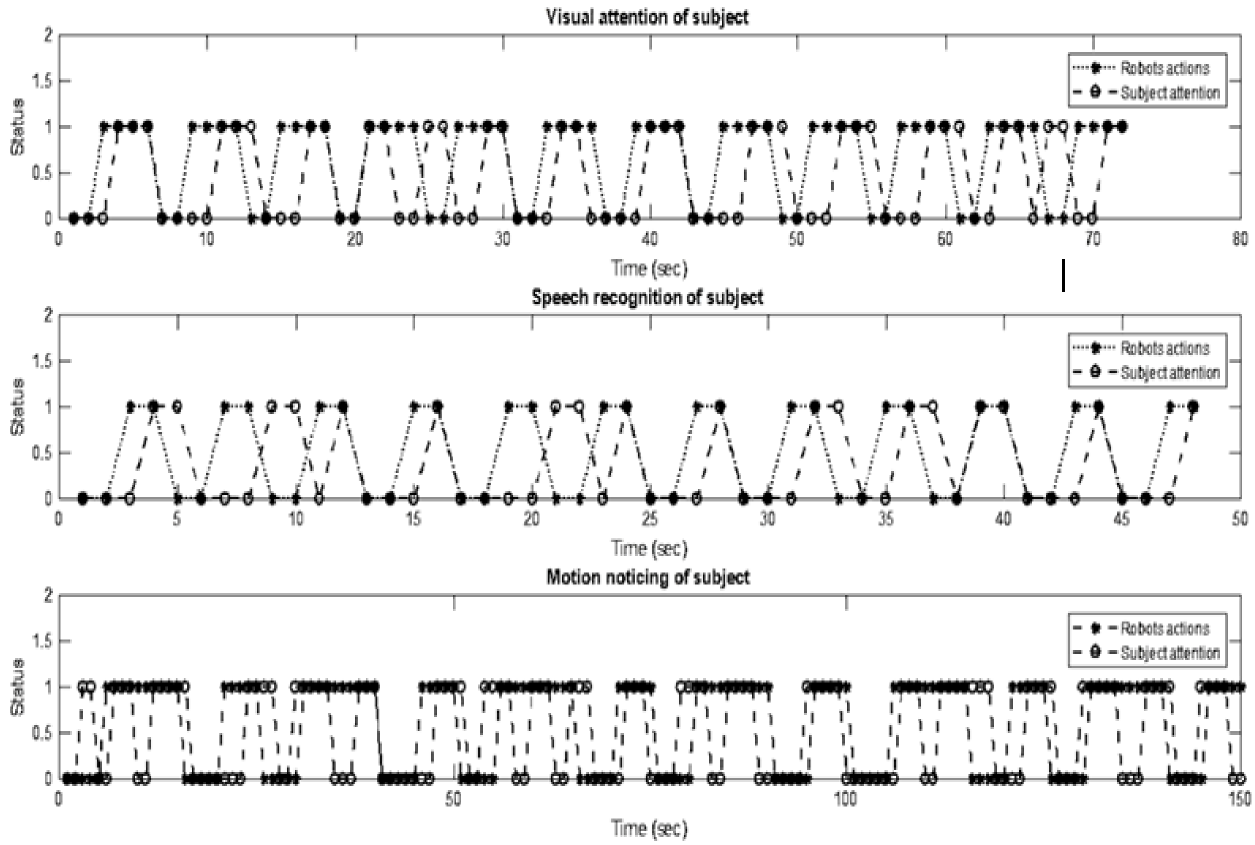


Figure 6.2 Delay in gaze shifting for joint attention module represented by a pulse plot.

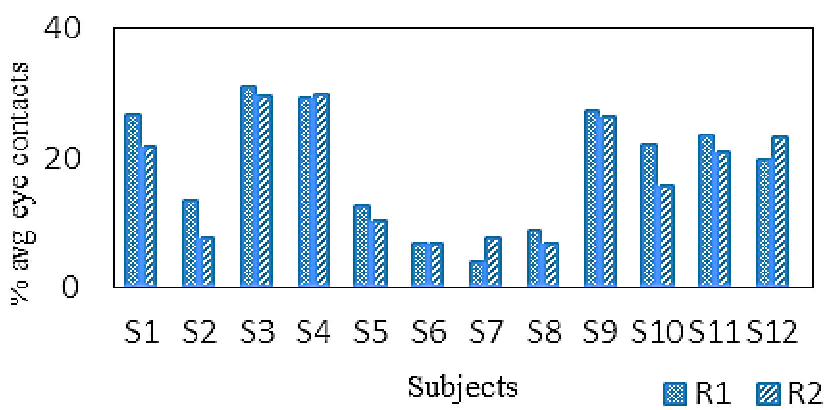


Figure 6.3 Average number of eye gaze contacts of each subject with robot 1 (R1) and robot 2(R2) over the experiments to check the biasness towards any of the robot.

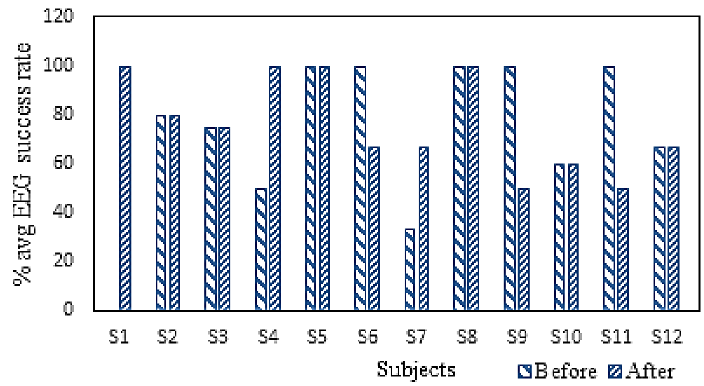


Figure 6.4 Average EEG success rate of each individual before and after joint attention module

Table 6.1 Improvement in joint attention of 12 ASD subjects.

Subjects	**Type of gaze movement**	**Joint attention accuracy of week one**	**Joint attention accuracy of all weeks**
S1	Delayed	47.5	63.6
S2	Delayed	53.5	68.8
S3	Delayed	23.1	59.6
S4	Delayed	42.18	52.5
S5	Delayed	73.1	67.9
S6	Delayed	32.6	66.1
S7	Immediate	78.8	63.1
S8	Immediate	93.4	85.5
S9	Delayed	28.9	43.4
S10	Delayed	66.7	72.2
S11	Delayed	52.4	76.1
S12	Delayed	51.5	67.6

Similarly, the results for the imitation module were assessed after the child established gaze contact with any of the robot. The following parameters were measured for imitation module to check the improvement skills of imitation in an ASD child.

1) The motor skills of an ASD child was measured by recording the imitation of the child when the robot gives a stimulus as shown in Figure 6.4

2) Measuring the stimulus-based social interaction and biasness based on the actuation of robots is shown in Figure 6.5.

3) The results in Figure 6.6 correspond to the EEG pre/post-intervention results for imitation module triggered by joint attention.

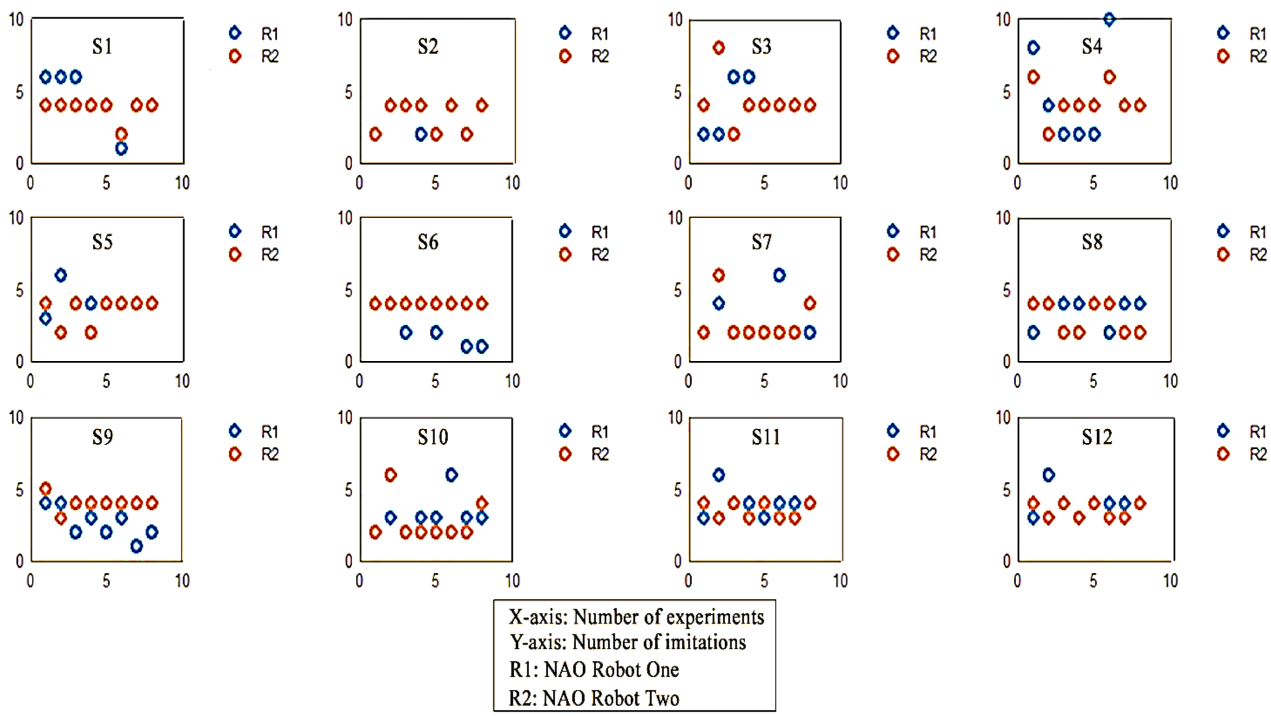


Figure 6.5 Improvement in imitation skills of ASD children over the experiments.

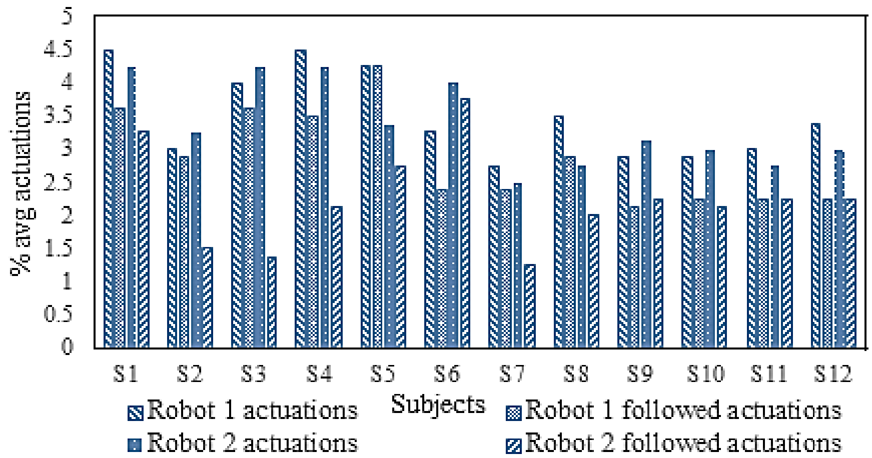


Figure 6.6 Average actuations given by the robot and followed by the child.

The overall progress in imitation behavior of ASD children from week one is shown in Table 6.2. Experimental results for both types of experiments i.e. joint attention and imitation modules triggered by JA were verified using the CARS score before and after the intervention, as shown in Table 6.3 and Table 6.4.

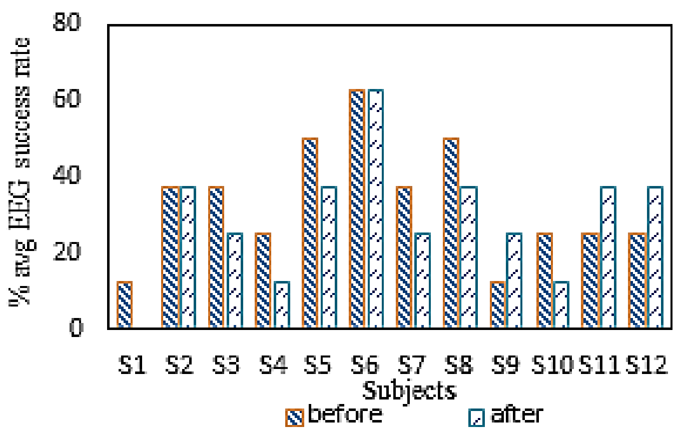


Figure 6.7 Average EEG success rate of each individual before and after imitation module triggered by joint attention.

Table 6.2 Improvement in imitation skills of 12 ASD subjects.

Subjects	Type of gaze contact	Imitation accuracy of week one	Imitation accuracy of all weeks
S1	Immediate	83.3	74.5
S2	Immediate	75	73.3
S3	Immediate	75	58.9
S4	Delayed	70.8	64.2
S5	Immediate	100	90.6
S6	Immediate	87.5	81.3
S7	Immediate	75	67.2
S8	Immediate	100	75
S9	Immediate	83.3	91.1
S10	Immediate	100	82.3
S11	Immediate	100	92.2
S12	Immediate	100	89.1

Table 6.3 CARS for human-robot interaction showing improvement in joint attention and imitation skills of ASD children.

Subjects	Age (YEARS)	avg_imi Before	avg.ja Before	CARS Before	avg_imi After	avg_ja After	CARS After
S1	7.5	2	2.3	30.5	1.3	1.5	28
S2	8	2.3	1.8	30.5	2	1.8	27.5
S3	9	2.3	2.5	35	2.5	2	33
S4	10	2	2.8	40	2	2.8	37
S5	5	2.5	2.5	33.5	1.3	1.8	28
S6	8.5	2.3	2.3	33.5	1	1	33
S7	4.3	1	1.8	22.5	1.3	1	19.5
S8	3.7	1.5	1.3	20.5	1.3	1.3	19
S9	9.9	1.5	1.5	22.5	1.3	1.3	21
S10	9.8	1.3	1.5	27.5	1.5	1.3	26
S11	10.4	2.3	2.3	36	1.3	1.3	32.5
S12	9.4	1.8	2.3	34.5	1.5	2.3	31

6.2.2 Human-Robot Interaction with Inter-Robot Communication

Total four parameters that were evaluated for each session conducted over the period of 8 weeks. Figure 6.6 shows the number of gaze contacts, the average time for gaze contact and distribution of eye gaze contact of an ASD child with both robots. Figure 6.7 shows average EEG success rate of each individual before and after imitation module triggered by joint attention. Table 6.4 shows the parameters that are evaluated for inter-robot communication within the therapy. Table 6.5 represents the results of this therapy in which waving and speech response towards robots along with attention paid by the ASD child towards intercommunication of robots was measured. The effect of this intervention can be seen by pre and post CARS showing improvement in communication skills as the score has reduced. It is represented in Table 6.6. Moreover, Figure 6.8 shows results for joint attention, imitation and inter-robot communication. Figure 6.9 shows the results for the joint attention of a subject over 8 experiments.

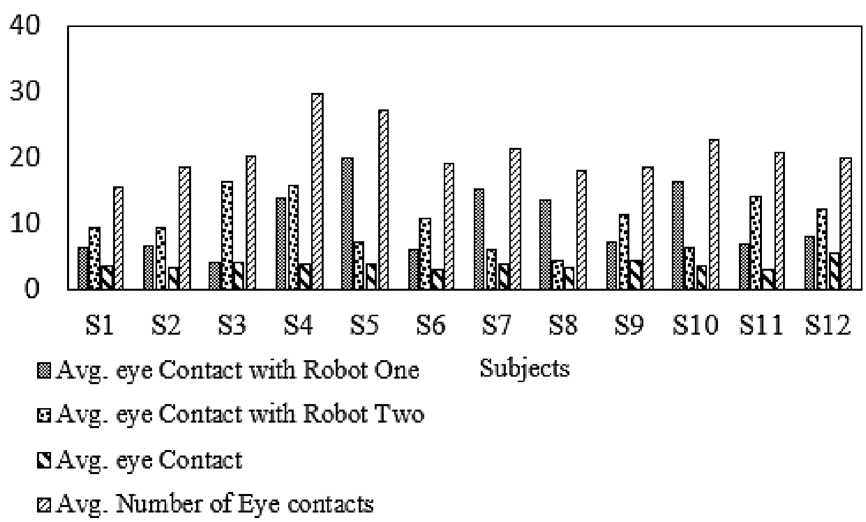


Figure 6.8 Results for joint attention, imitation and inter-robot communication.

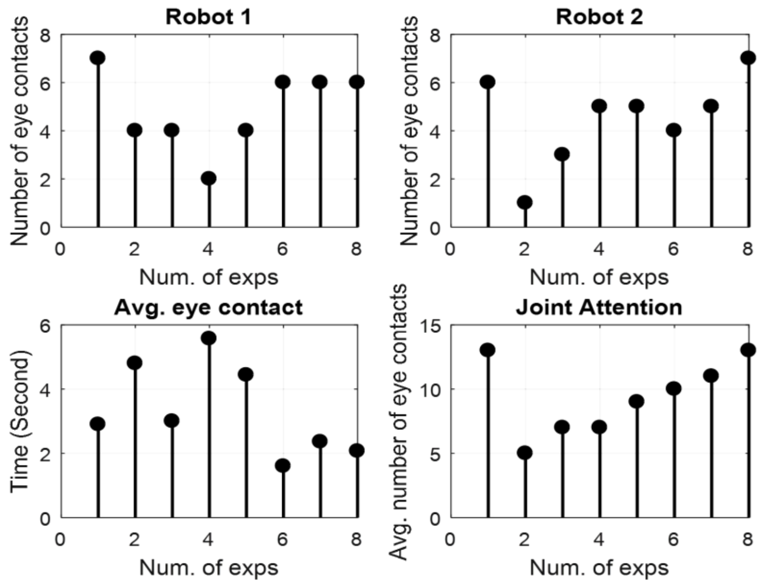


Figure 6. 9 Results for joint attention of a subject over 8 experiments.

Table 6.4 Description of parameters used for evaluation during inter-robot communication.

Parameter	Description
WR	Waving response of ASD child towards any robot
R_1-ASD	Robot one is interacting with ASD child
R_2-ASD	Robot two is interacting with ASD child
SR	Speech Response of ASD child towards a robot
COMM	Communication / interaction between the robots presented to ASD child
$R_1 - R_2$	Robot one is interacting with robot two
$R_2 - R_1$	Robot two is interacting with robot one
WR %	Accumulative waving response %age of ASD child for robot one and two
SR %	Accumulative speech response %age of ASD child for robot one and two
COMM %	Attention paid towards the robot-robot communication

Table 6.5 Results for human-robot communication during inter-robot communication over 8 experiments.

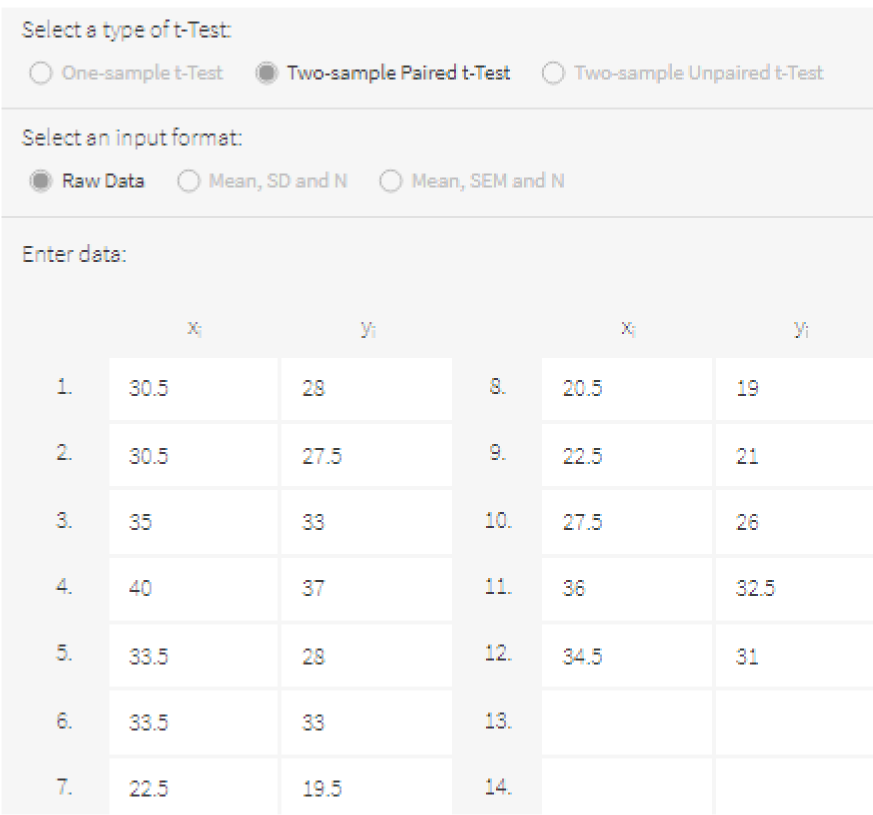
Subj.	WR		SR		COMM		WR %	SR %	COMM %
	R_1-ASD	R_2-ASD	R_1-ASD	R_2-ASD	$R_1 - R_2$	$R_2 - R_1$			
S1	7	5	5	6	8	8	75	68.75	100
S2	8	8	8	8	8	8	100	100	100
S3	8	8	8	7	8	8	100	93.75	100
S4	7	8	5	4	8	8	93.75	56.25	100
S5	8	7	7	8	8	8	87.5	93.75	100
S6	6	6	4	3	7	8	80	46.66	93.75
S7	7	3	7	6	8	7	66.66	86.66	93.75
S8	3	0	3	1	8	7	20	26.66	93.75
S9	2	4	2	2	6	6	50	33.33	75
S10	8	8	7	8	8	8	100	93.75	100
S11	4	3	6	4	7	7	50	71.42	87.5
S12	6	5	7	5	6	8	68.75	75	87.5

Table 6.6 Pre/Post CARS score for human-robot interaction during inter-robot communication during experimentation

SUBJECTS	AGE (YEARS)	CARS BEFORE	CARS AFTER
S1	7.5	28	25.5
S2	8	27.5	27
S3	9	33	32.5
S4	10	37	35
S5	5	28	24
S6	8.5	33	19.5
S7	4.3	19.5	17.5
S8	3.7	19	18
S9	9.9	21	19.5
S10	9.8	26	25.5
S11	10.4	32.5	26.5
S12	9.4	31	30

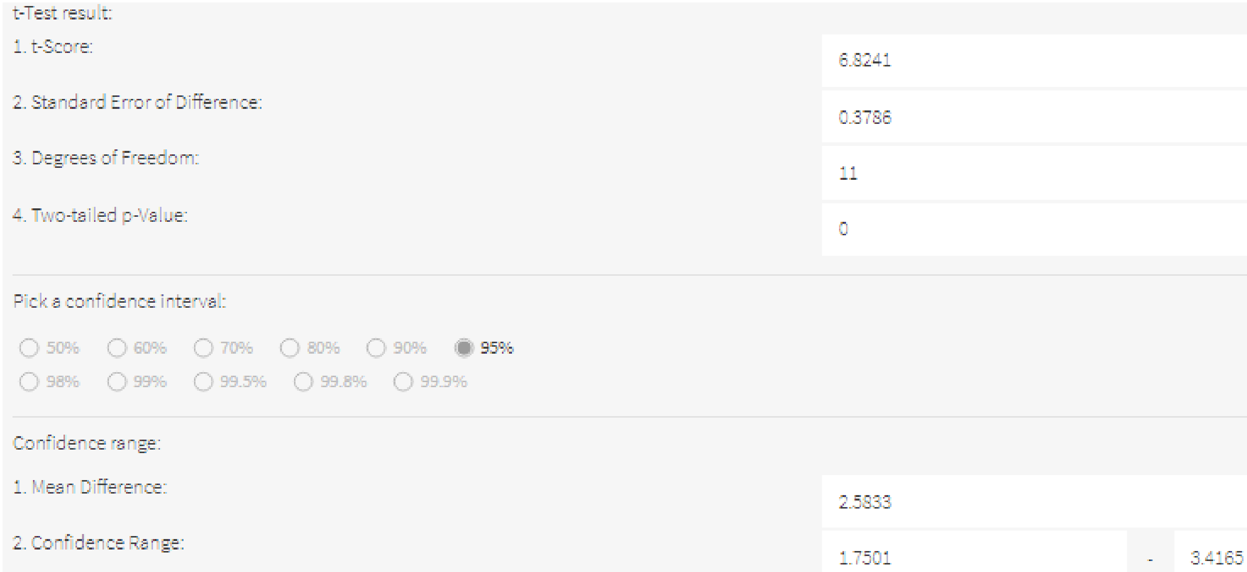
6.2.3 Statistical Analysis (Therapy-1)

Two-sample paired t-test is used for the statistical analysis of each module of this research. The results obtained for CARS before and CARS after shows the improvement in joint attention and imitation skills of the ASD children. Results for t-test of therapy-1 are shown in Figure 6.10 and Figure 6.11. Figure 6.10 shows the input format for raw data of CARS before and CARS after. Figure 6.11 shows the results for t-test. For therapy-1 the t-score = 6.8241 > t critical = 2.2010 and *p*-value is 0 < 0.05 therefore showing that data is significant. Moreover, standard error of difference is 0.3786 with DOF as 11.


Select a type of t-Test:
One-sample t-Test ◉ Two-sample Paired t-Test Two-sample Unpaired t-Test
Select an input format:
◉ Raw Data Mean, SD and N Mean, SEM and N
Enter data:

	x_i	y_i		x_i	y_i
1.	30.5	28	8.	20.5	19
2.	30.5	27.5	9.	22.5	21
3.	35	33	10.	27.5	26
4.	40	37	11.	36	32.5
5.	33.5	28	12.	34.5	31
6.	33.5	33	13.		
7.	22.5	19.5	14.		

Figure 6.10 Raw data for two-sample paired t-test


t-Test result:

1. t-Score:	6.8241
2. Standard Error of Difference:	0.3786
3. Degrees of Freedom:	11
4. Two-tailed p-Value:	0

Pick a confidence interval:

50% 60% 70% 80% 90% 95%
98% 99% 99.5% 99.8% 99.9%

Confidence range:

1. Mean Difference:	2.5833
2. Confidence Range:	1.7501 - 3.4165

Figure 6.11 t-test results for therapy-1 indicating improvement in joint attention and imitation skills of ASD children.

ANOVA (single factor) is also used for the statistical analysis of each therapy of this research. Results for joint attention and imitation for robotic therapy shows following statistical analysis: F value =12.599 > F critical value = 2.81 and *p*-value = 4.46E-06 <0.05. Moreover, paired two sample t-test has also been applied on the data of joint attention and imitation. For joint attention, t Stat = 2.60 > t Critical two-tail = 2.20 and P(T<=t) two tail = 0.02 < 0.05. For imitation, t Stat = 3.88 > t Critical two-tail = 2.20 and P(T<=t) two tail = 0.002 < 0.05.

Calculation of effect size for average joint attention and average imitation results of therapy-1 pre/post CARS score is shown in Figure 6.12. Where joint attention score is average of visual response and relating to people postulates of CARS2-ST form and imitation score is average of imitation and body use postulates of CARS2-ST form, as per therapist recommendation. The link used for effect size is http://biomath.info/power/ttest1gp.htm. For this research paired t-test has been applied to find the effect size. This test uses standard deviation and number of subject were known. The effect size reported is 0.46 showing the smallest detectable difference with alpha:

Prob(reject H0 when H0 is true) was 0.05 and Power: Prob(reject H0 when H1 is true) was 0.80. The value of beta is (1-power) = 0.2, indicating type II error i.e., false positives.

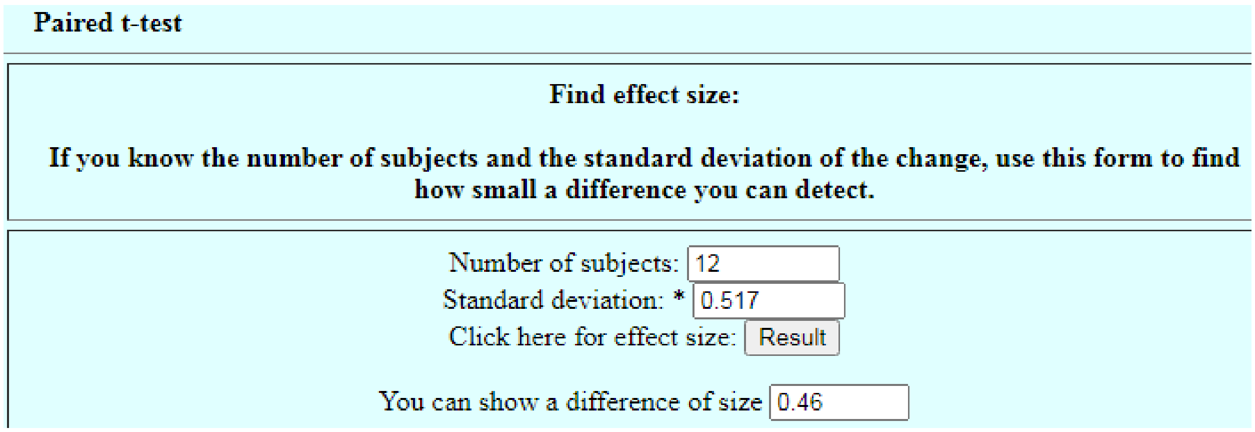


Figure 6.12 Effect size calculations for therapy-1

6.3 Experimental Results and Statistical Analysis of Therapy-2

6.3.1 Experimental Results

Results for pre-therapy human-human interaction, human-robot interaction and post-therapy human-human interaction are shown in Table 6.6. The results are at the initial week, mid-therapy and final week of the intervention so to show the improvement in the child's behavior during the intervention. However, the accuracy claimed is based on pre and post-therapy improvement in human-human interaction. Results show that the multi-human interaction of the child is improved because of this multi-robot therapy. The abbreviations used in Table 6.6 are: TC represents total commands, FC represents followed commands, AHS represents average hit score, VC represents visual commands, VCF represents visual commands followed, AC represents auditory commands, ACF represents auditory commands followed, (V+A) represents visual and auditory commands and (V+A)F represents visual and auditory commands followed. The results of the initial and final session on 10th week for HHI are used to calculate the accuracy as shown below in Table 6.7.

Table 6.7 Results for pre and post human-human interaction along with the human-robot.

	HHI	HRI	HHI	HHI	HRI	HHI	HHI	HRI	HHI	Overall Improvement in HHI(%)
	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

Table 6.8 Results for pre and post human-human interaction for different set of commands.

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

S4	1	HHI-1	14	11	78.57	6	6	6	4	2	1
		HHI-3	14	6	42.86	6	2	6	4	2	0
	10	HHI-1	14	10	71.43	6	5	6	4	2	1
		HHI-3	14	5	35.71	6	2	6	2	2	1
S5	1	HHI-1	14	12	85.71	6	5	6	5	2	2
		HHI-3	14	12	85.71	6	5	6	5	2	2
	10	HHI-1	14	12	85.71	6	5	6	5	2	2
		HHI-3	14	12	85.71	6	5	6	5	2	2
S6	1	HHI-1	14	12	85.71	6	5	6	5	2	2
		HHI-3	14	12	85.71	6	5	6	5	2	2
	10	HHI-1	14	12	85.71	6	5	6	5	2	2
		HHI-3	14	12	85.71	6	5	6	5	2	2
S7	1	HHI-1	14	0	0.00	6	0	6	0	2	0
		HHI-3	14	14	100	6	6	6	6	2	2
	10	HHI-1	14	10	71.43	6	4	6	4	2	2
		HHI-3	14	12	85.71	6	5	6	5	2	2
S8	1	HHI-1	14	12	85.71	6	5	6	5	2	2
		HHI-3	14	10	71.43	6	4	6	4	2	2
	10	HHI-1	14	12	85.71	6	5	6	5	2	2
		HHI-3	14	9	64.29	6	4	6	4	2	1

Figure 6.14 shows average accuracy of human-human interaction for Stage 1 (HHI-S1) and human-human interaction Stage 3 (HHI-S3). Figure 6.15 shows the average number of followed commands of different categories i.e. visual commands followed, audio commands followed and visual and audio commands followed by each subject. In Figure 6.16 shows the progress of each participant is shown 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.

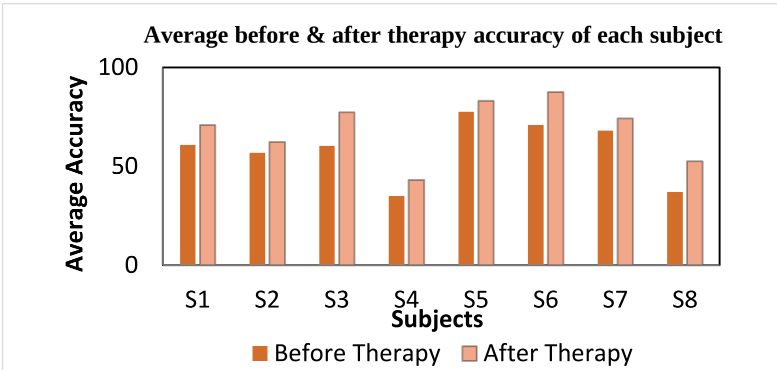


Figure 6.13 Average accuracy of human-human interaction for Stage 1 (HHI-S1) and human-human interaction Stage 3 (HHI-S3).

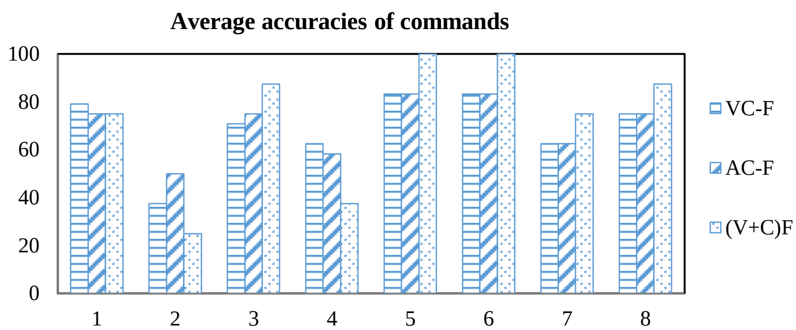


Figure 6.14 Average accuracy of different types of commands followed by the subjects, X-axis represents the subjects' whereas Y-axis represents the average accuracies of commands.

Based on the results, the main contribution of this research is the validation of the concept that the multi-robot therapy can improve multi-human interaction of an ASD child. The effectiveness of the therapy is also proved by the clinical evaluation of ASD children using CARS score as shown in Table 6.9. From the results of this therapy and statistical analysis, noticeable improvements in multi-interaction scenarios can be seen.

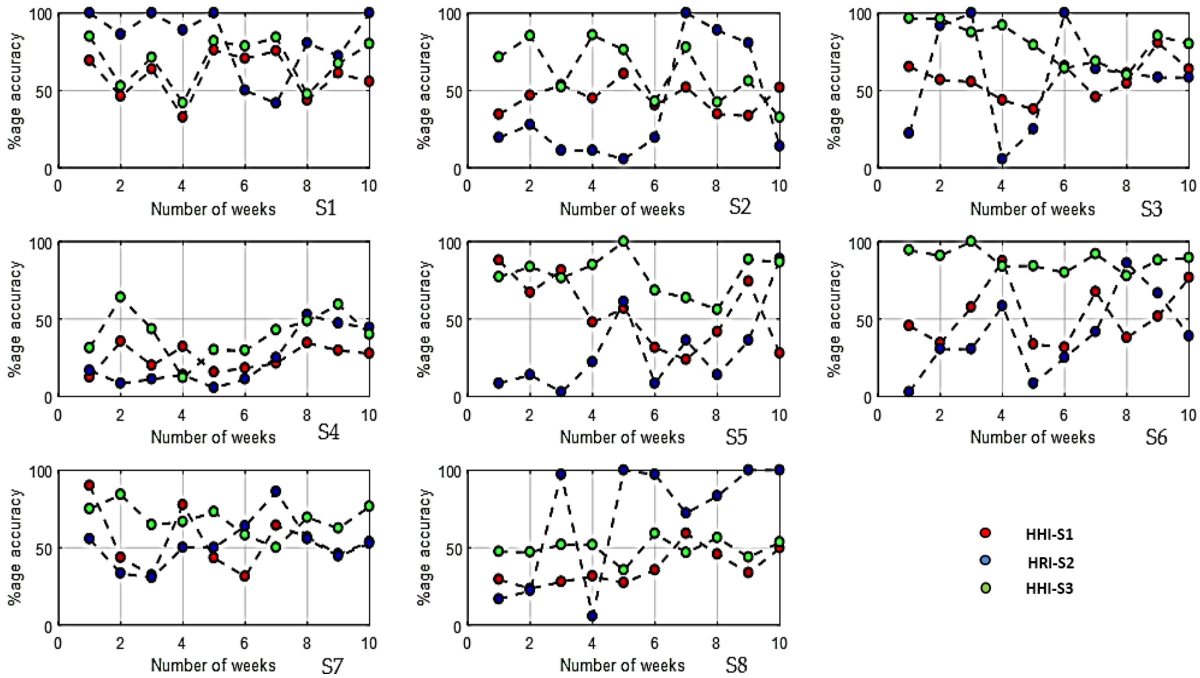


Figure 6.15 Results for all three stages of intervention for 8 subjects from week 1 to week 10.

Table 6.9 Clinical Evaluation-CARS table.

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

Table 6.9 is the clinical evaluation of CARS. This has been done along with the psychologists at ARC. The parameters that were evaluated in the experimentation were Avg_IMI and Avg_JA. There were several factors in CARS form contributing towards these two main factors as suggested

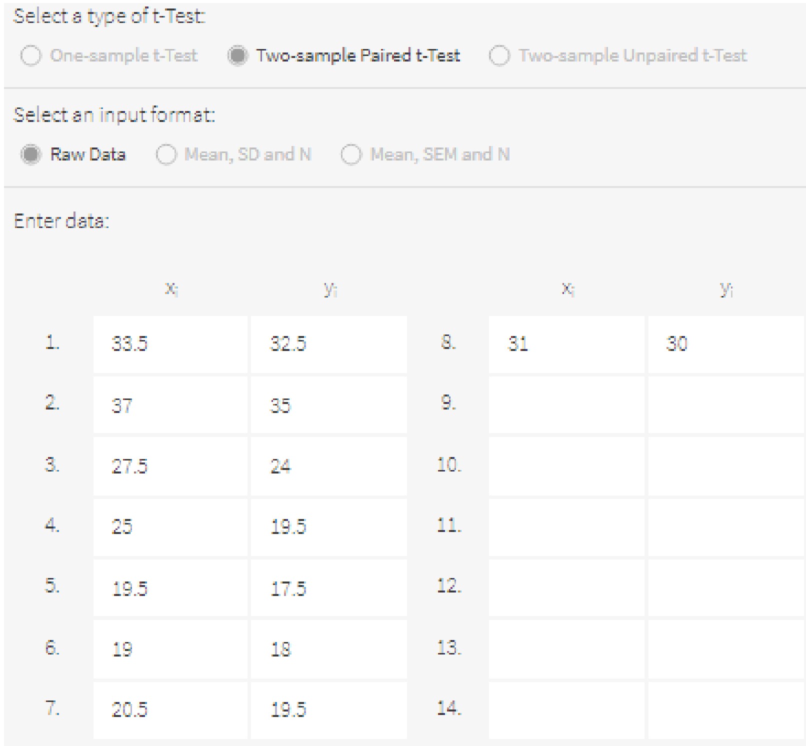


Figure 6.16 Raw data input for two-sample paired t-test of therapy-2

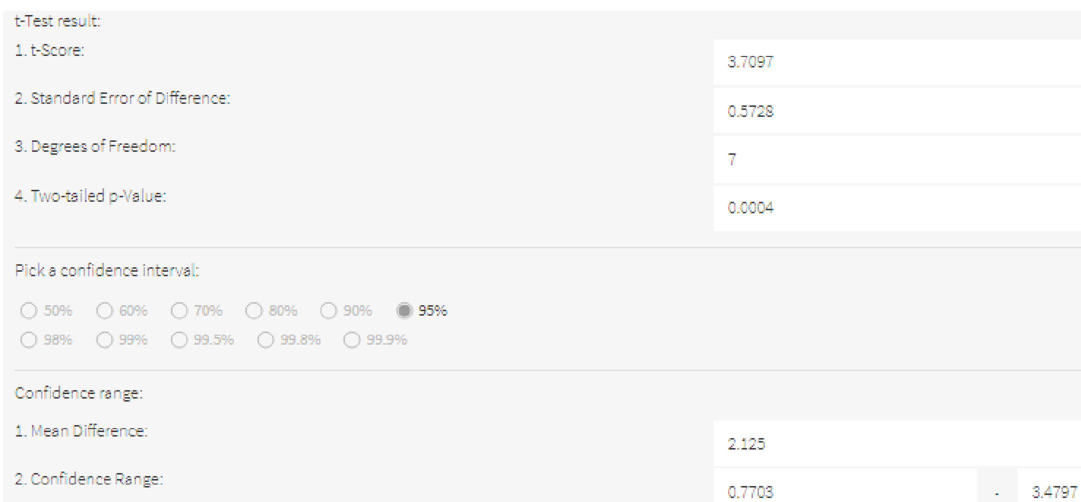


Figure 6.17 Statistical analysis using t-test for therapy-2.

by psychologists. The results of all those were considered to get this score. The reduction in score basically results in CARS improvement.

6.3.2 Statistical Analysis (Therapy-2)

Two-sample paired t-test is used for the statistical analysis of each module of this research. The results obtained for CARS before and CARS after shows the improvement in joint attention and imitation skills of the ASD children. Results for t-test of therapy-2 are shown in Figure 6.16 and Figure 6.17. Figure 6.16 shows the input format for raw data of CARS before and CARS after. Figure 6.17 shows the results for t-test. For therapy-2 the t-score = 3.7097 > t critical = 2.3646 and *p*-value is 0 < 0.05 therefore showing that data is significant. Moreover, standard error of difference is 0.5728 with DOF as 7.

ANOVA (single factor) is also used for the statistical analysis of each therapy of this research. 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 the hypothesis of this research. Statistical analysis has been applied on 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. Moreover, paired two sample t-test has also been applied on the data of joint attention during robotic intervention in stage 2. For that, t Stat = 2.56 > t Critical two-tail = 2.36 and P(T<=t) two tail = 0.03 < 0.05.

Calculation of effect size for average joint attention and average imitation results pre/post CARS score for therapy-2 is shown in Figure 6.18. Where, joint attention score is average of visual response and relating to people postulates of CARS2-ST form and imitation score is average of imitation and body use postulates of CARS2-ST form, as per therapist recommendation. The link used for effect size is http://biomath.info/power/ttest1gp.htm. For this research paired t-test has been applied to find the effect size. This test uses standard deviation and number of subject were known. The effect size reported is 0.65 showing the smallest detectable difference with alpha: Prob(reject H0 when H0 is true) was 0.05 and Power: Prob(reject H0 when H1 is true) was 0.80. The value of beta is (1-power) = 0.2, indicating type II error i.e., false positives.

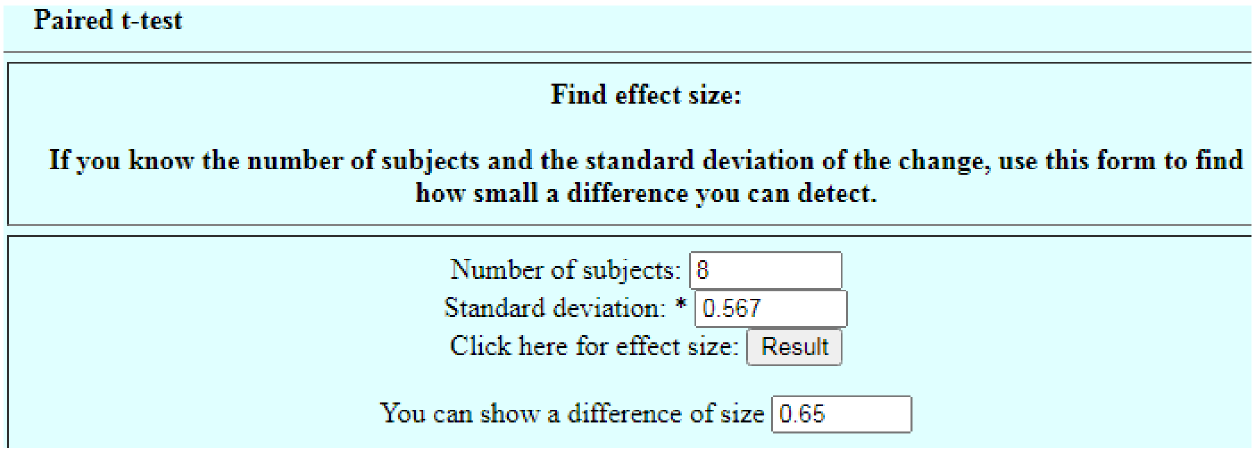


Figure 6.18 Effect size calculations for therapy-2

6.4 Experimental Results and Statistical Analysis of Therapy-3

The results obtained from the third therapy shows that among visual (color-based), auditory and motion-based reinforcement stimuli, visual is the most effective and speech is the least effective one. Table 6.10 shows the average accuracies of all subjects against each type of stimuli and their sensitivities. Comparing the two columns i.e., autism case and sensitivity column, there can be seen a general trend. Almost all minimal autism cases were deviated / most sensitive towards visual stimuli and all other mild cases were inclined towards physical motion stimuli except S11 case. Total numbers of cues were 12 and each type of cue was given four times. Moreover, each subject performs differently against these individual reinforcement stimuli. Therefore, average time consumed in these three individual reinforcement stimuli was also calculated as shown in Table 6.11.

Table 6.10 Average accuracies of all subjects against each type of stimuli and their sensitivities

Subjects	Autism case	Total cues	Accuracies			Most sensitive towards
			Visual	Auditory	Motion	
S1	Mild	12	66.30	56.32	68.23	Motion stimuli
S2	Minimal	12	77.34	67.94	61.25	Visual stimuli
S3	Minimal	12	66.93	59.18	52.73	Visual stimuli
S4	Minimal	12	59.64	37.60	43.75	Visual stimuli
S5	Mild	12	65.63	68.20	69.92	Motion stimuli
S6	Mild	12	65.84	65.52	66.88	Motion stimuli
S7	Minimal	12	69.05	57.68	62.50	Visual stimuli
S8	Minimal	12	93.23	83.34	78.97	Visual stimuli
S9	Minimal	12	90.23	81.34	74.97	Visual stimuli
S10	Minimal	12	83.85	70.99	61.72	Visual stimuli
S11	Mild	12	88.98	73.52	65.94	Visual stimuli
S12	Minimal	12	82.81	45.70	74.22	Visual stimuli

Figure 6.19 is representing 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 that motion is more sensitive as compare to speech-based reinforcement stimuli.

The mean age for mild category was 7.7 years whereas for minimal category it was 8.4 years. As the difference in mean is not much therefore the category of autism is considered as a reason for checking the effectiveness of stimulus rather than age.

Table 6.11 Average time given to each stimulus by each subject

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-

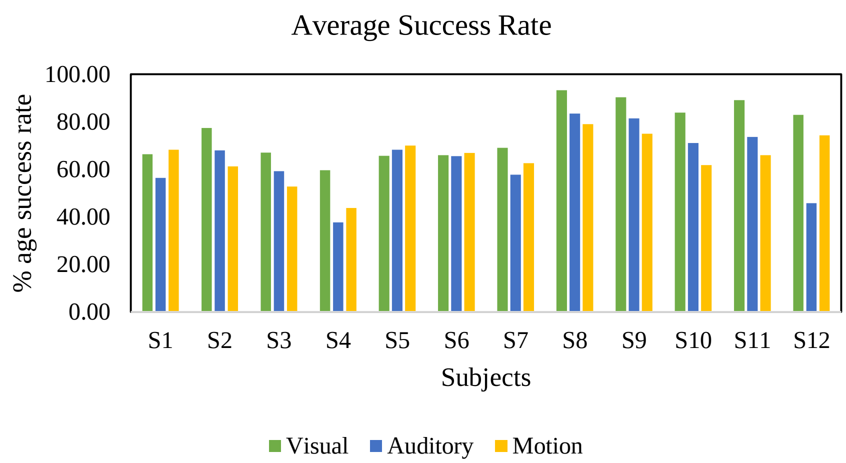


Figure 6.19 Average success rate of each subject against all stimuli

6.4.1 Statistical Analysis (Therapy-3)

Two- factor ANOVA (without replication) is applied on the average accuracies of visual, auditory and motion stimulus for the statistical analysis of this therapy. According to the analysis, the statistical significance for rows i.e., among different subjects is: F value was 6.101 while the F critical value was 2.258. The *p*-value was 0.00016 < 0.05. The statistical significance for columns i.e., among different types of stimulus is also significant with F value was 10.116 while the F critical value was 3.443. The *p*-value was 0.00076 < 0.05. The results from statistical analysis verify that visual stimulus is the most effective one as it has the highest average value. Furthermore, t-Test: paired two sample for means has been applied between different categories of stimulus. For visual and motion stimulus, the data was significant with t Stat = 4.04 > t Critical two-tail = 2.20 and P(T<=t) two tail = 0.001 < 0.05. For auditory and motion stimulus, the data was not significant with t Stat = 0.36 > t Critical two-tail = 2.20 and P(T<=t) two tail = 0.36 > 0.05. For visual and auditory stimulus, the data was significant with t Stat = 4.04 > t Critical two-tail = 2.20 and P(T<=t) two tail = 0.001 < 0.05.

Calculation of effect size for time data of three different stimuli for therapy-3 is shown in Figure 6.20. The link used for effect size is http://biomath.info/power/ttest1gp.htm. For this research paired t-test has been applied to find the effect size. This test uses standard deviation and number of subject were known. The effect size reported for time in minutes of all the three stimulus is 0.37 showing the smallest detectable difference with alpha: Prob(reject H0 when H0 is true) was 0.05 and Power: Prob(reject H0 when H1 is true) was 0.80. The value of beta is (1-power) = 0.2, indicating type II error i.e., false positives and alpha shows 95% trust on acquired data.

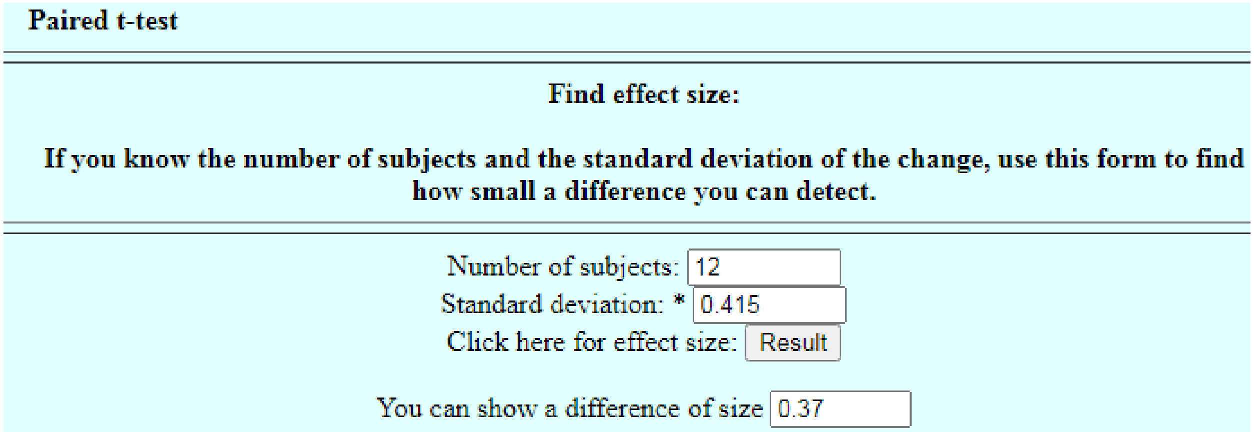


Figure 6.20 Effect size calculations for therapy-3

6.5 Parent's Interview

At the end of the research, a telephonic interview with parents and therapist was conducted. The questionnaire for the interview was designed by Manchester Metropolitan University (MMU) in a collaborative research. The questionnaire is shown in Figure 6.21. Interview questionnaire for parents of participants was based on USUS evaluation framework that includes usability, social acceptance, user experience, and societal impact. The theoretical framework USUS is based on a multi-level indicator model to operationalize the evaluation factors. Qualitative analysis of parent's interview is given below in Table 6.12. There were ten questions and each question was given an equal weightage. For quantitative analysis the parents were introduced with the Likert scale from 0 to 10, with 0 being not at all likely/unacceptable and 10 being extremely likely or acceptable. Average and standard deviation of each question is shown in the analysis done below. Total there were 7 parents and 2 therapists involved in the interview session.

Table 6.12 Interview question analysis of parents and therapists

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
P1	6	7	7	7	10	6	8	10	7	8
P2	8	7	9	9	10	10	10	10	9	9
P3	7	7	8	9	9	9	10	9	9	10
P4	7	7	8	8	9	10	10	6	10	10
P5	6	7	5	9	9	9	10	10	10	10
P6	5	7	5	9	5	6	5	5	7	5
P7	8	8	9	9	10	10	10	10	10	9
T1	9	9	10	8	9	10	10	10	9	9
T2	10	10	9	9	9	10	8	9	10	10
Avg	7.33	7.66	7.77	8.55	8.88	8.88	9	8.77	9	8.88
SD	1.58	1.11	1.78	0.72	1.53	1.69	1.73	1.92	1.22	1.61

	Questions	***FOR TRANSCRIPTION OF INTERVIEW RECORDINGS***
1	What do you think of the use of robots in autism therapy?	
2	Have you come across robots used in autism therapy before? If yes, how? When?	
3	In what ways do you think the robot therapy was useful?	
4	In what other ways do you think robots could be used in autism therapy?	
5	Do you think your child found the robot easy to understand/interact with?	
6	Did you think your child enjoyed interacting with the robot? Why? Why not?	
7	What impact do you think the robot had on your child's behaviour? e.g. achieve tasks, improved communication	
8	Did you notice any changes in your child's behaviour after interacting with the robot?	
9	Do you see any problems with the use of robots in autism therapy?	
10	Do you think any other technologies could help with autism therapy? e.g. Augmented Reality, Artificial Intelligence. I etc	

Figure 6.21 Interview questionnaire for parents of participants based on USUS criteria.

CHAPTER 7

CONCLUSION AND FUTURE WORK

For the first therapy (Therapy-1) designed, both joint attention, as well as imitation modules, are adaptive. Research shows that the LTM-based prompt method can be used for any robotic therapy generally [166]. The proposed model of therapy has three main contributions. 1) Design and development of an adaptive mathematical model for both multi-robot based therapy of children with Autism Spectrum Disorder. 2) CARS based validation and effectiveness of MRIS system. 3) Prominent improvement in multi interaction of an ASD child. In the first therapy, MRIS i.e., the novel autonomous multi-robot based mediated therapy for joint attention and imitation has been proposed. For this, humanoid robots (NAO) were used for interaction as non-human therapist for an ASD child. Interaction of a child was recorded in two different modules i.e. joint attention and imitation module. In joint attention module, the parameters measured were: eye gaze and delay in shifting the gaze when a stimulus was given. This was recorded using NAO camera. The implemented prompts for joint attention module are based on LTM-RI hierarchy. The imitation module was activated using JA module as it depends on eye gaze of an ASD child, therefore, making the module adaptive. The child's imitation, as well as joint attention was measured over several experiments to observe the pattern of improvement in the behavior of ASD children. The interventions involving inter-robot communication was observed to record enhancement in multi-communication skills of the child as to listen or watch to other person's communication is a usual convention in daily life. In this therapy, the child was introduced to eight sessions of each intervention. The time for each intervention was two months. Therefore, total therapy was over a period of 6 months. All 12 subjects participated in each intervention. The attention duration of each subject has improved over the experiments as shown by the results. Improvement was shown by every participant of this therapy. Moreover, the subjects tend to be more responsive after the therapy as delay in shifting the gaze when the robot gave a stimulus was reduced. For the imitation module, the actuation of both the robots was the same for almost all participants showing the concept of multi-interaction during the therapy. Moreover, the cognitive brain state that was measured before and after each experiment validates the mathematical model for MRIS. Moreover, the improvement in child's behavior is significant looking at the CARS score before and after the therapy. Moreover, the statistical analysis implemented on the results also supports the conclusion firmly.

For the second therapy (Therapy-2), the research proposed the pioneer multi-robot intervention for improving the multi-communication and social interaction skills of ASD children in common social scenario. The proposed intervention is a three-stage therapy. In Stage 1, the child interacts with more than one person creating a usual multi-communication scenario. In Stage 2 of the proposed intervention, two robots are introduced prompting various audio and visual cues along with combinations of both. In Stage 3, the child again interacts with humans as in Stage 1. The effect of the therapy is measured by noticing the difference of command following in Stage 1 and Stage 3. This therapy 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. The estimated time for each session is 6 minutes. We measured the command following the child for pre-HHI and post-HHI. It is reflected from the results that post-HHI has considerably increased after the therapy. The average improvement shown by our proposed therapy is 86 %. A statistical analysis of the results was also performed to validate our hypothesis that multi-robot communication can improve multi-human interaction, a common social tendency.

For the third proposed therapy (Therapy-3), the effectiveness of three different stimuli was tested on 8 ASD children for a period of 2 months in which 8 trials were given to each subject. There were total of 12 cues that were repeatedly given to the subject. It was found that almost all minimal autism cases were deviated / most sensitive towards visual stimuli and all the mild cases were inclined towards physical motion stimuli except one case. Results obtained from the third therapy clearly show that among visual (color-based), auditory and motion-based reinforcement stimuli, visual is the most effective and speech is the least effective one.

Some advantage of the proposed models includes: 1) no sensor touches the body of the child during the intervention to make the child uncomfortable. 2) Chances of error have been reduced as the behavior of the child is recorded using sensor integration, ensuring correctness of results. 3) One of the advantages 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, keeping in view the non-human participation, it has certain disadvantages specifically if the child gets frustrated, how to situation will be managed? Moreover, willingness of the child to wear EEG is another problem, therefore for future work, it is recommended to use some other device instead of EEG. Moreover, the proposed research does not focus on the comparison of the two models i.e. human-robot interaction without inter-robot communication and human-robot interaction with inter-robot communication. Therefore, the emphasis of this study is not to show any kind of comparison of therapies as both of them have a different protocol and depends on the choice of intervention. However, the comparison of two therapies can be focused as a future research area targeting a larger set of ASD children. 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 [117]? 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.

REFERENCES

[1] J. Baio, "Prevalence of autism spectrum disorder among children aged 8 years-autism and developmental disabilities monitoring network, 11 sites, United States, 2010," 2014.

[2] G. S. Mayerson, "Generalization after Endrew F.: Shrinking the Gap between Access and Outcome for Students Diagnosed with Autism," *NYL Sch. L. Rev.*, vol. 63, p. 51, 2018.

[3] R. V Burke, M. N. Andersen, S. L. Bowen, M. R. Howard, and K. D. Allen, "Evaluation of two instruction methods to increase employment options for young adults with autism spectrum disorders," *Res. Dev. Disabil.*, vol. 31, no. 6, pp. 1223–1233, 2010.

[4] P. T. Shattuck, S. C. Narendorf, B. Cooper, P. R. Sterzing, M. Wagner, and J. L. Taylor, "Postsecondary education and employment among youth with an autism spectrum disorder," *Pediatrics*, vol. 129, no. 6, pp. 1042–1049, 2012.

[5] P. Howlin, P. Moss, S. Savage, and M. Rutter, "Social outcomes in mid-to later adulthood among individuals diagnosed with autism and average nonverbal IQ as children," *J. Am. Acad. Child Adolesc. Psychiatry*, vol. 52, no. 6, pp. 572–581, 2013.

[6] D. L. Sharpe and D. L. Baker, "Financial issues associated with having a child with autism," *J. Fam. Econ. Issues*, vol. 28, no. 2, pp. 247–264, 2007.

[7] Volkow, N.D., Chang, L., Wang, G.J., Fowler, J.S., Leonido-Yee, M., Franceschi, D., Sedler, M.J., Gatley, S.J., Hitzemann, R., Ding, Y.S. and Logan, J., "Association of dopamine transporter reduction with psychomotor impairment in methamphetamine abusers," *Am. J. Psychiatry*, vol. 158, no. 3, pp. 377–382, 2001.

[8] Baghdadli, A., Assouline, B., Sonié, S., Pernon, E., Darrou, C., Michelon, C., Picot, M.C., Aussilloux, C. and Pry, R., "Developmental trajectories of adaptive behaviors from early childhood to adolescence in a cohort of 152 children with autism spectrum disorders," *J. Autism Dev. Disord.*, vol. 42, no. 7, pp. 1314–1325, 2012.

[9] P. Howlin, S. Savage, P. Moss, A. Tempier, and M. Rutter, "Cognitive and language skills in adults with autism: a 40-year follow-up," *J. Child Psychol. Psychiatry*, vol. 55, no. 1, pp. 49–58, 2014.

[10] G. Melzi and A. Schick, "Language and literacy in the school years," in *The development of language*, Pearson Allyn & Bacon, 2016.

[11] E. Hoff and M. Shatz, *Blackwell handbook of language development*. John Wiley & Sons, 2009.

[12] K. Zelazny and L. J. Simms, "Confirmatory factor analyses of DSM-5 posttraumatic stress disorder symptoms in psychiatric samples differing in Criterion A status," *J. Anxiety Disord.*, vol. 34, pp. 15–23, 2015.

[13] B. Scassellati, H. Admoni, and M. Matarić, "Robots for use in autism research," *Annu. Rev. Biomed. Eng.*, vol. 14, pp. 275–294, 2012.

[14] E. S. Kim, R. Paul, F. Shic, and B. Scassellati, "Bridging the research gap: Making HRI

useful to individuals with autism," *J. Human-robot Interact.*, vol. 1, no. 1, pp. 26–54, 2012.

[15] I. Fujimoto, T. Matsumoto, P. R. S. De Silva, M. Kobayashi, and M. Higashi, "Mimicking and evaluating human motion to improve the imitation skill of children with autism through a robot," *Int. J. Soc. Robot.*, vol. 3, no. 4, pp. 349–357, 2011.

[16] Kim, E.S., Berkovits, L.D., Bernier, E.P., Leyzberg, D., Shic, F., Paul, R. and Scassellati, B., "Social robots as embedded reinforcers of social behavior in children with autism," *J. Autism Dev. Disord.*, vol. 43, no. 5, pp. 1038–1049, 2013.

[17] 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. Ment. Dev.*, vol. 6, no. 3, pp. 183–199, 2014.

[18] 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, 2016.

[19] G. S. MacDuff, P. J. Krantz, and L. E. McClannahan, "Prompts and prompt-fading strategies for people with autism.," 2001.

[20] S. Eikeseth, T. Smith, E. Jahr, and S. Eldevik, "Outcome for children with autism who began intensive behavioral treatment between ages 4 and 7: A comparison controlled study," *Behav. Modif.*, vol. 31, no. 3, pp. 264–278, 2007.

[21] H. Kozima, M. P. Michalowski, and C. Nakagawa, "Keepon," *Int. J. Soc. Robot.*, vol. 1, no. 1, pp. 3–18, 2009.

[22] J. Greczek, E. Kaszubski, A. Atrash, and M. Matarić, "Graded cueing feedback in robot-mediated imitation practice for children with autism spectrum disorders," in *The 23rd IEEE international symposium on robot and human interactive communication*, 2014, pp. 561–566.

[23] Dautenhahn, K., Nehaniv, C.L., Walters, M.L., Robins, B., Kose-Bagci, H., Mirza, N.A. and Blow, M., "KASPAR--a minimally expressive humanoid robot for human--robot interaction research," *Appl. Bionics Biomech.*, vol. 6, no. 3–4, pp. 369–397, 2009.

[24] B. Robins, K. Dautenhahn, and J. Dubowski, "Does appearance matter in the interaction of children with autism with a humanoid robot?," *Interact. Stud.*, vol. 7, no. 3, pp. 479–512, 2006.

[25] T. Kanda, T. Hirano, D. Eaton, and H. Ishiguro, "Participation of Interactive Humanoid Robots in Human Society," *J. Robot. Soc. Japan*, vol. 22, no. 5, pp. 636–647, 2004.

[26] I. Leite, C. Martinho, and A. Paiva, "Social robots for long-term interaction: a survey," *Int. J. Soc. Robot.*, vol. 5, no. 2, pp. 291–308, 2013.

[27] S. Tariq, S. Baber, A. Ashfaq, Y. Ayaz, M. Naveed, and S. Mohsin, "Interactive therapy approach through collaborative physical play between a socially assistive humanoid robot and children with autism spectrum disorder," in *International Conference on Social Robotics*, 2016, pp. 561–570.

[28] Esubalew, T., Lahiri, U., Swanson, A.R., Crittendon, J.A., Warren, Z.E. and Sarkar, N., "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, 2012.

[29] "Autism Spectrum Disorder." [Online]. Available: https://medlineplus.gov/autismspectrumdisorder.html. [Accessed: 25-Dec-2019].

[30] A. Speaks, "What is autism," *Retrieved Novemb.*, vol. 17, p. 2011, 2011.

[31] Hossain, M.D., Ahmed, H.U., Uddin, M.J., Chowdhury, W.A., Iqbal, M.S., Kabir, R.I., Chowdhury, I.A., Aftab, A., Datta, P.G., Rabbani, G. and Hossain, S.W., "Autism Spectrum disorders (ASD) in South Asia: a systematic review," *BMC Psychiatry*, vol. 17, no. 1, p. 281, 2017.

[32] Rahman, A., Divan, G., Hamdani, S.U., Vajaratkar, V., Taylor, C., Leadbitter, K., Aldred, C., Minhas, A., Cardozo, P., Emsley, R. and Patel, V., "Effectiveness of the parent-mediated intervention for children with autism spectrum disorder in south Asia in India and Pakistan (PASS): a randomised controlled trial," *The Lancet Psychiatry*, vol. 3, no. 2, pp. 128–136, 2016.

[33] N. Imran and M. W. Azeem, "Autism spectrum disorders: perspective from Pakistan," *Compr. Guid. to Autism*, pp. 2483–2496, 2014.

[34] A. P. Association and others, "Diagnostic and statistical manual of mental disorders," *BMC Med*, vol. 17, pp. 133–137, 2013.

[35] G. Baird, "Commentary: diverging trajectories from a similar starting point: the outcome in adults whose autism was diagnosed in childhood--reflections on Howlin et al.(2013)," *J. Child Psychol. Psychiatry*, vol. 55, no. 1, pp. 59–60, 2014.

[36] Wong, C., Odom, S.L., Hume, K.A., Cox, A.W., Fettig, A., Kucharczyk, S., Brock, M.E., Plavnick, J.B., Fleury, V.P. and Schultz, T.R., "Evidence-based practices for children, youth, and young adults with autism spectrum disorder: A comprehensive review," *J. Autism Dev. Disord.*, vol. 45, no. 7, pp. 1951–1966, 2015.

[37] S. L. Odom, L. Collet-Klingenberg, S. J. Rogers, and D. D. Hatton, "Evidence-based practices in interventions for children and youth with autism spectrum disorders," *Prev. Sch. Fail. Altern. Educ. Child. youth*, vol. 54, no. 4, pp. 275–282, 2010.

[38] M. Tincani and E. A. Boutot, "Technology and autism: Current practices and future directions," *Handb. Spec. Educ. Technol. Res. Pract.*, pp. 413–421, 2005.

[39] Vasquez, E., Nagendran, A., Welch, G.F., Marino, M.T., Hughes, D.E., Koch, A. and Delisio, L., "Virtual learning environments for students with disabilities: A review and analysis of the empirical literature and two case studies," *Rural Spec. Educ. Q.*, vol. 34, no. 3, pp. 26–32, 2015.

[40] E. Schopler, R. J. Reichler, and B. R. Renner, *CARS: The childhood autism rating scale*. Western Psychological Services, 1988.

[41] C. Lord, M. Rutter, and A. Le Couteur, "Autism Diagnostic Interview-Revised: a revised

version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders," *J. Autism Dev. Disord.*, vol. 24, no. 5, pp. 659–685, 1994.

[42] Lord, C., Risi, S., Lambrecht, L., Cook, E.H., Leventhal, B.L., DiLavore, P.C., Pickles, A. and Rutter, M., "The Autism Diagnostic Observation Schedule—Generic: A standard measure of social and communication deficits associated with the spectrum of autism," *J. Autism Dev. Disord.*, vol. 30, no. 3, pp. 205–223, 2000.

[43] E. Schopler, R. J. Reichler, R. F. DeVellis, and K. Daly, "Toward objective classification of childhood autism: Childhood Autism Rating Scale (CARS)," *J. Autism Dev. Disord.*, vol. 10, no. 1, pp. 91–103, 1980.

[44] A. Perry and N. Freeman, "Psychometric properties of the Childhood Autism Rating Scale (CARS)," *Poster Present. Ontario Assoc. Dev. Disabil. Res. Spec. Interes. Gr. Res. Day, Toronto,* 1996.

[45] V. Nordin, C. Gillberg, and A. Nydén, "The Swedish version of the Childhood Autism Rating Scale in a clinical setting," *J. Autism Dev. Disord.*, vol. 28, no. 1, pp. 69–75, 1998.

[46] H. Tachimori, H. Osada, and H. Kurita, "Childhood Autism Rating Scale- Tokyo Version for screening pervasive developmental disorders," *Psychiatry Clin. Neurosci.*, vol. 57, no. 1, pp. 113–118, 2003.

[47] P. Mundy and M. Crowson, "Joint attention and early social communication: Implications for research on intervention with autism," *J. Autism Dev. Disord.*, vol. 27, no. 6, pp. 653–676, 1997.

[48] C. Kasari, S. Freeman, and T. Paparella, "Joint attention and symbolic play in young children with autism: A randomized controlled intervention study," *J. Child Psychol. Psychiatry*, vol. 47, no. 6, pp. 611–620, 2006.

[49] M. R. Sherer and L. Schreibman, "Individual behavioral profiles and predictors of treatment effectiveness for children with autism.," *J. Consult. Clin. Psychol.*, vol. 73, no. 3, p. 525, 2005.

[50] P. Yoder and W. L. Stone, "A randomized comparison of the effect of two prelinguistic communication interventions on the acquisition of spoken communication in preschoolers with ASD," *J. Speech, Lang. Hear. Res.*, 2006.

[51] G. P. Barnhill, K. Tapscott Cook, K. Tebbenkamp, and B. Smith Myles, "The effectiveness of social skills intervention targeting nonverbal communication for adolescents with Asperger syndrome and related pervasive developmental delays," *Focus Autism Other Dev. Disabl.*, vol. 17, no. 2, pp. 112–118, 2002.

[52] N. Bauminger, "The facilitation of social-emotional understanding and social interaction in high-functioning children with autism: Intervention outcomes," *J. Autism Dev. Disord.*, vol. 32, no. 4, pp. 283–298, 2002.

[53] C. Carter, L. Meckes, L. Pritchard, S. Swensen, P. P. Wittman, and B. Velde, "The friendship club: An after-school program for children with Asperger syndrome," *Fam. Community Health*, vol. 27, no. 2, pp. 143–150, 2004.

[54] I.-T. Chiang, Y. Lee, G. Frey, and B. McCormick, “Testing the situationally modified social rank theory on friendship quality in male youth with high-functioning autism spectrum disorder,” *Ther. Recreation J.*, vol. 38, no. 3, p. 261, 2004.

[55] M. Nakabayashi and M. Matsumoto, “Psychological Tests and Asperger Syndrome: The Association with Continuing Facilitative Assistance.,” *Japanese J. Child Adolesc. Psychiatry*, 2003.

[56] B. Rosenwasser and S. Axelrod, “The contributions of applied behavior analysis to the education of people with autism,” *Behav. Modif.*, vol. 25, no. 5, pp. 671–677, 2001.

[57] F. C. Mace, “The significance and future of functional analysis methodologies,” *J. Appl. Behav. Anal.*, vol. 27, no. 2, pp. 385–392, 1994.

[58] O. I. Lovaas, “Behavioral treatment and normal educational and intellectual functioning in young autistic children.,” *J. Consult. Clin. Psychol.*, vol. 55, no. 1, p. 3, 1987.

[59] R. J. Landa and L. G. Kalb, “Long-term outcomes of toddlers with autism spectrum disorders exposed to short-term intervention,” *Pediatrics*, vol. 130, no. Supplement 2, pp. S186--S190, 2012.

[60] H. Cohen, M. Amerine-Dickens, and T. Smith, “Early intensive behavioral treatment: Replication of the UCLA model in a community setting,” *J. Dev. Behav. Pediatr.*, vol. 27, no. 2, pp. S145--S155, 2006.

[61] Carroll, D.M., Harbour, J.L., Bauer, S.G., Bruemmer, D.J., Pacis, E.B., Mullens, K.D. and Everett, H.R., “Enabling technologies for unmanned protection systems,” in *Unmanned Ground Vehicle Technology VII*, 2005, vol. 5804, pp. 577–584.

[62] Singh, A., Stealey, M.J., Chen, V., Kaiser, W.J., Batalin, M., Lam, Y., Zhang, B., Dhariwal, A., Oberg, C., Pereira, A. and Sukhatme, G.S., “Human assisted robotic team campaigns for aquatic monitoring,” *J. F. Robot.*, vol. 24, no. 11–12, pp. 969–989, 2007.

[63] J. Forlizzi and C. DiSalvo, “Service robots in the domestic environment: a study of the roomba vacuum in the home,” in *Proceedings of the 1st ACM SIGCHI/SIGART conference on Human-robot interaction*, 2006, pp. 258–265.

[64] S. Turkle, “Authenticity in the age of digital companions,” *Interact. Stud.*, vol. 8, no. 3, pp. 501–517, 2007.

[65] D. Feil-Seifer, K. Skinner, and M. J. Matarić, “Benchmarks for evaluating socially assistive robotics,” *Interact. Stud.*, vol. 8, no. 3, pp. 423–439, 2007.

[66] T. Fong, I. Nourbakhsh, and K. Dautenhahn, “A survey of socially interactive robots,” *Rob. Auton. Syst.*, vol. 42, no. 3–4, pp. 143–166, 2003.

[67] S. Chakrabarti and E. Fombonne, “Pervasive developmental disorders in preschool children,” *Jama*, vol. 285, no. 24, pp. 3093–3099, 2001.

[68] E. Taub, G. Uswatte, D. K. King, D. Morris, J. E. Crago, and A. Chatterjee, “A placebo-controlled trial of constraint-induced movement therapy for upper extremity after stroke,” *Stroke*, vol. 37, no. 4, pp. 1045–1049, 2006.

[69] Wolf, S.L., Thompson, P.A., Morris, D.M., Rose, D.K., Winstein, C.J., Taub, E., Giuliani, C. and Pearson, S.L., "The EXCITE trial: attributes of the Wolf Motor Function Test in patients with subacute stroke," *Neurorehabil. Neural Repair*, vol. 19, no. 3, pp. 194–205, 2005.

[70] B. Scassellati, "Quantitative metrics of social response for autism diagnosis," in *ROMAN 2005. IEEE International Workshop on Robot and Human Interactive Communication, 2005.*, 2005, pp. 585–590.

[71] B. Scassellati, "Using social robots to study abnormal social development," 2005.

[72] K. Dautenhahn and I. Werry, "A quantitative technique for analysing robot-human interactions," in *IEEE/RSJ international conference on intelligent robots and systems*, 2002, vol. 2, pp. 1132–1138.

[73] H. Kozima, C. Nakagawa, and Y. Yasuda, "Interactive robots for communication-care: A case-study in autism therapy," in *ROMAN 2005. IEEE International Workshop on Robot and Human Interactive Communication, 2005.*, 2005, pp. 341–346.

[74] Michaud, F., Laplante, J.F., Larouche, H., Duquette, A., Caron, S., Létourneau, D. and Masson, P., "Autonomous spherical mobile robot for child-development studies," *IEEE Trans. Syst. Man, Cybern. A Syst. Humans*, vol. 35, no. 4, pp. 471–480, 2005.

[75] S. Woods, M. Walters, K. L. Koay, and K. Dautenhahn, "Comparing human robot interaction scenarios using live and video based methods: towards a novel methodological approach," in *9th IEEE International Workshop on Advanced Motion Control, 2006.*, 2006, pp. 750–755.

[76] D. Feil-Seifer and M. Matarić, "Using proxemics to evaluate human-robot interaction," in *2010 5th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, 2010, pp. 143–144.

[77] H. Akechi, Y. Kikuchi, Y. Tojo, K. Hakarino, and T. Hasegawa, "Mind perception and moral judgment in autism," *Autism Res.*, vol. 11, no. 9, pp. 1239–1244, 2018.

[78] Y. Funabiki and T. Shiwa, "Weakness of visual working memory in autism," *Autism Res.*, vol. 11, no. 9, pp. 1245–1252, 2018.

[79] Kumazaki, H., Warren, Z., Swanson, A., Yoshikawa, Y., Matsumoto, Y., Ishiguro, H., Sarkar, N., Minabe, Y. and Kikuchi, M., "Impressions of humanness for android robot may represent an endophenotype for autism spectrum disorders," *J. Autism Dev. Disord.*, vol. 48, no. 2, pp. 632–634, 2018.

[80] 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. Robot. Syst.*, vol. 9, no. 3, p. 72, 2012.

[81] O. Rudovic, J. Lee, L. Mascarell-Maricic, B. W. Schuller, and R. W. Picard, "Measuring engagement in robot-assisted autism therapy: A cross-cultural study," *Front. Robot. AI*, vol. 4, p. 36, 2017.

[82] K. Dautenhahn, "Robots as social actors: Aurora and the case of autism," in *Proc. CT99*,

The Third International Cognitive Technology Conference, August, San Francisco, 1999, vol. 359, p. 374.

[83] I. Werry, K. Dautenhahn, B. Ogden, and W. Harwin, "Can social interaction skills be taught by a social agent? The role of a robotic mediator in autism therapy," in *International Conference on Cognitive Technology*, 2001, pp. 57–74.

[84] Richardson, K., Coeckelbergh, M., Wakunuma, K., Billing, E., Ziemke, T., Gómez, P., Vanderborght, B. and Belpaeme, T., "Robot enhanced therapy for children with autism (DREAM): A social model of autism," *IEEE Technol. Soc. Mag.*, vol. 37, no. 1, pp. 30–39, 2018.

[85] Dawson, G., Toth, K., Abbott, R., Osterling, J., Munson, J., Estes, A. and Liaw, J., "Early social attention impairments in autism: social orienting, joint attention, and attention to distress.," *Dev. Psychol.*, vol. 40, no. 2, p. 271, 2004.

[86] E. Bekele, U. Lahiri, J. Davidson, Z. Warren, and N. Sarkar, "Development of a novel robot-mediated adaptive response system for joint attention task for children with autism," in *2011 RO-MAN*, 2011, pp. 276–281.

[87] Petric, F., Hrvatinić, K., Babić, A., Malovan, L., Miklić, D., Kovačić, Z., Cepanec, M., Stošić, J. and Šimleša, S., "Four tasks of a robot-assisted autism spectrum disorder diagnostic protocol: First clinical tests," in *IEEE Global Humanitarian Technology Conference (GHTC 2014)*, 2014, pp. 510–517.

[88] S. M. Mavadati, H. Feng, A. Gutierrez, and M. H. Mahoor, "Comparing the gaze responses of children with autism and typically developed individuals in human-robot interaction," in *2014 IEEE-RAS International Conference on Humanoid Robots*, 2014, pp. 1128–1133.

[89] H. Feng, A. Gutierrez, J. Zhang, and M. H. Mahoor, "Can NAO robot improve eye-gaze attention of children with high functioning autism?," in *2013 IEEE International Conference on Healthcare Informatics*, 2013, p. 484.

[90] C. Shi, T. Kanda, M. Shimada, F. Yamaoka, H. Ishiguro, and N. Hagita, "Easy development of communicative behaviors in social robots," in *2010 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2010, pp. 5302–5309.

[91] T. Ende, S. Haddadin, S. Parusel, T. Wüsthoff, M. Hassenzahl, and A. Albu-Schäffer, "A human-centered approach to robot gesture based communication within collaborative working processes," in *2011 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2011, pp. 3367–3374.

[92] B. Huskens, R. Verschuur, J. Gillesen, R. Didden, and E. Barakova, "Promoting question-asking in school-aged children with autism spectrum disorders: Effectiveness of a robot intervention compared to a human-trainer intervention," *Dev. Neurorehabil.*, vol. 16, no. 5, pp. 345–356, 2013.

[93] B. Huskens, A. Palmen, M. der Werff, T. Lourens, and E. Barakova, "Improving collaborative play between children with autism spectrum disorders and their siblings: The effectiveness of a robot-mediated intervention based on Lego®therapy," *J. Autism Dev. Disord.*, vol. 45, no. 11, pp. 3746–3755, 2015.

[94] 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. Disord.*, vol. 18, pp. 51–63, 2015.

[95] S. M. Srinivasan, I.-M. Eigsti, T. Gifford, and A. N. Bhat, "The effects of embodied rhythm and robotic interventions on the spontaneous and responsive verbal communication skills of children with Autism Spectrum Disorder (ASD): A further outcome of a pilot randomized controlled trial," *Res. Autism Spectr. Disord.*, vol. 27, pp. 73–87, 2016.

[96] J. Hadfield, G. Chalvatzaki, P. Koutras, M. Khamassi, C. S. Tzafestas, and P. Maragos, "A Deep Learning Approach for Multi-View Engagement Estimation of Children in a Child-Robot Joint Attention task," *arXiv Prepr. arXiv1812.00253*, 2018.

[97] T. Nakano, N. Kato, and S. Kitazawa, "Lack of eyeblink entrainments in autism spectrum disorders," *Neuropsychologia*, vol. 49, no. 9, pp. 2784–2790, 2011.

[98] Bugnariu, N., Young, C., Rockenbach, K., Patterson, R.M., Garver, C., Ranatunga, I., Beltran, M., Torres-Arenas, N. and Popa, D., "Human-robot interaction as a tool to evaluate and quantify motor imitation behavior in children with Autism Spectrum Disorders," in *2013 International Conference on Virtual Rehabilitation (ICVR)*, 2013, pp. 57–62.

[99] Z. Zheng, E. M. Young, A. Swanson, A. Weitlauf, Z. Warren, and N. Sarkar, "Robot-mediated mixed gesture imitation skill training for young children with ASD," in *2015 International Conference on Advanced Robotics (ICAR)*, 2015, pp. 72–77.

[100] N. Gonçalves, S. Costa, J. Rodrigues, and F. Soares, "Detection of stereotyped hand flapping movements in Autistic children using the Kinect sensor: A case study," in *2014 IEEE international conference on autonomous robot systems and competitions (ICARSC)*, 2014, pp. 212–216.

[101] R. Suzuki and J. Lee, "Robot-play therapy for improving prosocial behaviours in children with Autism Spectrum Disorders," in *2016 International Symposium on Micro-NanoMechatronics and Human Science (MHS)*, 2016, pp. 1–5.

[102] POP, C.A., PETRULE, A.C., PINTEA, S., PECA, A., SIMUT, R., VANDERBORGHT, B. and DAVID, D.O., "Imitation and Social Behaviors of Children with ASD in Interaction with Robonova. A Series of Single Case experiments.," *Transylvanian J. Psychol.*, vol. 14, no. 1, 2013.

[103] S. Costa, H. Lehmann, K. Dautenhahn, B. Robins, and F. Soares, "Using a humanoid robot to elicit body awareness and appropriate physical interaction in children with autism," *Int. J. Soc. Robot.*, vol. 7, no. 2, pp. 265–278, 2015.

[104] Guha, T., Yang, Z., Ramakrishna, A., Grossman, R.B., Hedley, D., Lee, S. and Narayanan, S.S., "On quantifying facial expression-related atypicality of children with autism spectrum disorder," in *2015 IEEE international conference on acoustics, speech and signal processing (ICASSP)*, 2015, pp. 803–807.

[105] M. Hirokawa, A. Funahashi, Y. Pan, Y. Itoh, and K. Suzuki, "Design of a robotic agent that measures smile and facing behavior of children with Autism Spectrum Disorder," in *2016*

25th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN), 2016, pp. 843–848.

[106] M. J. Salvador, S. Silver, and M. H. Mahoor, “An emotion recognition comparative study of autistic and typically-developing children using the zeno robot,” in *2015 IEEE International Conference on Robotics and Automation (ICRA)*, 2015, pp. 6128–6133.

[107] S. Costa, F. Soares, A. P. Pereira, C. Santos, and A. Hiolle, “Building a game scenario to encourage children with autism to recognize and label emotions using a humanoid robot,” in *The 23rd IEEE International Symposium on Robot and Human Interactive Communication*, 2014, pp. 820–825.

[108] A. O. Barajas, H. Al Osman, and S. Shirmohammadi, “A Serious Game for children with Autism Spectrum Disorder as a tool for play therapy,” in *2017 IEEE 5th International Conference on Serious Games and Applications for Health (SeGAH)*, 2017, pp. 1–7.

[109] Chen, C.H., Bobzien, J., Giannakos, M., Bruhn, A., Bruggeman, A., Mohrehkesh, S., Zhang, M., Hsu, W.W. and Chrisochoides, N.P., “Familiar Video Stories as a Means for Children with Autism: An Analytics Approach,” in *2015 International Conference on Healthcare Informatics*, 2015, pp. 368–373.

[110] S. Matsumoto, S. Horiguchi, H. Shigeno, and K.-I. Okada, “Visual effect on the odor identification ability of children with Autism spectrum disorder,” in *2016 IEEE International Conference on Healthcare Informatics (ICHI)*, 2016, pp. 349–355.

[111] W. K. Shams and A. Wahab, “Source-temporal-features for detection EEG behavior of autism spectrum disorder,” in *2013 5th International Conference on Information and Communication Technology for the Muslim World (ICT4M)*, 2013, pp. 1–5.

[112] P. N. Jadhav, D. Shanamugan, A. Chourasia, A. R. Ghole, A. A. Acharyya, and G. Naik, “Automated detection and correction of eye blink and muscular artefacts in EEG signal for analysis of Autism Spectrum Disorder,” in *2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, 2014, pp. 1881–1884.

[113] Y. Feng, Q. Jia, G. Chen, and C. Li, “Control architecture design for intelligent robot assisted intervention for children with autism,” in *2016 IEEE 11th Conference on Industrial Electronics and Applications (ICIEA)*, 2016, pp. 1345–1349.

[114] Y. Feng, Q. Jia, M. Chu, and W. Wei, “Engagement evaluation for autism intervention by robots based on dynamic Bayesian network and expert elicitation,” *IEEE Access*, vol. 5, pp. 19494–19504, 2017.

[115] Pennisi, P., Tonacci, A., Tartarisco, G., Billeci, L., Ruta, L., Gangemi, S. and Pioggia, G., “Autism and social robotics: A systematic review,” *Autism Res.*, vol. 9, no. 2, pp. 165–183, 2016.

[116] A. R. Taheri, M. Alemi, A. Meghdari, H. R. Pouretemad, and S. L. Holderread, “Clinical application of humanoid robots in playing imitation games for autistic children in Iran,” *Procedia-Social Behav. Sci.*, vol. 176, pp. 898–906, 2015.

[117] 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. Disord.*,

vol. 6, no. 1, pp. 249–262, 2012.

[118] D. François, S. Powell, and K. Dautenhahn, "A long-term study of children with autism playing with a robotic pet: Taking inspirations from non-directive play therapy to encourage children's proactivity and initiative-taking," *Interact. Stud.*, vol. 10, no. 3, pp. 324–373, 2009.

[119] G. Pioggia, R. Igliozzi, M. Ferro, A. Ahluwalia, F. Muratori, and D. De Rossi, "An android for enhancing social skills and emotion recognition in people with autism," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 13, no. 4, pp. 507–515, 2005.

[120] Pioggia, G., Igliozzi, R., Sica, M.L., Ferro, M., Muratori, F., Ahluwalia, A. and De Rossi, D., "Exploring emotional and imitational android-based interactions in autistic spectrum disorders," *J. CyberTherapy*, pp. 49–61, 2008.

[121] D. Feil-Seifer and M. J. Matarić, "Automated detection and classification of positive vs. negative robot interactions with children with autism using distance-based features," in *2011 6th ACM/IEEE international conference on human-robot interaction (HRI)*, 2011, pp. 323–330.

[122] F. Tanaka, J. R. Movellan, B. Fortenberry, and K. Aisaka, "Daily HRI evaluation at a classroom environment: reports from dance interaction experiments," in *Proceedings of the 1st ACM SIGCHI/SIGART conference on Human-robot interaction*, 2006, pp. 3–9.

[123] A. Duquette, F. Michaud, and H. Mercier, "Exploring the use of a mobile robot as an imitation agent with children with low-functioning autism," *Auton. Robots*, vol. 24, no. 2, pp. 147–157, 2008.

[124] H. Kozima, C. Nakagawa, and Y. Yasuda, "Children--robot interaction: a pilot study in autism therapy," *Prog. Brain Res.*, vol. 164, pp. 385–400, 2007.

[125] A. Peca, R. Simut, S. Pintea, C. Costescu, and B. Vanderborght, "How do typically developing children and children with autism perceive different social robots?," *Comput. Human Behav.*, vol. 41, pp. 268–277, 2014.

[126] M. G. Baxter, "'I've seen it all before': Explaining age-related impairments in object recognition. Theoretical comment on Burke et al.(2010).," 2010.

[127] R. E. Cimera and R. J. Cowan, "The costs of services and employment outcomes achieved by adults with autism in the US," *Autism*, vol. 13, no. 3, pp. 285–302, 2009.

[128] K. L. Hess, M. J. Morrier, L. J. Heflin, and M. L. Ivey, "Autism treatment survey: Services received by children with autism spectrum disorders in public school classrooms," *J. Autism Dev. Disord.*, vol. 38, no. 5, pp. 961–971, 2008.

[129] A. Shick, "Romibo robot project: an open-source effort to develop a low-cost sensory adaptable robot for special needs therapy and education," in *ACM SIGGRAPH 2013 Studio Talks*, 2013, p. 16.

[130] Shamsuddin, S., Yussof, H., Ismail, L., Hanapiah, F.A., Mohamed, S., Piah, H.A. and Zahari, N.I., "Initial response of autistic children in human-robot interaction therapy with humanoid robot NAO," in *2012 IEEE 8th International Colloquium on Signal Processing*

and its Applications, 2012, pp. 188–193.

[131] J.-J. Cabibihan, H. Javed, M. Aldosari, T. Frazier, and H. Elbashir, "Sensing technologies for autism spectrum disorder screening and intervention," *Sensors*, vol. 17, no. 1, p. 46, 2017.

[132] K. Dautenhahn, "Roles and functions of robots in human society: implications from research in autism therapy," *Robotica*, vol. 21, no. 4, pp. 443–452, 2003.

[133] Cao, H.L., Esteban, P.G., Simut, R., Van de Perre, G., Lefeber, D. and Vanderborght, B., "A collaborative homeostatic-based behavior controller for social robots in human--robot interaction experiments," *Int. J. Soc. Robot.*, vol. 9, no. 5, pp. 675–690, 2017.

[134] Z. Zheng, H. Zhao, A. R. Swanson, A. S. Weitlauf, Z. E. Warren, and N. Sarkar, "Design, development, and evaluation of a noninvasive autonomous robot-mediated joint attention intervention system for young children with ASD," *IEEE Trans. human-machine Syst.*, vol. 48, no. 2, pp. 125–135, 2017.

[135] M. A. Gernsbacher, J. L. Stevenson, S. Khandakar, and H. H. Goldsmith, "Why Does Joint Attention Look Atypical in Autism?," *Child development perspectives*, vol. 2, no. 1, p. 38, Apr. 2008, doi: 10.1111/j.1750-8606.2008.00039.x.

[136] Social cognition, joint attention, and communicative competence from 9 to 15 months of age. Carpenter M, Nagell K, Tomasello M Monogr Soc Res Child Dev. 1998; 63(4):i-vi, 1-143.

[137] The autism diagnostic observation schedule-generic: a standard measure of social and communication deficits associated with the spectrum of autism. Lord C, Risi S, Lambrecht L, Cook EH Jr, Leventhal BL, DiLavore PC, Pickles A, Rutter M J Autism Dev Disord. 2000 Jun; 30(3):205-23.

[138] M. Nagel and W. H. Zangemeister, "The effect of transcranial magnetic stimulation over the cerebellum on the synkinesis of coordinated eye and head movements," *Journal of the Neurological Sciences*, vol. 213, no. 1–2, pp. 35–45, Sep. 2003, doi: 10.1016/S0022-510X(03)00145-X.

[139] N. Akhtar and M. A. Gernsbacher, "Joint Attention and Vocabulary Development: A Critical Look," *Lang Linguist Compass*, vol. 1, no. 3, pp. 195–207, May 2007, doi: 10.1111/j.1749-818X.2007.00014.x.

[140] H.-L. Cao et al., "'Hmm, Did You Hear What I Just Said?': Development of a Re-Engagement System for Socially Interactive Robots," Robotics, vol. 8, no. 4, Art. no. 4, Dec. 2019, doi: 10.3390/robotics8040095.

[141] B. Steenwinckel, "Self-learning algorithms for the personalized interaction with people with dementia", 2017, https://lib.ugent.be/fulltxt/RUG01/002/367/389/RUG01-002367389_2017_0001_AC.pdf

[142] T. Hecht, "Context Aware Robot Assistance Applying Reinforcement Learning to Make Pepper Offer Help to a Human Memory Player",2018, https://cogsys.uni-bamberg.de/theses/hecht/TobiasHecht_MA.pdf

[143] M. Podpora and A. Różańska, "Making Eye Contact with a Robot - Exploring User Experience in Interacting with Pepper," 2018, pp. 172–183.

[144] A. Ben-Youssef, G. Varni, S. Essid, and C. Clavel, "On-the-Fly Detection of User Engagement Decrease in Spontaneous Human–Robot Interaction Using Recurrent and Deep Neural Networks," Int J of Soc Robotics, vol. 11, no. 5, pp. 815–828, Dec. 2019, doi: 10.1007/s12369-019-00591-2.

[145] A. Ben Youssef, C. Clavel, and S. Essid, "Early Detection of User Engagement Breakdown in Spontaneous Human-Humanoid Interaction," IEEE Trans. Affective Comput., pp. 1–1, 2019, doi: 10.1109/TAFFC.2019.2898399.

[146] M. Bilac, M. Chamoux, and A. Lim, "Gaze and filled pause detection for smooth human-robot conversations," in 2017 IEEE-RAS 17th International Conference on Humanoid Robotics (Humanoids), Birmingham, Nov. 2017, pp. 297–304, doi: 10.1109/HUMANOIDS.2017.8246889.

[147] A. Gonsiorowski, R. A. Williamson, and D. L. Robins, "Imitation of Object-Directed Acts in Young Children with Autism Spectrum Disorders," *J Autism Dev Disord*, vol. 46, no. 2, pp. 691–697, Feb. 2016, doi: 10.1007/s10803-015-2596-1.

[148] G. Vivanti, A. Nadig, S. Ozonoff, and S. J. Rogers, "What do children with autism attend to during imitation tasks?," J Exp Child Psychol, vol. 101, no. 3, pp. 186–205, Nov. 2008, doi: 10.1016/j.jecp.2008.04.008.

[149] B. Ingersoll, "Brief Report: Effect of a focused imitation intervention on social functioning in children with autism," J Autism Dev Disord, vol. 42, no. 8, pp. 1768–1773, Aug. 2012, doi: 10.1007/s10803-011-1423-6.

[150] R. Canitano and Y. Bozzi, *Autism Spectrum Disorders: Developmental Trajectories, Neurobiological Basis, Treatment Update*. Frontiers Media SA, 2017.

[151] M. Kaur and A. Bhat, "Creative Yoga Intervention Improves Motor and Imitation Skills of Children With Autism Spectrum Disorder," *Phys Ther*, vol. 99, no. 11, pp. 1520–1534, Nov. 2019, doi: 10.1093/ptj/pzz115.

[152] A. Aryania, H. S. Aghdasi, E. A. Beccaluva, and A. Bonarini, "Social engagement of children with autism spectrum disorder (ASD) in imitating a humanoid robot: a case study," *SN Appl. Sci.*, vol. 2, no. 6, p. 1085, May 2020, doi: 10.1007/s42452-020-2802-4.

[153] J. Greczek, E. Kaszubski, A. Atrash, and M. Mataric, "Graded cueing feedback in robot-mediated imitation practice for children with autism spectrum disorders," in *The 23rd IEEE International Symposium on Robot and Human Interactive Communication*, Edinburgh, UK, Aug. 2014, pp. 561–566, doi: 10.1109/ROMAN.2014.6926312

[154] 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, doi: 10.1109/TNSRE.2015.2475724.

[155] P. Mundy, C. Delgado, J. Block, M. Venezia, A. Hogan, and J. Seibert, “A manual for the abridged Early Social Communication Scales,” *Retrieved December*, vol. 3, p. 2005, 2003.

[156] S. K. Berument, M. Rutter, C. Lord, A. Pickles, and A. Bailey, “Autism screening questionnaire: diagnostic validity,” *Br. J. Psychiatry*, vol. 175, no. 5, pp. 444–451, 1999.

[157] M. E. Libby, J. S. Weiss, S. Bancroft, and W. H. Ahearn, “A comparison of most-to-least and least-to-most prompting on the acquisition of solitary play skills,” *Behav. Anal. Pract.*, vol. 1, no. 1, pp. 37–43, 2008.

[158] D. J. Feil-Seifer and M. J. Matarić, “A simon-says robot providing autonomous imitation feedback using graded cueing,” in *Poster paper in International Meeting for Autism Research (IMFAR)*, 2012.

[159] N. Roy, P. Newman, and S. Srinivasa, Robotics. MIT Press, 2013.

[160] A. Al-Nafjan, M. Hosny, Y. Al-Ohali, and A. Al-Wabil, “Review and Classification of Emotion Recognition Based on EEG Brain-Computer Interface System Research: A Systematic Review,” Applied Sciences, vol. 7, no. 12, Art. no. 12, Dec. 2017, doi: 10.3390/app7121239.

[161] J. Onton, A. Delorme, and S. Makeig, “Frontal midline EEG dynamics during working memory,” NeuroImage, vol. 27, no. 2, pp. 341–356, Aug. 2005, doi: 10.1016/j.neuroimage.2005.04.014.

[162] E. Başar, C. Başar-Eroglu, S. Karakaş, and M. Schürmann, “Gamma, alpha, delta, and theta oscillations govern cognitive processes,” International Journal of Psychophysiology, vol. 39, no. 2, pp. 241–248, Jan. 2001, doi: 10.1016/S0167-8760(00)00145-8.

[163] "Synchronous neural oscillations and cognitive processes - ScienceDirect.” https://www.sciencedirect.com/science/article/abs/pii/S1364661303002894 (accessed Aug. 13, 2020).

[164] E. Başar and B. Güntekin, “A short review of alpha activity in cognitive processes and in cognitive impairment,” International Journal of Psychophysiology, vol. 86, no. 1, pp. 25–38, Oct. 2012, doi: 10.1016/j.ijpsycho.2012.07.001.

[165] B. Robins *et al.*, “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, 2010.

[166] 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, 2015.

Appendix-A- Subject's Details

Table A. 1. Shows the complete details of subjects participated in the intervention.

Sr.	Age (Year)	Sex	Autism case
1	8-9	M	Severe
2	9	M	Moderate
3	9	M	Minimal
4	6	M	Moderate
5	8-9	M	Moderate
6	9	M	Minimal
7	8-9	M	Moderate
8	8-9	M	Mild
9	4	F	Minimal
10	5-6	M	Moderate
11	3	M	Minimal
12	8-9	M	Mild

Appendix-B- Consent Form

Consent form signed by parents of ASD children during the research

Consent to Participate in a Research Study

Defining Futures

SCHOOL OF MECHANICAL AND MANUFACTURING ENGINEERING
NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY,
H-12, Islamabad, Pakistan.

Therapy for ASD Children using Robotics

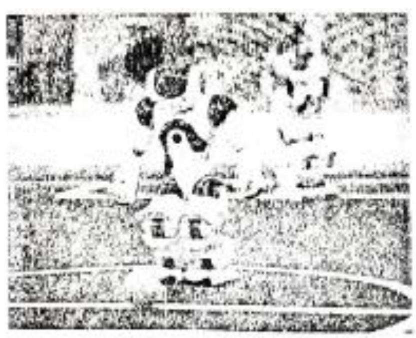
Dear Parents,

- We kindly request you to allow us to include your child in our robotic therapy session that is designed to improve the social skills of ASD children.
- We are using humanoid robots that are globally used in activity based education of children. With their predictable and repetitive behavior, humanoid robots are helpful in providing stability to a child's social skills.
- We request that you read this form and ask us any questions that you may have before agreeing to be a part in the study.
- The **purpose of the study** is to see if ASD kids can interact with robots and how well do they respond to technology. Instead of being told what to do, we will teach them by showing them how the task at hand is done.

Description of the Activity

- Your child will:

Play football with the robot(s); that includes passing the ball, following instructions, calculating, verbal communication with the robot.



a. Wearable Sensors

- If you allow us, an EMG band will be worn on your child's leg to monitor his movement and muscular activity. It is just like a bracelet.

- EEG headset will be worn before and after the intervention for recording brain activity.

b. Non-contact sensors

- Overhead camera for recording aerial view of the activity to recognize accuracy of kicking and movement of child.
- Kinect V2 sensor which is used in Xbox for playing games to detect the posture of the child when playing football. It will be recording video.
- Video recording of the session for internal use and academic purposes only. If published in any research paper, prior consent will be taken.
- There are no other reasonable/foreseeable (or expected) risks.

Confidentiality

- The identity of the child will be kept confidential. We will not be collecting or retaining any information about you/your child's identity. We only need the information about the age and gender of the child. If the parents allow, a picture or video may be taken for the analysis of behavior. However, no public release of them.

- Your/your child's identity will not be disclosed in the material that is published.

Contact

- If you have any questions about this activity then please feel to reach us.

Dr. Jawad Khan
Assistant Professor – RIME Department
School of Mechanical and Manufacturing Engineering
National University of Sciences and Technology, Islamabad
+92-345-5496789

Result Sharing:

- As this is a team work effort, you working with us to help the kids, we gladly inform you that we will share our findings with you to help understand Autistic children and your child better.

Consent

- Your signature below indicates that you have read and understood the information provided above and have decided to volunteer as a research participant for this study

Child's Name: MUHAMMAD HUSSAIN

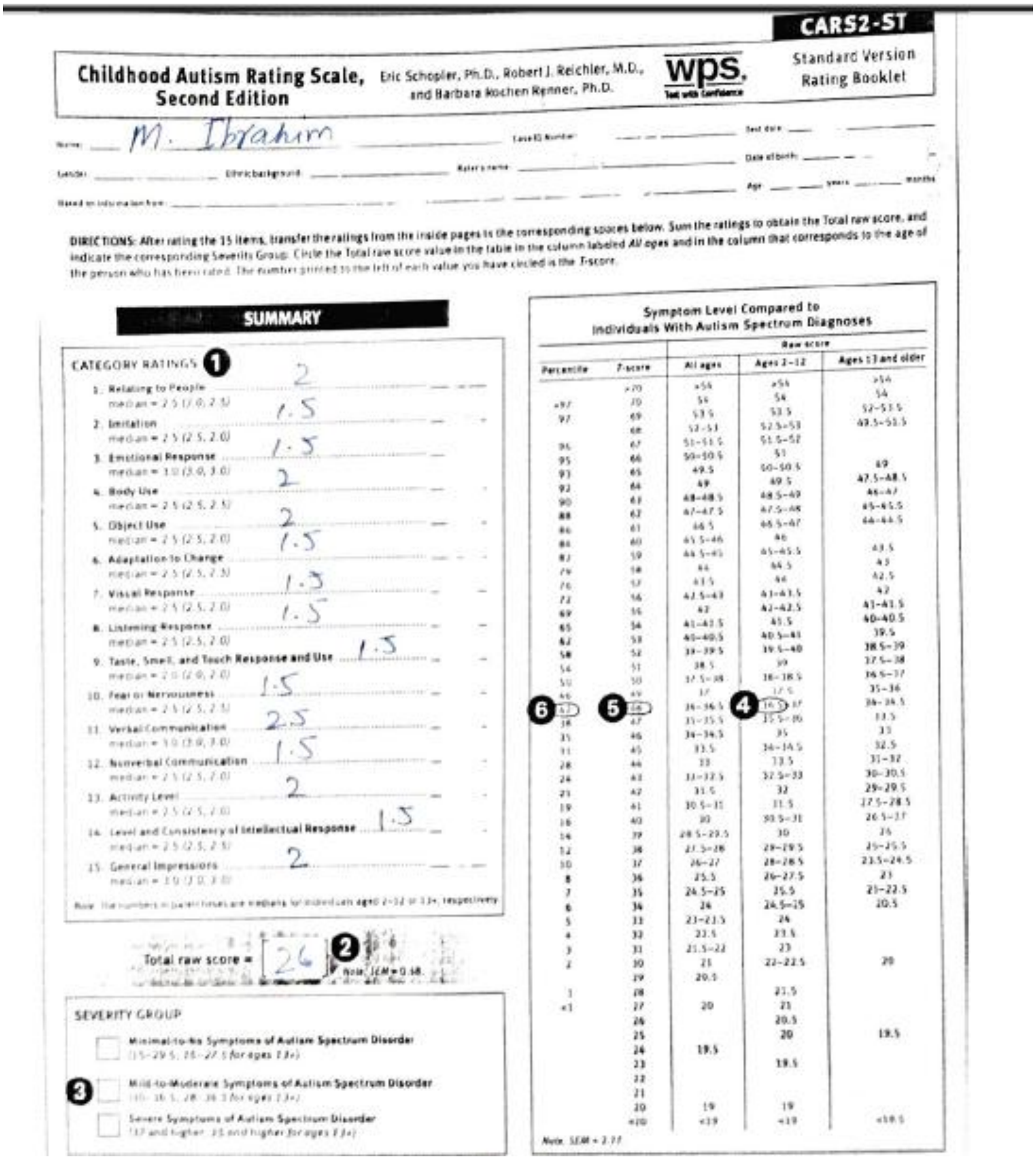
Parent's Signature: [signature] Date: 3-5-18

Dr. Yasar Ayaz
Head of Department
RIME- SMME
National University of Sciences and Technology
(NUST), Islamabad

Ms. Haleema Sadia
Director
Autism Resource Centre
Islamabad (ARCI)

Appendix-C- CARS Form

CARS form used during the research



CARS2-ST

Childhood Autism Rating Scale, Second Edition Eric Schopler, Ph.D., Robert J. Reichler, M.D., and Barbara Rochen Renner, Ph.D. WPS Test with Confidence — Standard Version Rating Booklet

Name: M. Ibrahim Case ID Number: ____ Test date: ____
Gender: ____ Ethnic background: ____ Rater's name: ____ Date of birth: ____
Age: ____ years ____ months
Based on information from: ____

DIRECTIONS: After rating the 15 items, transfer the ratings from the inside pages to the corresponding spaces below. Sum the ratings to obtain the Total raw score, and indicate the corresponding Severity Group. Circle the Total raw score value in the table in the column labeled *All ages* and in the column that corresponds to the age of the person who has been rated. The number printed to the left of each value you have circled is the *T*-score.

SUMMARY

CATEGORY RATINGS ❶

1. Relating to People (median = 2.5 (2.0, 2.5)): 2
2. Imitation (median = 2.5 (2.5, 2.0)): 1.5
3. Emotional Response (median = 3.0 (3.0, 3.0)): 1.5
4. Body Use (median = 2.5 (2.5, 2.5)): 2
5. Object Use (median = 2.5 (2.5, 2.0)): 2
6. Adaptation to Change (median = 2.5 (2.5, 2.5)): 1.5
7. Visual Response (median = 2.5 (2.5, 2.0)): 1.5
8. Listening Response (median = 2.5 (2.5, 2.0)): 1.5
9. Taste, Smell, and Touch Response and Use (median = 2.0 (2.0, 2.0)): 1.5
10. Fear or Nervousness (median = 2.5 (2.5, 2.5)): 1.5
11. Verbal Communication (median = 3.0 (3.0, 3.0)): 2.5
12. Nonverbal Communication (median = 2.5 (2.5, 2.0)): 1.5
13. Activity Level (median = 2.5 (2.5, 2.0)): 2
14. Level and Consistency of Intellectual Response (median = 2.5 (2.5, 2.5)): 1.5
15. General Impressions (median = 3.0 (3.0, 3.0)): 2

Note. The numbers in parentheses are medians for individuals aged 2–12 or 13+, respectively.

Total raw score = 26 ❷ *Note.* SEM = 0.58

SEVERITY GROUP

☐ Minimal-to-No Symptoms of Autism Spectrum Disorder (15–29.5; 15–27.5 for ages 13+)

❸ ☐ Mild-to-Moderate Symptoms of Autism Spectrum Disorder (30–36.5; 28–34.5 for ages 13+)

☐ Severe Symptoms of Autism Spectrum Disorder (37 and higher; 35 and higher for ages 13+)

Symptom Level Compared to Individuals With Autism Spectrum Diagnoses

Percentile	*T*-score	Raw score: All ages	Raw score: Ages 2–12	Raw score: Ages 13 and older
	>70	>55	>55	>54
>97	70	55	54	54
97	69	53.5	53.5	52–53.5
	68	52–53	52.5–53	49.5–51.5
96	67	51–51.5	51.5–52	
95	66	50–50.5	51	
93	65	49.5	50–50.5	49
92	64	49	49.5	47.5–48.5
90	63	48–48.5	48.5–49	46–47
88	62	47–47.5	47.5–48	45–45.5
86	61	46.5	46.5–47	44–44.5
84	60	45.5–46	46	
82	59	44.5–45	45–45.5	43.5
79	58	44	44.5	43
76	57	43.5	44	42.5
73	56	42.5–43	43–43.5	42
69	55	42	42–42.5	41–41.5
66	54	41–41.5	41.5	40–40.5
62	53	40–40.5	40.5–41	39.5
58	52	39–39.5	39.5–40	38.5–39
54	51	38.5	39	37.5–38
50	50	37.5–38	38–38.5	36.5–37
46	49	37	37.5	35–36
42 ❻	48 ❺	36–36.5	36.5 ❹–37	34–34.5
38	47	35–35.5	35.5–36	33.5
35	46	34–34.5	35	33
31	45	33.5	34–34.5	32.5
28	44	33	33.5	31–32
24	43	32–32.5	32.5–33	30–30.5
21	42	31.5	32	29–29.5
19	41	30.5–31	31.5	27.5–28.5
16	40	30	30.5–31	26.5–27
14	39	28.5–29.5	30	26
12	38	27.5–28	29–29.5	25–25.5
10	37	26–27	28–28.5	23.5–24.5
8	36	25.5	26–27.5	23
7	35	24.5–25	25.5	21–22.5
6	34	24	24.5–25	20.5
5	33	23–23.5	24	
4	32	22.5	23.5	
3	31	21.5–22	23	
2	30	21	22–22.5	20
	29	20.5		
1	28		21.5	
<1	27	20	21	
	26		20.5	
	25		20	19.5
	24	19.5		
	23		19.5	
	22			
	21			
	20	19	19	
	<20	<19	<19	<19.5

Note. SEM = 2.77