Abstract

The objective of the study is to use humanoid robots like Nao in a play setting to serve as a channel for education, collaborative learning and play. Nao has an inherent likeness to humans and an adaptability which facilitates inclusion of children with special needs such as Down syndrome and autism spectrum disorder in learning programs. This study is divided in two application areas for children with Down syndrome and children with autism spectrum disorder. Human Robot Interaction mediated Autism therapy is a novel approach to delivering therapy for Autism Spectrum Disorders using robotics and technology.

This proposed study leading to intervention utilizes a NAO robot in social constructs and interactions with autistic individuals and assesses their response to collaborative play in 3 major development areas of 1) Social cues, 2) Joint Attention and 3) Eye Contact. This will also explore the application and limitations of socially assistive robots in applied therapy and improve their acceptability in medical environments to achieve a significant progress in social, behavioral and developmental attitudes of children with Autism Spectrum Disorder.

Key Words: *Autism, Robotic Intervention, Down Syndrome, NAO robot,Human robot interaction, Socially Assistive Robots, ASD children, Joint attention, .*

LIST OF ABBREVIATIONS

ASD	Autism spectrum disorder
DS	Down syndrome
TD	Typically developed
AOSI	Autism Observation Scale for Infants
HRI	Human Robot Interaction
ABA	Adaptive Behavior Analysis
SAM SAR	Socially Animated Machine Socially Assistive Robotics
TCP	Transmission Control Protocol
JA	Joint Attention

CHAPTER 1

INTRODUCTION

The research work in this dissertation has been presented in two parts. First part is related to designing of humanoid robot based joint attention/Imitation and communication measurement and improvement system with different reinforcement stimuli for children with autism. The main objective set out in this part is to identify issues related to joint attention, communication eye contact and imitation in children with ASD and suggest and implement a methodology to quantitatively and qualitatively measure and improve the using a humanoid robot, NAO. Inclusion of different reinforcement stimuli helps us to get some information about the sensitivity of ASD child towards a scene. This part showcases a study of exploratory nature in which children who are diagnosed autism spectrum disorder (ASD) has an interactive session with a humanoid robot in collaborative scenario governed by a football game.

Part 2 describes an intervention on the applicability of socially assistive robotics in therapy of children with Down syndrome (DS). The context of the experiment measures social behavioral markers such as pointing, touching and expressing emotions towards the robot. The robotic platform used is the humanoid robot NAO. During the intervention the impact of NAO in assisting the children to improve and develop their social skills while engaging in various interactive scenarios is observed. In order to establish comparative data, similar scenarios are carried out with their caregivers in place of the robot as well.

1.1 Background, Scope and Motivation

Recently in the last few years, the application of humanoid systems and their role in therapy of ASD children has been posthumously explored [3, 4] with breakthrough directions, inferences, results and way forwards. Bounded by comprehensive therapeutic clinical protocol, a number of interventions show that continuous and industrious robot-human interactions result in to enhanced beneficial results when taskspecific self-directed behaviors are employed and consequently they can be easily assimilated on prevailing robotic systems. [5]

Research has also demonstrated that humanoid robots, when used in a free play setting can elicit collaborative play behaviour among children with Autism Spectrum Disorder [6].

Behaviors developed by children during freeform play and interaction contribute towards physical, cognitive and social development [1]. The specific nature of most play activities however, make them inaccessible for a lot of children with cognitive and social disabilities. These children with special needs are often unable to participate play activities with their peers, consequently they have difficulty in establishing relationships and in exploring their social development [2]. Socially assistive robots are fast emerging as tools to develop and facilitate behavioral social and physiological development of aforementioned children. [3,10].

For Autism existing research has focused on delivering robot-mediated therapy to children in controlled static environments where most of the responses of the individuals were constrained. Furthermore socially assistive robots have been used widely in evoking imitative responses along with joint attention but they haven’t explored these responses in a dynamic environment where both the individual and the robot has the freedom to choose the next action. Similarly no research has explored collaborative play that engages both upper and lower body motions and an unconstrained environment.

For Down syndrome this research is novel since any application robotics in social play and learning as not been carried out before.

In therapeutic settings Physical appearance of robot matters for both ASD and Down Syndrome children. The childlike and simplistic features are not overwhelming for the children and they tend to take well to the inanimate object in the begging. Research has shown that the underwhelming appearance but its likeness to human features tends to improve the rate of learning and skill building in children with autism during therapy/intervention [1, 2]. This is further augmented by observations that that humanoid robots have large impact on ASD children in robotic intervention because of their huge resemblance with human being.

The scope and application of humanoid robots is very flexible and ever expanding. Application of humanoid robots has been significantly used in healthcare and education domain. The following section briefly lists some of the popular experimental setups and applications of humanoid robots in various domains. It’s been broadly categorized in three areas

Healthcare Humanoid Robot

I. Humanoid Robots as companion

Research is being done to explore and practically implement Robots as personal assistant and companions. With the diversification of healthcare a lot of specialized fields are being created which are solely catered to by robot. Moreover, studies on the effect and efficacy of a humanoid robot on a spectrum of emotions such as anger, anxiety, and depression has also been groundbreaking with significant results. These studies have been evaluated by comparing the effect social robot-assisted therapy" [2] with human psychotherapy to children who had cancer.

II. Humanoid Robots as care taker in hospital and elderly homes

In hospitals and elderly homes, robots are being used as caretakers that can repeat same action multiple times which a human being cannot because sometimes human will become frustrated.

III. Humanoid Robots in Medicine and Healthcare

Surgical Robots have driven a significant improvement in healthcare that both doctors, PR actioners and users have appreciated.

Education Humanoid Robot

IV. Humanoid robots in education

Computers and Elearning have made great strides in education especially by increasing their access to education worldwide. However, given its popularity and promising results - the recent trend in education domain is towards the application of humanoid robots. Increasingly, Humanoid robots are becoming an essential component of education domain as they possess reasoning and analyzing capabilities that can logically support human learning and as a computer agent are better in terms of engagement than a virtual agent [27] [28]

Socially Assistive Robot

V. Humanoid Robots in industry

Socially assistive robots (SAR) a re a subcategory of social robots and as assistive robots, their use and application is gaining a lot of popularity especially among hospitality and caregiving industries. The general concept of Social robot is to assist their subjects in their day to day life and replaces manual human and hospitality activities. Domestically social robots have made their mark in terms of performance. Elderly adults or autistic individuals respond well to the use of these robots. Among children, social entertain [23] and play games [17]. Infact, it has been observed among autistic children that they choose to spend and engage more time with a robot [12] since the robots is a more predictive companion and appears less intimidating than humans [14]. Additionally humanoid robots have also shown to evoke emotion of nurturing care and improve awareness of social behavior [21].

In this particular area of study, the impact of age, gender and appearance of the robot on response, feasibility, users social behaviour, acceptance and trust towards the humanoid robot has been highlighted greatly. There has been a diverse opinion on the robot appearance among Children and elderly users. Where some preferred humanoid whereas, some preferred a more machine-like appearance [10]. However humanoid robots have been established to be a much better and more relatable fit for companionship since they look like a human,[10,25].

Autism, a developmental disorder and its symptoms are usually exhibited during the first three years of life, is characterized by difficulties in social interaction and communication as well as repetitive behavior and hyperactivity.

It is estimated that 350,000 children in Pakistan suffer from autism and this number is increasing day by day. Parents with autism spectrum disorder diagnosed children dea with challenges such as lack of of professional and relevant medical expertise, awareness, unavailable health care and, worst of all, social stigma. These challenges result in denial, frustration and isolation.

A large number of cases in Pakistan are not even diagnosed in the first place. Doctors do not have the expertise to diagnose ASD and family members usually due to lack of information or awareness, deny the existence of any brain-related disorder. It is also done inrder to avoid social stigma. On a government institutions level, autism spectrum disirder is often incorrectly lumped with mental illnesses.

Down syndrome is reported one in every 800 live births worldwide and in Pakistan particularly this is wrongly attributed to mental retardation. Individuals with Down syndrome exhibit intelligence and emotion and when treated right they can grow up to do great many things

1.2 Autism Spectrum Disorder

ASD is predominantly a disorder categorized under developmental that affects behavior and communication. It is categorized as a "developmental disorder" owing to the timings of its symptoms that generally appear in early two to three years of a child's life. Autism directly affects multiple social skills such as communication, eye contact, joint attention and imitation, motor skills, sensory skills that are very crucial for proper behavioral and social interaction. Autism directly affects either one of them or all of them. An autism observation scale for infants AOSI has been developed to quantitively measure the autism. This scale helps classify infants between typically developing and on the spectrum. There are different mechanisms which are being used for the early detection of autism in children. Most common approach is to contact corresponding therapists and psychologist, dealing in autism. These people identify the autism and rate it according to AOSI [3]. Normally, they divide autistic children into three major categories: Asperger syndrome, Low functioning autistic, and Hi functioning autistic etc. Curing of autism is possible via two major ways: medication, and interventions. We are dealing in treatment of autism via interventions. Now interventions are also broadly classified into three categories: human based interventions, robot-based interventions and human-robot based interventions.

1.3 Interventions for Autism Spectrum Disorder

Three types of interventions for Autism has already been mentioned, above paragraph. HumanHuman interaction-based intervention is most conventional one which is also being used right now where robotic based interventions have not been introduced yet. Human-Robot and only Robot-based interventions are recently introduced in this filed. In both types, this thing falls in Human-Robot Interaction (HRI) research field. Research have proved that robotic interventions are also capable of medicating autism in children [4], [5], and [6]. Depending upon the deficit, which ASD have, different interventions are used e.g., joint attention lack [7], imitation lack [8]. Commonly used interventions are: ABA, Speech therapy, PT, circle time, and many others. There are multiple factors which affects the interventions for ASD children being conducted by robots, such as physical appearance, interactivity, motion sequence and learning motivations [9].

1.4 Robotic interventions for Autism Spectrum Disorder

In human robot interaction, different children will be having different initial responses [10]. Robotic interventions are now being introduced in Autism Spectrum Disorder domain. These interventions are designed based on specific strategic plans which are suggested by either therapist or psychiatrist. The robots which are being used in these therapies are different in nature [11]. Few are humanoid, like human being in appearance, [12], few are anthromorphic and few are zoomorphic. [4, 8, 13, 14] and [7] presented few robotic based interventions and knowledge of robots being used in autism spectrum disorder. These robotic interventions are targeting either one deficit or multiple deficits present in ASD children, as mentioned above.

1.5 Types of robots and their appearance

Robots are categories in to three major types. They are: aerial robots, mobile robots, and humanoid robots. Each type of robot has its own physical and functional limitations. According to different applications and uses, their roles are also different from each other.

In autism, we usually use either mobile or humanoid robots or sometimes a mixture of these as well. Children with ASD are more deviated towards these robots to whom they consider toys mostly. [15] has presented a comparison between TD and ASD children regarding their perception about these robots. They reported that most of the TD and ASD children, categories these different types of robots as toys.

While they have also reported that few ASD children also categorized them as machines. [11] presented different robots which are being utilized in autism spectrum disorder, few of them are shown in figure 1.1, and figure 1.2, below.

Figure 1.1: Different types of humanoid robots available in Autism Spectrum Disorder

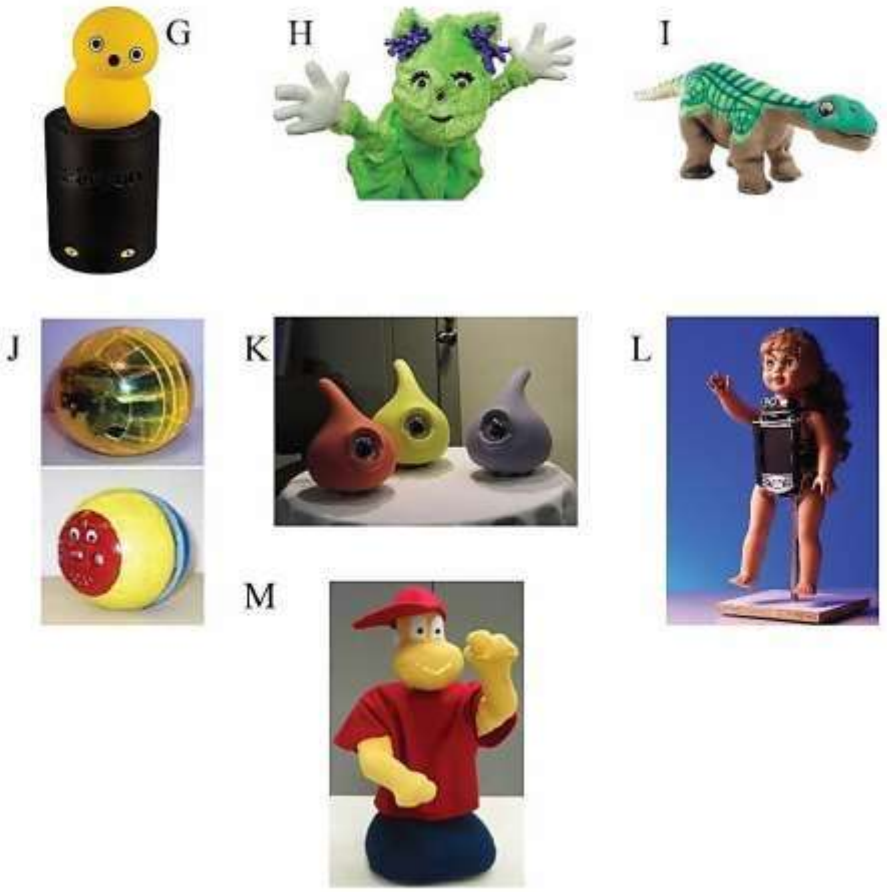


Figure 1. 2: Different types of non-humanoid, partially humanoid, and humanoid robots available in Autism Spectrum Disorder

These different robots belong to different categories with in humanoid and mobile robots. They are further divided into two more categories: Anthromorphic and zoomorphic robots.

Table 1-1 Robots along with their names, given in figure 1.1

Figure Number	Alphabet Allotted	Robot's Name
1.1	A	Bandit
1.1	B	iCUB
1.1	C	KASPAR
1.1	D	NAO
1.1	E	ZENO
1.1	F	Pepper

Anthromorphic robots are the combination of animal and humanoid robots while zoomorphic robots are completely animal like structure. All these robots along with their name and allotted letters are given in table 1-1 and 1-2.

Table 1-2 Robots along with their names, given in figure 1.2

Figure Number	Alphabet Allotted	Robot's Name
1.2	G	Keepon
1.2	H	Charlie
1.2	I	Pleo
1.2	J	Roball
1.2	K	Muu
1.2	L	Robota Doll
1.2	M	Tito

Near autistic children, appearance of robots matters highly [16]. It is observed that those robots have higher impact and capable of transferring high social skills, which closely resemble with human being, [1] and [16]. Moreover, different types of sensing technologies [17] , being used in autism, have proved that initial responses of ASD children towards humanoid robots are more as compare to other robots [10]. Interacting with robots physically, is one of the most initial response of ASD child. [13] Used tactile sensing technology for capturing this information. There are different roles of robots in autism spectrum disorder. They are: therapeutic playmate , social mediator, and model social agent [2] along with different controlling schemes [18] so that human robot interaction can make more and more collaborative and independent so that it resembles to natural reactions of human beings. [19] Checks that whether joint attention is dependent upon different social cues being given by robot? Along with these social cues, emotions recognition is also important because it will be a key of successful human-robot interaction. For this, [20] introduced Socially Animated Machine (SAM) which preserves the characteristics of human being while the body appearance is like animal. Moreover, NAO robot can also opt different emotional postures which can be perceived differently by different people [21].

1.8 Down Syndrome

Down syndrome happens on a chromosomal level and manifests when an individual has a full or partial extra copy of chromosome 21. This additional copy of chromosome in the genetic material alters the development of the individual and also manifest itself in the characteristics typical of Down syndrome. Some of the physical characteristics and traits are low muscle tone, an upward slant to the eyes, a single deep crease across the center of the palm and small.

That being said however, each person with Down syndrome is a unique when it comes to these traits and can retain these characteristics to different degrees, or not at all. There are three different types of Down syndrome

1. **Type 1: TRISOMY 21 – NONDISJUNCTION**

   Trisomy 21 is a very common form of Down Syndrome manifest itself for 95% of the cases. It is generally caused by non-disjunction with is primarily a error in cell division. Non disjunction results in an embryo that carries three copies of chromosome21 instead of the usual two copies. Therefore over the span of the gestation period as the embryo develops its extra chromosome continues to be replicated in each cell of the body leading to this condition.

2. **MOSAICISM**

   Mosiacism is the least common of all Down Syndrome with less than 1% of all reported cases. According to research research it is a an established indication that individuals with mosaic Down syndrome may have fewer traits and various characteristics that are otherwise typical of other types of Down syndrome. Mosaicism down syndrome manifests when two types of cells are present – 46 chromosomes and 47 chromosome cells. The cells with the 47 chromosomes are the ones that contain the extra chromosome 21.

3. **TRANSLOCATION**

   Translocation down syndrome accounts for about 4% of cases of Down syndrome. In this type the total number of chromosomes in the cells remains 46; however, there in an extra entire or partial copy of chromosome 21 attaches to another chromosome, usually chromosome 14. This extra or full partial chromose 21 presence is directly responsible for the characteristics of Down syndrome.

1.8 Types of Interventions for Down syndrome

Early intervention of Down syndrome primarily revolves around below three major types of therapy:

- Physical therapy: It is one of the most necessary interventions at an early stage since al lot of babies with Down syndrome have low muscle tone also known as hypotonia that slows their physical development and develops in to problems such as bad posture later in life if left untreated.

- Speech therapy: Children with Down syndrome have features that make it very hard for them to talk properly or clearly – these features are characterized by small mouth and large tounges. Aforementioned Hypotonia can make these problems worse since low muscle tone affects face. Speech development is also hindered by hearing loss. Speech therapy can help a child with Down syndrome to learn how to overcome these obstacles and communicate more clearly. The gradual Learning and using sign language also benefits.

- Occupational therapy It helps children learn develop and practice the skills they'll need to have for independent actions and decision-making. Occupational therapy includes a range of activities from learning to pick up and let go of objects to turning knobs, pushing buttons to self-feeding and dressing.

1.8 Robotic Interventions for Down syndrome

Technology and its rapid advancement there is an ever-growing array of items that can help people with Down syndrome negotiate their individual challenges more easily and successfully. However robotics haven't quite yet made it to the list of emerging devices for therapy of down syndrome which makes this study very novel in terms of gathering results and establishing a use case in a healthcare scenario.

1.7 Aims

The pertinent objectives of this thesis are to develop existing collaborative and social therapies on a robot and use various metrics of HRI to measure the efficacy and of the therapy. By developing an integrated vision and mobile system this thesis will be used in clinical trials to achieve behavioral improvements. Detailed objectives are given below

- To determine the response of children with down syndrome and autism to robot mediated therapy in areas of joint attention, education and collaborative play
- To determine the improvement in motor skills as a direct consequence of this therapy
- To determine the overall improvement on social and motor skills based on the therapy session when the ASD children are compared with their counterparts.
- To encourage executive functions in children with Down Syndrome

1.8 Hypothesis

I. Multi-humanoid robots, with reinforcement stimuli, can measure and increase the pro social behaviors of ASD children and Down Sydeome.

CHAPTER 2

ARCHITECTURE OF DESIGNED ROBOTIC THEREAPUTIC INTERVENTIONS

This chapter thoroughly defines the complete architecture of designed interventions. It is divided into two parts. Part one deals with intervention used for Autism Spectrum Disorder and part two deals with intervention used for Down Syndrome.

2.1 Humanoid Robot Based Pro-Social Behavior Measurement and Improvement System for Children with ASD

This multi humanoid robots-based system is designed for measuring the joint attention/communication eye contact and proximity of ASD child quantatively as well as qualitatively. This entire procedure was broken down into steps – each step recording a specific behavior for offline and automatic coding. .

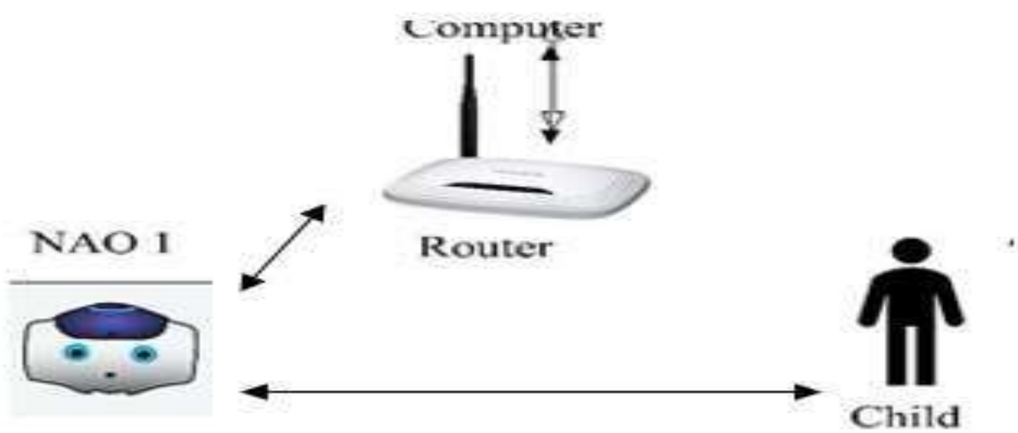


Figure 2.1: Architecture of Prosocial Behavior measurement and improvement system

This study has been carried out to develop, structure and physically implement a structured play scenario of a football game between a child with autism spectrum disorder and a socially assistive NAO robot. The main intent behind this intervention is to observe and record substantial improvement in communication and social interaction. The socially assistive robot implemented for the intervention is NAO robot due to its wide availability and effortlessness of operation/access. This intervention/study also attempts to demonstrate and validate the feasibility of a exclusive robot-assisted methodology and number of precise independent behaviors that can very possibly develop into further studies on cross-platform SAR implementations and wide-ranging effectiveness of a Socially Assistive Robots in clinical studies-intervention.

2.1.1 Experiment Setup and Design:

The initial sessions of the pilot phase of the intervention/study were conducted at the Picture Autism Center in Islamabad where participants matching a criteria were also shortlisted. The center was purpose built to accommodate a inclusive education model for children and youth with special needs. Another reason for carrying out the intervention at the center was to ensure a degree of ease for the participants and parents in familiar settings. An Illuminated and well-lit room which was a part of a large hall was selected for the intervention execution. The room also had safety furnishings and temperature control. A camera was set at one side to record the overall intervention.

During the intervention and interaction with the robot, each subject was attached with either a designated therapist/shadow or his parent (and in some cases both). One of the reasons for this arrangement was to allow the child to easily transition into the intervention surrounded by familiar people - the shadows and/or the parents were to merely facilitate the child as shown in the figure below while the child was exposed to the humanoid robot for the very first time.

Figure 2.2: Architecture of Prosocial Behavior measurement and improvement system

2.1.1 Metrics Measured

- Proxemics
- Communication
- Turn Taking
- Eye Contact

2.1.2 Intervention Setup

The procedure, modules and experimental setup was design with the collaboration and input of behavioral experts at Picture Autism Institute who recommended the intervention be loosely structured around the applied behavior therapy training method. The ABA method is also a globally approved method and accepted widely for autism interventions. Each module followed a stimulus response and feedback method. If the participant demonstrated accurate response to the given prompt, no reinforcement prompts are triggered.

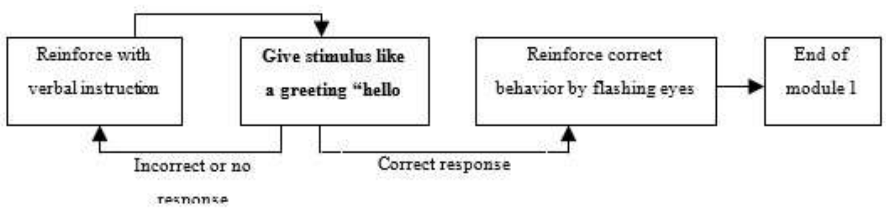


Fig. 2.3 Breakdown of ABA therapy for module 1 to model and teach social greetings.

Above module observed and recorded the behavior and response of the subject. Multiple readings and observations were being recorded by the through externally positioned and inbuilt robot cameras. Parents and student shadows supervised the child's behavior throughout the interaction.. Intervention with each participant ran a duration of 15 minutes. Its detailed step by step setup as well as flow has been given below in table 2-1.

Table 2-1 Experimental setup and modules.

Module no	Description	Intended Response
1	Introductory Rapport	Attention of participant engaged
2	NAO asks questions (do you want to play football? etc)	Participant engages in a conversation with the robot
3	NAO initiate a game of football	Participant observes the robot and the ball and demonstrates response though kicking the ball
4	NAO gives multi-sensory feed back	Behavior reinforced in the participant.
5	NAO concludes the sessions with farewell remarks	Participant takes the cue and exits

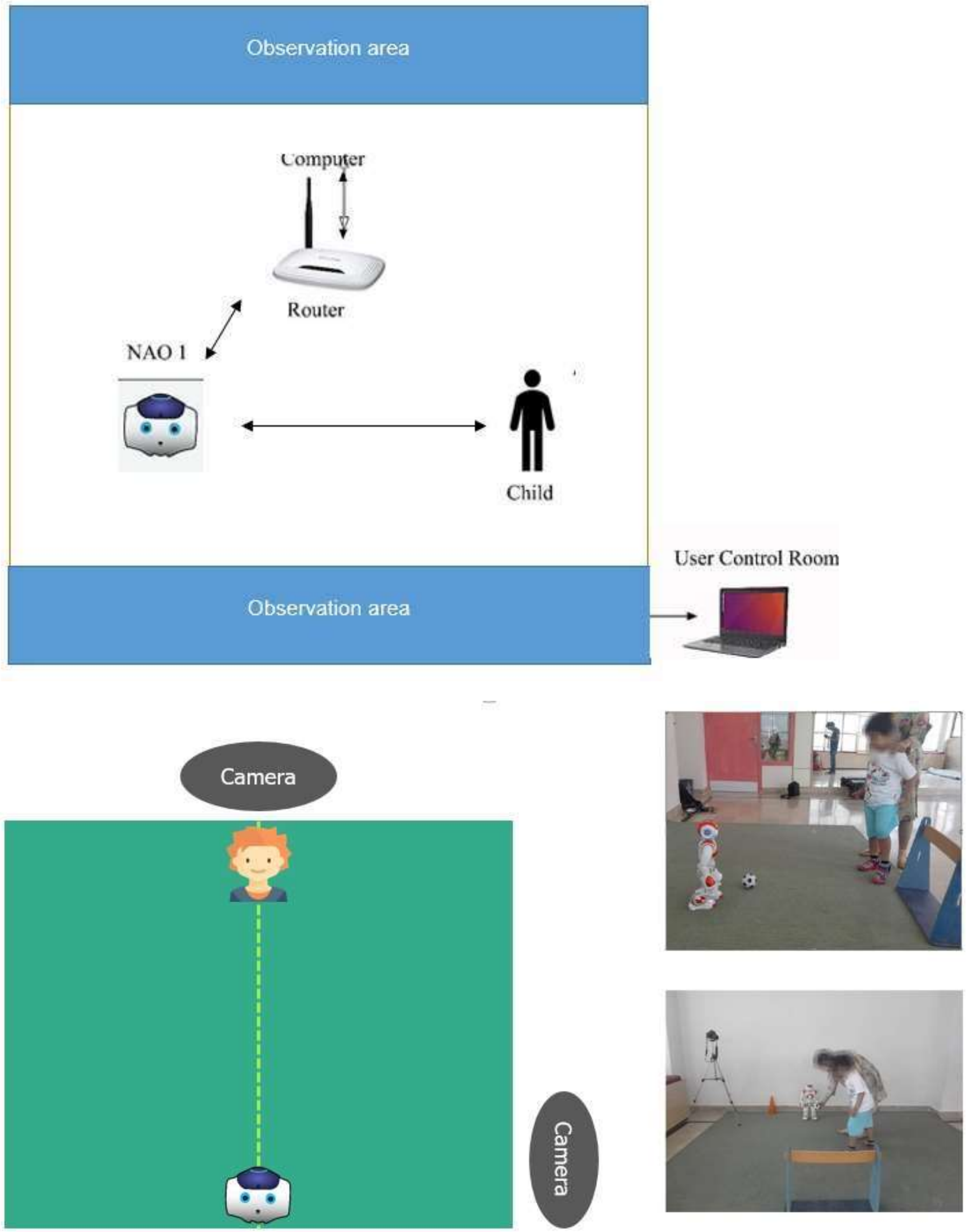


Figure 2.4: Intervention Sequence and setup

During the intervention, we also structured the setting in a way to record and observe how quickly the joint attention of ASD child shifts between the NAO robot and the ball between the robot and the child. Reinforcement stimuli are given by the robot in the form of verbal encouragement or sensory cues such as lighting of eyes or applause sounds.

2.1.3 Data Collection and Analysis

All interventions and experiments were recorded from one camera placed independantly and one camera in the NAO robot that was prebuilt to assess various human robot interaction markers markers such as eye contact, communication (verbal) and duration of the engagement between child and robot. Following each intervention a questionnaire survey with a range items about children's attitude during the intervention ranging from – interaction social and otherwise, emotional state, state of activeness, interest, and – in training scenarios was rated by children's mothers or shadows, and each question on the survey was evaluated against a 5 point Likert scale that ranged from

'strongly disagree' (1) to 'strongly agree' (5). The results of these surveys will be shown in section 3 Under Experiment Results.

The data collection also recorded a post intervention interaction of the child with his parents or shadows in similar setting to assess the knowledge transfer and learning. At the end of each session the robot was removed from the intervention room to determine how well the child performed the same behavior without the social cues from its earlier interaction with the robot. The childs ability to relate to those social cues and apply them in a human to human scenario in a social context was also measured.

2.1.8 Assessed parameters of Measured Metrics

Joint attention measurement and improvement system can record different parameters. These parameters, along with their detailed description, are given in table 2-2, below.

Table 2-2 Parameters recorded by humanoid robot

Sr.#	**Parameter**	**Description**	**Sensor / Technique**
1	N_e	Total number of eye contacts recorded by NAO robot	NAO robots' cameras

2	t_e	Array of time of each eye contact with NAO robot	-do-
4	N_{fn}	Number of eye contacts with first NAO robot	-do-
6	t_{Max}	Maximum eye contact duration	Mathematically calculated
7	t_{Min}	Minimum eye contact duration	-do-
8	t_{Avg}	Average eye contact duration	-do-
9	t_i	Total time for intervention	-do-
10	c	Communication Utterances	-do-
11	d	Distance between the child and robot	-do-
17	N_{ri}	Number of accurately captured reinforcement stimuli	NAO Robot
18	N_{mri}	Numbered of missed reinforcement stimuli	NAO Robot

2.2 Humanoid Robot Based Pro-Social Behavior Measurement and Improvement System for Children with Down syndrome

2.2.1 Experiment Design

The interventions were carried out at the Down syndrome club in Islamabad in an open room free of distractions. The primary reason of choosing the club instead of the lab was to facilitate the comfort of the children in their natural environment. More specifically the environment and activities were structured in a manner to facilitate

(1) An organized structure of time and activities in order to create a more suitable setting for DS children

(2) Timed end and start cycles for the activities owing to the low attention spans of the children

(3) Identification and reduction in possible sources of distraction

(4) A manageable and small number of children for each group

(5) A more relevant and easier narrative context.

Figure 2.5: Imitation system actuated by interaction with the DS Child

The procedure was divided into two interventions.

(1) Adapted model-rival method AMRM for indirect learning

- The synthesized behaviors included learning alphabets, numbers and shapes

(2) Freeform Imitation/Fine Motor Exercise These

two interventions measured below metrics

- Emotion/Facial expressions
- Learning/Retention/Social Interaction
- Child's intention to complete a goal-directed task smoothly.

2.2.2 Adapted Model Rival Method

The Model-rival method is a label training procedure that has generally been used to train birds and animal in prior studies. Its feasibility for application in autism therapy has also been explored

This method is generally used to train animals and birds to learn and recognize the distinguishing features of a target object. These features range from things such as color and names by closely observing interactions between a trainer and the probable competitor involved in the intervention conversing about the different features. On some levels this technique relies on observation and a sense of competition for efficacy.

The label-training method itself is a variation of the model-rival method that relies of observing conversations to learn and develop cognitive abilities

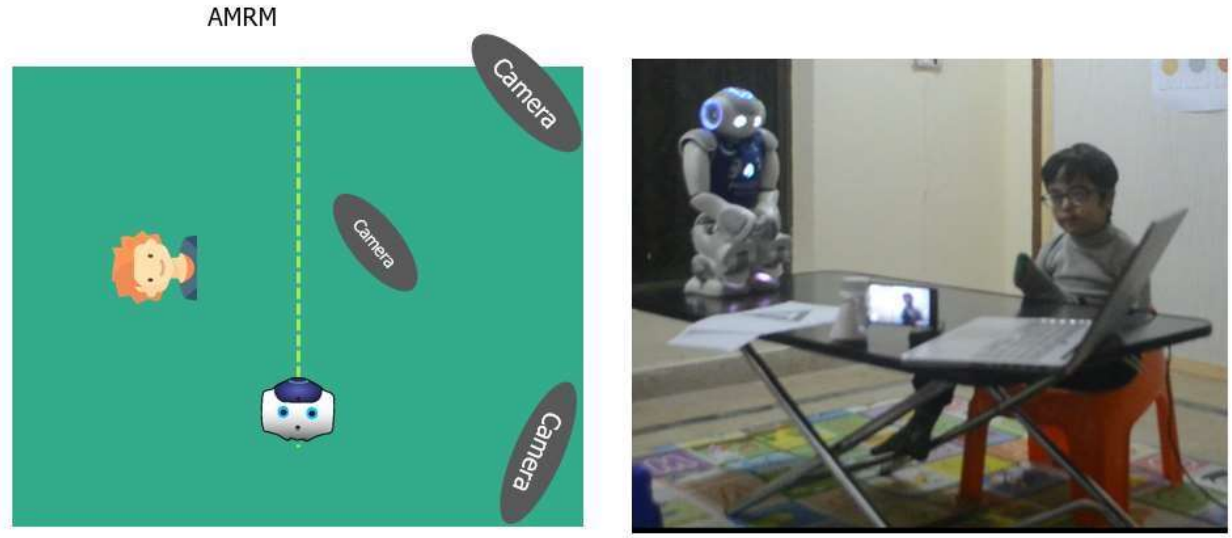


Figure 2.6: AMRM Intervention Sequence and setup

Hypotheses set for this pilot study with model rival method:

- Children with Down syndrome would find the robot friendly and approachable.
- Modal Rival Method would be greatly helpful in improving the learning and social interaction abilities of the children.

Figure 2.7: AMRM Therapy in progress

2.2.3 Intervention sequence and setup

The imitation sequence environment setting is given in the figure below. In order to ensure proper data collection there were two cameras in the room along with

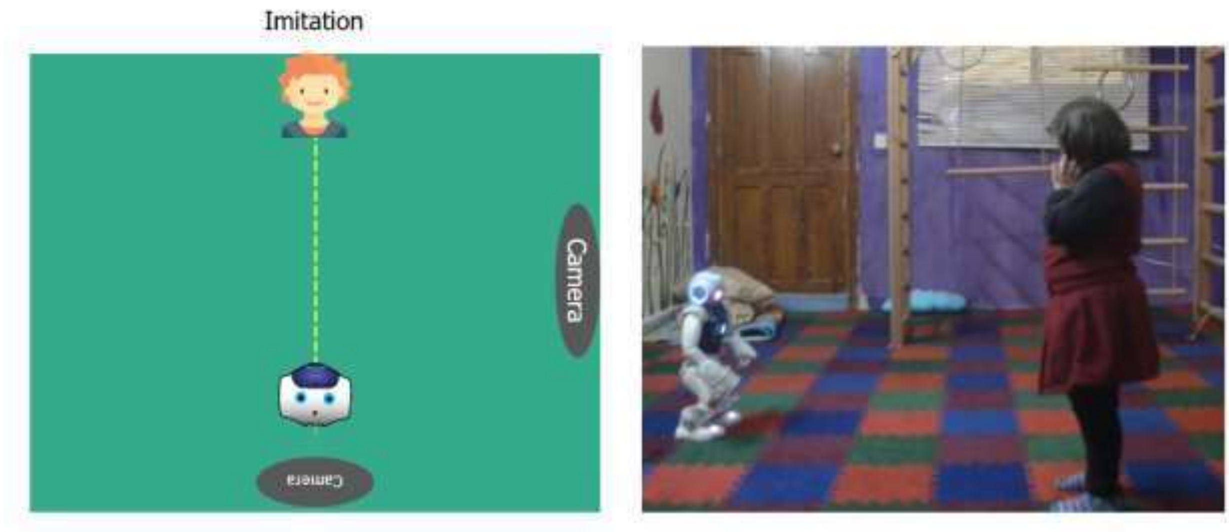


Figure 2.8: Intervention setup

The intervention sequence is given below.

Module no	Description(**Freeform Imitation**)	Intended Response
1	Introductory Rapport	Attention of participant engaged
2	NAO asks the child if he/she would like to follow him	Participant engages in a conversation with the robot
3	NAO Strikes multiple sitting and standing poses	Participant observes the robot and imitates accordingly
4	NAO gives multi-sensory feed back	Behavior reinforced in the participant.
5	NAO concludes the sessions with farewell remarks	Participant takes the cue and exits

Table 2-3 Intervention Sequence for freeform Imitation

CHAPTER 03

EXPERIMENTAL RESULTS

Results section of thesis have been divided into two different parts. First part describes different results related to first intervention, (1) Autism Spectrum Disorder, second part describes results related to second intervention, (2) Down Syndrome,

3.1 ASD and DS subjects' details

These interventions were conducted with thirteen different subjects. Three for Autism and 7 for down syndrome. Their details: regarding age, place on spectrum, autism case category, type of Down syndrome are given in appendix A. Experimentation period was one month long for autism and 3 month long for Down syndrome.

For ASD the inclusion criteria was

(a) 3-10 years of age,

(b) A full-scale IQ range of 60 and 120 and

(c) A medically valid ASD diagnosis

Child	Age (y)	Gender	Diagnosis
P1	5	Male	ASD
P2	7	Male	ASD
P3	3.5	Male	ASD

Table 3.1: ASD Intervention Participant Details

For Down syndrome the inclusion criteria was

(a) 3–14 years of age,

(b) IQ scale between the range of 50 and 120 and

(c) A medically sound and legitimized DS diagnosis

The participants were divided into three groups

1) Group 1 <5y
2) Group 2 5y-10y
3) Group 3 >10y

Child	Age (y)	Gender	Diagnosis	Group
P1	3	Male	DS	1
P2	7	Male	DS	2
P3	4.5	Female	DS	1
P4	5	Female	DS	1
P5	14	Female	DS	3
P6	8	Female	DS	2
P7	15	Female	DS	3

Table 3.2: DS Intervention Participant Details

3.2 ASD Intervention

Below are some of the results that were measured and evaluated in the ASD intervention.

3.2.1 Proxemics

Initial Responses to the robot ranged from excitement to apprehension. This data was collected from our independent observations and qualitative analysis by the shadows

	S1			S2			S3		
	Positive	Negative	Neutral	Positive	Negative	Neutral	Positive	Negative	Neutral
P1		1		1					1
P2			1			1		1	
P3	1			1					1

Figure 3.1: Participant Response to the robot and stimulus

Proxemics were an important metric to measure to establish legitimacy with respect to participant interaction and a measure of their comfort in interaction with the robot. Close proximity of the participant with the robot (distance between the two <= 10 inches) measured the how familiar and comfortable the participant felt around the robot

	S1	S2	S3
P1	0.16	0.39	0.34
P2	0.31	0.26	0.31
P3	0.31	0.23	0.43

Figure 3.2: Proxemics and reactivity ratio

The figure 3.3 below demonstrates for each session - the total recorded time, during which there was a close proximity between the participant and the robot. Each session was timed between 900-1200 seconds and not more.

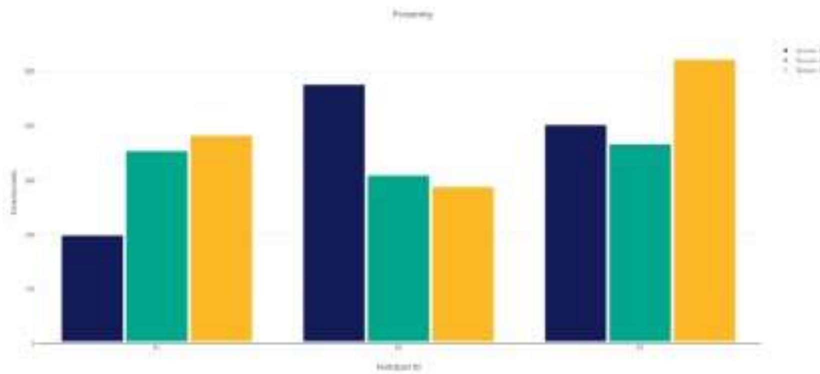


Figure. 3.3 Human robot proximity for participant 1,2 and 3 over the three sessions

3.2.2 Turn taking Instances

Table 3.3 show turn taking instances exhibited by the participant during the game. Each time the participant displayed that closely resembled turn taking, An instance was counted and recorded. An instance was counted each time the participant kicked the ball and waited for the robot to kick it back. The aggregate result and data for the three participants over the three sessions is given below in table 3.3.

Participant	Session 1	Session 2	Session3
P1	3	6	7
P2	3	1	5
P3	7	6	7

Table 3.3: Turn Taking instances by subjects

3.2.3 Communication

During this experiment it was demonstrated that Participants increased their communication while playing with the robot. Communication was measured each time occurrences of verbal utterances were directed at the robot in response to prompts which ranged from questions or phrases. As an additional layer this data was further measured and analyzed during and after the experiment by the researchers and therapists. It was observed in the study that P1 and P3 exhibited telltale autistic behaviors such as repetition in speech and the use of unintelligible words and conversations. Some had very animated and excited conversation. Table 3.4 shows these instances.

Participant ID	Session 1	Session 2	Session3
P1	12	11	15
P2	8	10	6
P3	2	3	5

Table 3.4 Instances recorded of verbal communication directed towards the robot.

3.2.4 Eye Contact

As a non-verbal communication, eye contact has a great significance in social behaviors. During the robot intervention, participants demonstrated an increase in duration of eye contact particularly during one on one interaction. Shifting gaze between ball and robot was alos exhibited demon. This was observed during the ball kicking module and it was a exercise in basic joint attention. The naos inbuilt camera measured eye contact while offline video coding and analytics were used in making estimates.

Figure 3.4: eye contact post analysis

Below figures illustrates the average eye contact duration that each participant had for three out of four sessions. Each session did not last for more than 900-1200 seconds

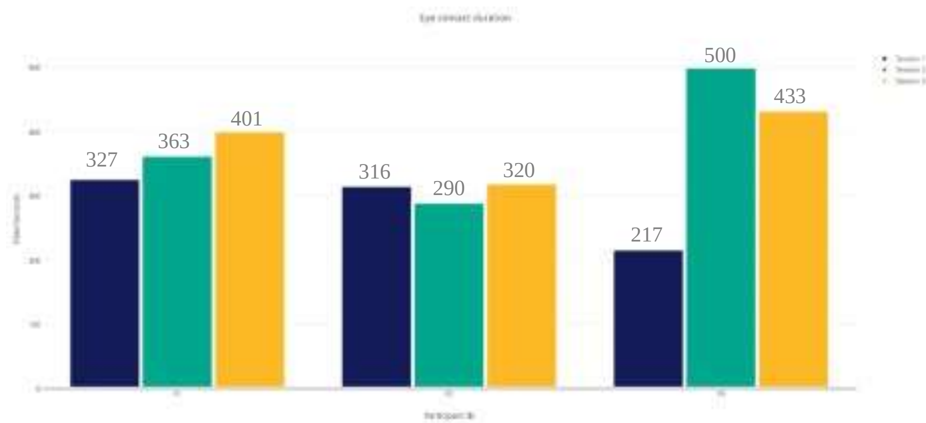


Fig. 3.5 Participant eye contact duration with the robot over the three sessions

Average eye contact durations of each subject in each experiment have been recorded in figure 3.5. All the subjects' readings showing an increasing trend except for subject 2. The non-increasing trend of P2 is due to having no interest in intervention.

Table 3-5 Different parameters measured by the system

Sr.	Variable	Description	Sensor used
1	N_e	Total number of eye contacts recorded by NAO robot	NAO robot' cameras
2	t_{max}	Maximum eye contact duration	Mathematically calculated
3	t_{min}	Minimum eye contact duration	-do-
4	t_{avg}	Average eye contact duration	-do-
5	N_{no}	Number of eye contacts with first NAO robot	-do-
7	t_i	Total time for intervention	-do-
8	N_{ri}	Number of accurately captured reinforcement stimuli	NAO Robots
9	N_{mri}	Numbered of missed reinforcement stimuli	NAO Robots
10	N_k	Total number of attention diversion recorded by Kinect	NAO robot' cameras

Table 3-6 Measured Parameter values

Subject	N_e	t_{max}	t_{min}	t_{avg}	N_{no}	t_i	N_{ri}	N_{mri}	N_k
p1	121.75	3.75	1.125	2.068	84.625	498.50	38.12	27.25	77.12

p2	57.42	4.428	0.4285	0.9514	31.571	244.28	39.14	18.00	66.571
p3	57.37	1.00	0.125	0.2901	44.00	494.37	35.875	21.125	32.125

* All time readings are measured in seconds

3.2.4 Over All Success rates of ASD Experiment

This scenario involving social & physical games encouraged children to make best use of their self-regulating decision making and instinctive problem solving aptitude which went on to nurture social exchanges that swiftly and effortlessly replicated themselves from the robot to the child and from the child to other children interactions.

Where we saw a demonstrated progress in Participant 1 (p1) and Participant 3 (p3) progress measured human robot interaction criteria there was also Paprticipant 2 (p2) who did not have similar improvements. There were a number of contributors that influenced this non confirming behavior such as age, high mental fragmentation, mood and emotional sensitivity.

This intervention however, measured important insights into the social constructs and settings that boost and teach prosocial behaviors among the children and robot.

One of the ways through which this intervention was validated was by removing the robot at the end of each session to observe how each participant would engage in a similar collaborative play with his peer or parent.. This post intervention module did not last longer than a two minutes and it measured improvement in the shared joint attention and play skills of participant 1 and 3. Parents/Shadows were given a questionnaire survey with various items pertaining the participant's attitude for the duration of the intervention over the various modules. Each item was evaluated on a five point Likert scale ranging from 'strongly disagree' (1) to 'strongly agree' (5). Figure 3.6 charts some general responses regarding the overall study.

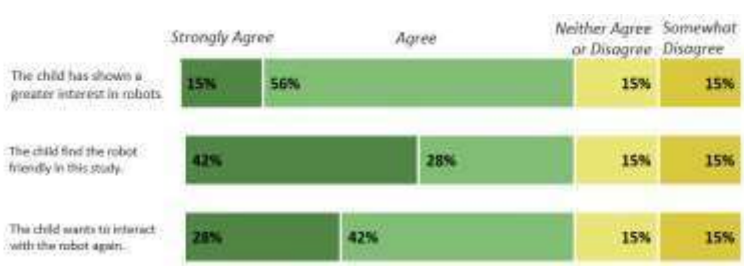


Figure 3.6: Evaluation of the subject's interaction with the robot used in study by the parents

Table 3.7 also lists some of the behavioral questions and how their measured against a cumulative Likert scale score on figure 3.7. Given how the sample size was small, the cumulative ratings are not entirely statistically robust nevertheless the study recognized and established that the proposed intervention showed results and effectiveness of play in developing social skills

Table 3.7. Sample questions on the survey to measure participants behavior.

Question-ID	
Q3	The participant displayed emotions and towards the robot
Q4	The participant engaged in communication with the robot
Q5	The participant was in close proximity of the robot
Q6	The participant was more active during the test study

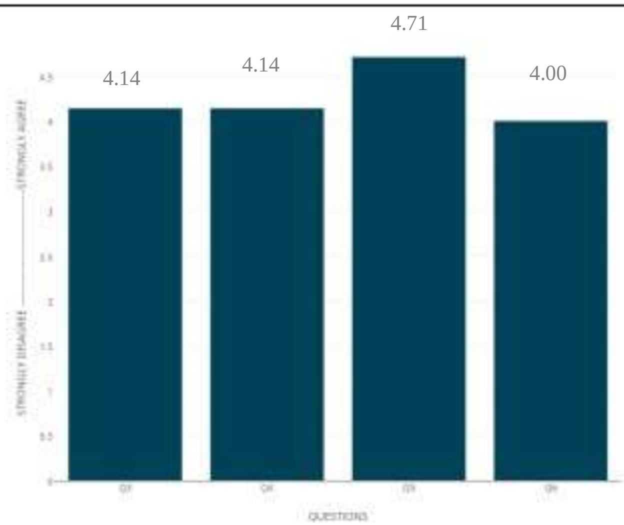


Figure. 3.7 Parental/shadow evaluation of the participant's social interactions and response to robot

3.2.5 Challenges

Some of the major challenges in working with ASD participants were

- Mental fragmentation of the participants
- Sensory limitations of some participants
- The small sample size of the population large age variance made it difficult to draw solid conclusion

3.3 Down Syndrome Intervention

The aim was to investigate the applicability of this method specifically for children with Down syndrome. The context of the experiment measured social behavioral markers such as pointing, touching and expressing emotions towards the robot. The robotic platform used was the humanoid robot NAO. During the intervention, the impact of NAO in assisting the children to improve and develop their social skills while engaging in various interactive scenarios was observed. In order to establish comparative data, similar scenarios were carried out with their caregivers in place of the robot as well. This intervention measured an increased response rate by children towards the robot along with other social behavioral markers such as the likeability, acceptance and interaction interests of participants with the robot. Psychological reactions were evaluated using facial images captured during the study

Children with DS interacted with the robot in individual sessions assisted/closely monitored by a caregiver and researcher. Before the start of each intervention with the robot the child was observed in social scenarios with his/her peers and caregivers and various behaviors were measured for comparison.

In each session the robot made conversation with the child and engaged in a free form interaction and imitation scenario. The child's responses to the robot were measured and based on the data various behaviors were measured.

All the sessions were recorded with 2 cameras placed at various locations in the room as well as a singular camera that was directly facing the participant to measure various emotions. Recorded content was also captured form NAOs internal front cameras but its data was too shaky to work on for conclusive results.

The emotions of the child pre and post assessment were measured using an emotion recognition API. The proxemics were coded offline using the recorded content.

3.3.1 AMRM

As stated before, the label-training procedure is a variant of the model-rival method that relies of observing conversations to learn and develop cognitive abilities. The Adapted model-rival method

AMRM for was used as a form of indirect learning. The synthesized behaviors included learning

1. Alphabets,
2. Numbers,
3. and shapes

The metrics measured were Emotion/Facial expressions

1. Learning
2. Retention
3. And Social Interaction

Four participants took part in this sub-intervention.

3.3.1.1 Skill Martix

For label training procedure a skill matrix had to be mapped for the participants. That could bench mark their current and target performance. Below table lists the skills measured

Sr #	Skill
1	Knowledge of Alphabets
2	Knowledge of Shapes
3	Knowledge of Colours
4	Knowledge of Numbers

Table 3.8 Skills measured for AMRM

Below Figures plot the participant's skill level at the beginning of the experiment and at the end of the experiment.

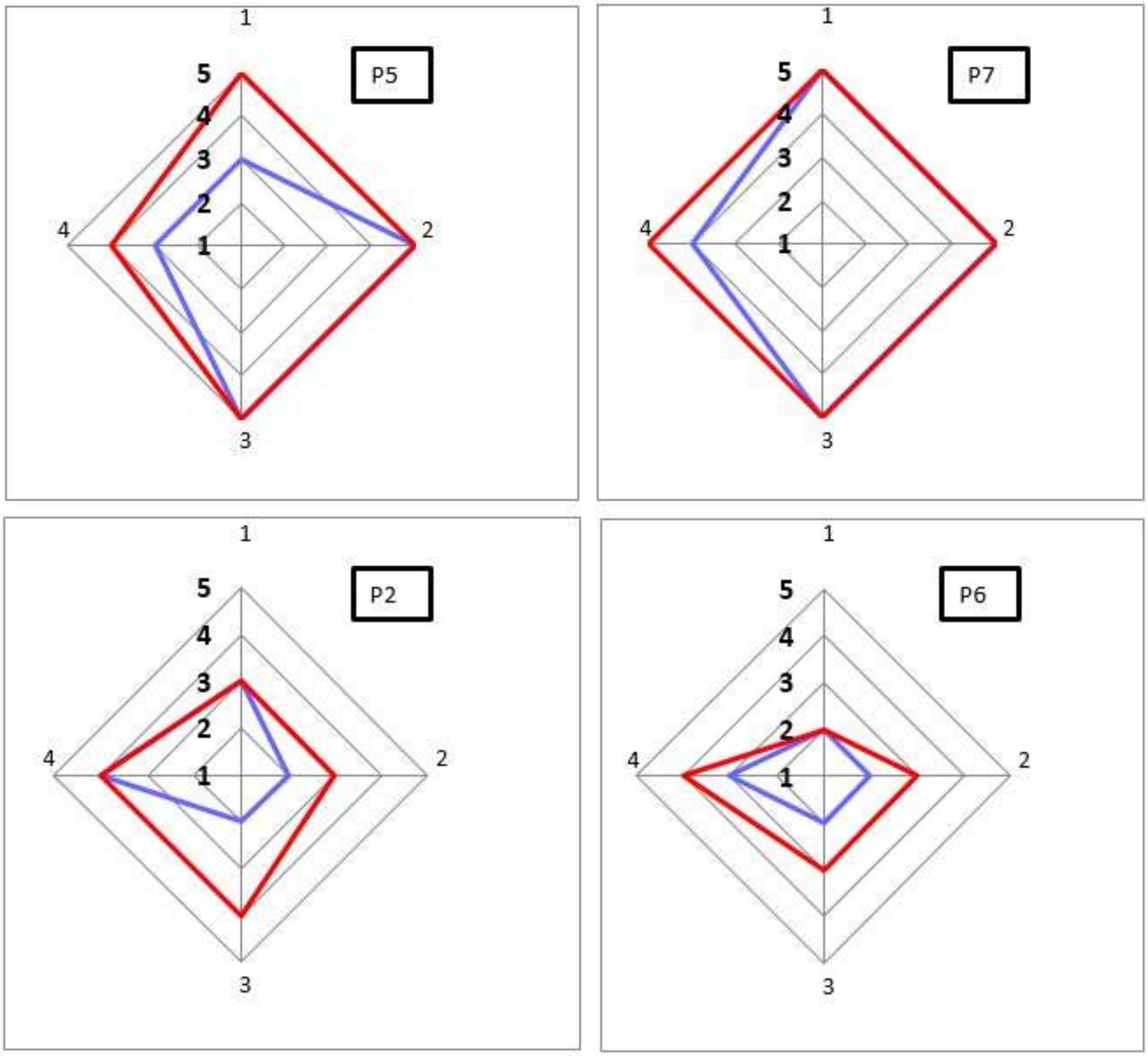


Figure 3.8 Pre and Post session skill assesment

3.3.1.2 Communication and Gaze

Below figures also plot the gaze and communication metrics of the participants over the course of the interventions. The parameters measured by the system are given in the table below

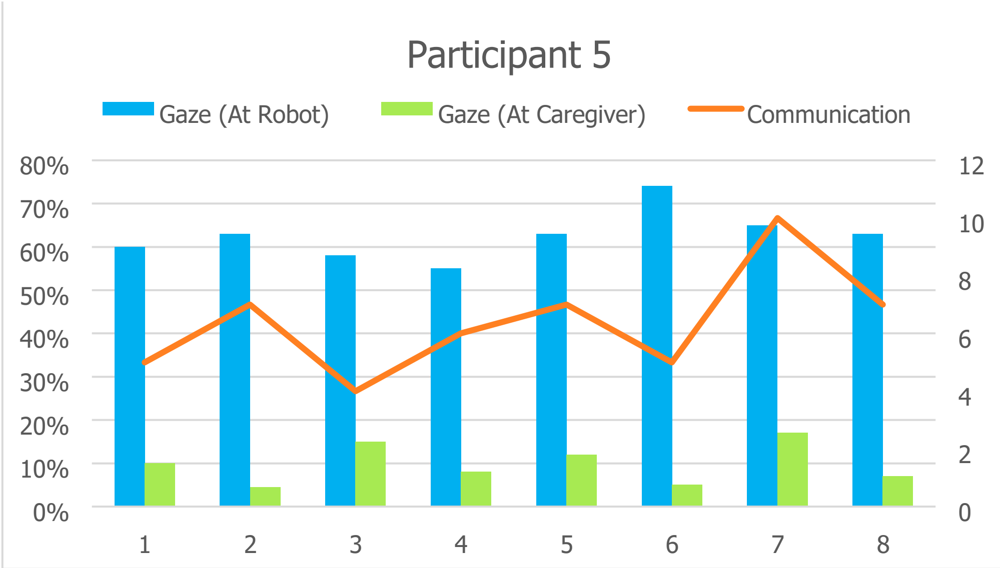
Sr.	Variable	Description	Sensor used
1	N_e	Total number of eye contacts recorded by NAO robot	NAO robot' cameras

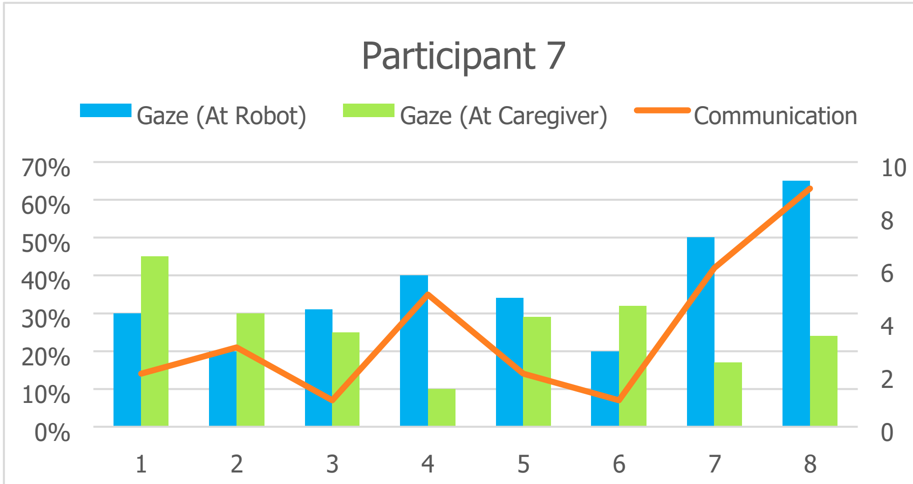
2	t_{max}	Maximum eye contact duration	Mathematically calculated
3	t_{min}	Minimum eye contact duration	-do-
4	t_{avg}	Average eye contact duration	-do-
5	N_{no}	Number of eye contacts with first NAO robot	-do-
6	N_{nt}	Number of eye contacts with Caregiver	Second camera
7	t_i	Total time for intervention	-do-
8	N_{ri}	Number of accurately captured reinforcement stimuli	NAO Robots
9	N_{mri}	Numbered of missed reinforcement stimuli	NAO Robots
10	N_k	Instances of communication recorded	NAO robot' cameras/mic

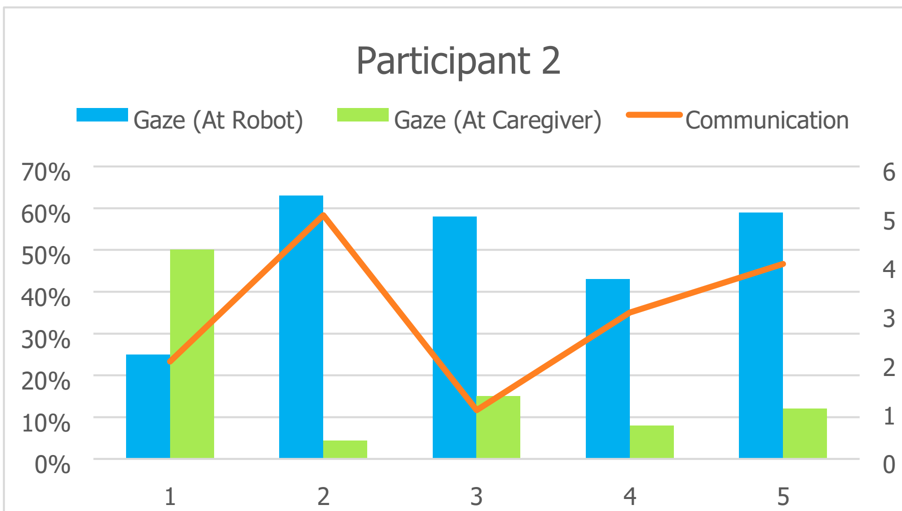
Table 3.9 Variables and parameters measured during the session

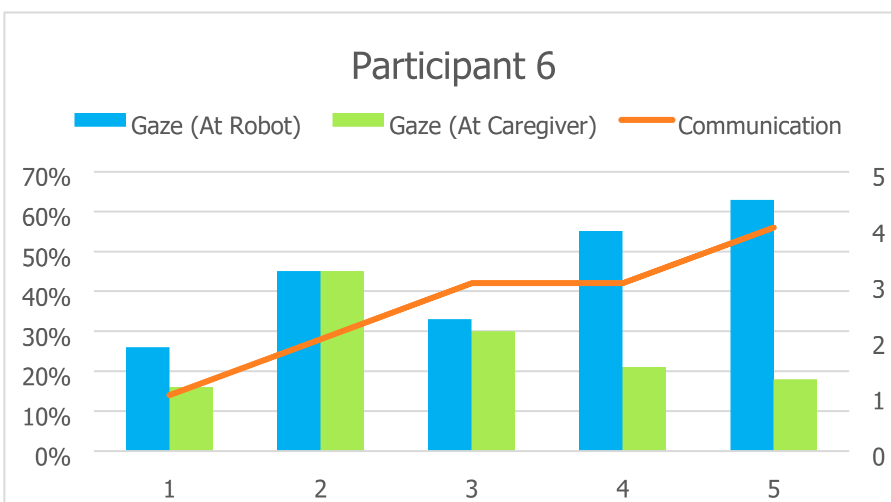
Below figures 3.9 represent the plotting of the observations.

Figure 3.9 AMRM Observation plotting




Participant 7
Gaze (At Robot)
Gaze (At Caregiver)
Communication
70%
60%
50%
40%
30%
20%
10%
0%
10
8
6
4
2
0
1
2
3
4
5
6
7
8


Participant 2
Gaze (At Robot)
Gaze (At Caregiver)
Communication
70%
60%
50%
40%
30%
20%
10%
0%
6
5
4
3
2
1
0
1
2
3
4
5


Participant 6
Gaze (At Robot)
Gaze (At Caregiver)
Communication
70%
60%
50%
40%
30%
20%
10%
0%
5
4
3
2
1
0
1
2
3
4
5

3.3.2 Imitation

For imitation the robot was performing 6 different actions for Imitation. They were:

$R_{Actions}$ = [$Raise\ hands, Hands\ down, Move\ forward, Move\ backward$, Sit, Stand]

The aim of the freeform imitation/fine Motor exercise was to measure the Child's intention and ability to smoothly complete a goal-directed task. Below Figure 3.10 is showing the success rate with respect to robot of all subjects averaged over all experiments.

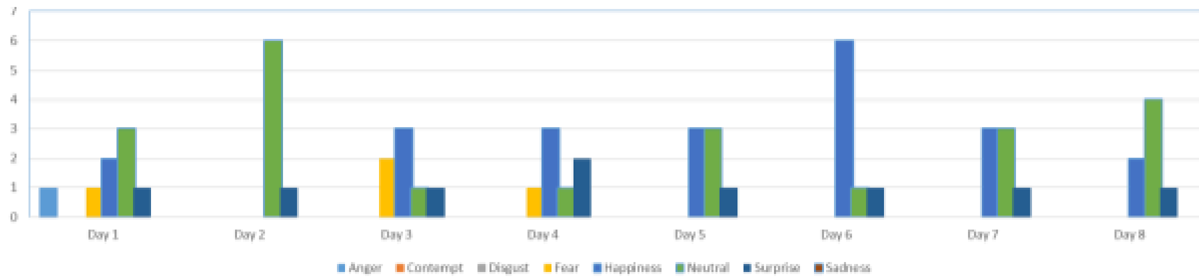


Figure 3.10 Imitation Emotion Observation plotting

Face Scale

Face scale readings were taken before during and after session to record their effectiveness in elevating mood and social behaviors. The scores recorded post intervention were always lower than those recorded pre intervention demonstrating the ability of the robot to uplift moods. The moods were also a precursor towards how well the overall session went and what the participant got out of it.

Fig.11 and 13 show examples of participants 1 and 4 who had a very angry and irritable disposition during the beginning of the sessions however the post session results showed better moods. Similarly participant 3 had neutral emotions pre intervention however post intervention interaction with the robot showed significant improvement in the overall mood.

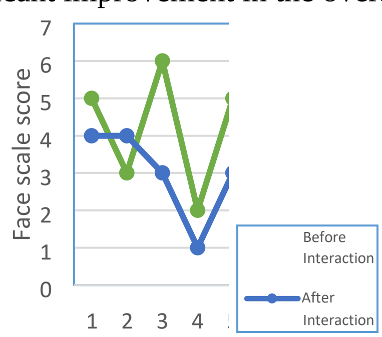


Figure 3.11 Change of facescale of Particiant 1 over 8 sessions (Score: 1=Best mood, 7=Worst Mood)

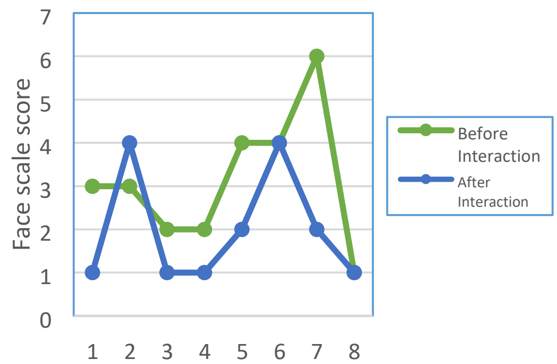


Figure 3.12 Change of facescale of Particiant 3 over 8 sessions (Score: 1=Best mood, 7=Worst Mood)

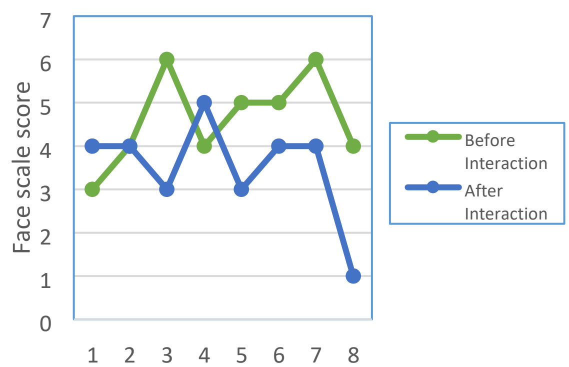


Figure 3.13 Change of facescale of Particiant 4 over 8 sessions (Score: 1=Best mood, 7=Worst Mood)

Using multiple camera emotions of the children were captured using the Oxford Emotion API by Microsoft. This API supported greatly in gauging the participant's estimation of the robot and its reaction towards it.

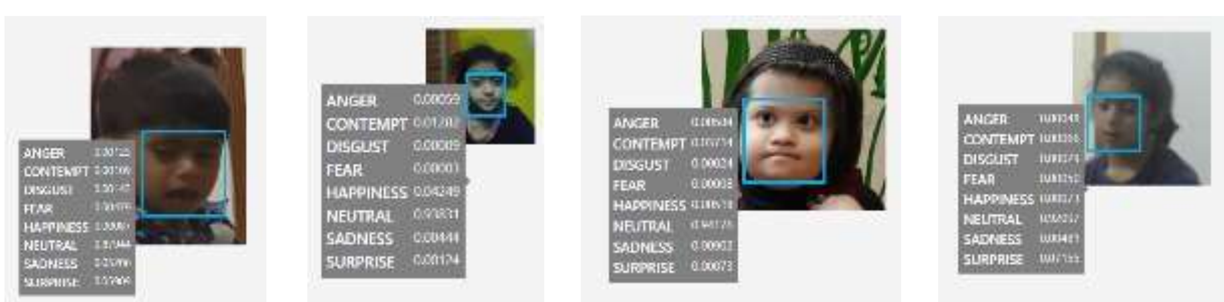


Figure 3.14 Emotion recognition

3.3.3 Overall Success Rate of the DS experiment

Executing the study in the participants own school was beneficial because it facilitated :

1) A highly structured format of time and activities, creating a more suitable setting for DS children;
2) Systematic cycles of start-pause-end of activities taking into account low attention spans;
3) A reduction of possible sources of distraction;
4) A customized positive reinforcement at the end of each session;
5) A small number of children for each group

The overall perception of the robot was positive and in particular the imitation therapy allowed them to get familiar with the robot. The novelty of the robot itself triggered prosocial responses. It proved to be an effective tool for catching the attention of the child with Down syndrome, and a combination of humanoid appearance and educational games might be an effective perspective for further developments in HRI

3.3.4 Challenges

The limitations of this study lie in the heterogeneity of sample (participants) in terms of age, cognitive developmental profiles and qualitative interpretation of data. The application of robotics in Down syndrome is widely untouched area and it can greatly benefit from more interventions and studies to establish concrete results. As this intervention establishes – humanoid robots such as NAO can play a significant role in eliciting prosocial behaviors in children with Down syndrome. Extrapolating on that there is much that can be done in educational and therapeutic contexts and will be an effective perspective for further developments in HRI. Some of the Challenges are given below and can be used as points for improvement in future work.

- The small sample size and large age variance
- The imitation activities were limited
- The exploratory nature of the intervention does not allow for definite predictions.

CHAPTER 04

CONCLUSION AND FUTURE WORK

4.1 Conclusion

Learning, Communication and imitation are some of the important social skills that ASD and Down Syndrome children struggle with.

In this research work, we have designed two novel therapeutic interventions for ASD and DS children. These interventions have been designed using a NAO humanoid robot which is closer to the human physical appearance. Designed therapies were:

i. Collaborative physical play with reinforcement stimuli for ASD children.

ii. Adaptive Model Rival Method and Imitation therapy for DS children.

In first intervention, we are quantitatively measuring the response of ASD children in a social play setting where the child has to interact with a robot in a game of football. Drawing on the data and results, this study has grounds in suggesting that the social and physical games build scenarios in a free environment can support a child to make the most of his or her independent decision making and instinctive problem solving aptitudes that can produce social exchanges which generalize over a broad spectrum of social interactions.

In second intervention two scenarios were designed for learning and behavior elicitation. The application of robotics in Down syndrome is widely untouched area and it can greatly benefit from more interventions and studies to establish concrete results. As this intervention establishes – humanoid robots such as NAO can play a significant role in eliciting prosocial behaviors in children with Down syndrome. Extrapolating on that there is much that can be done in educational and therapeutic contexts and will be an effective perspective for further developments in HRI.

Informal and semi-formal interviews with parents/caregivers of participating children and (in case of DS) a child psychologist and language trainer. An open informal interview was conducted with no pre-defined questions. The semi-formal interview was conducted as one-to-one session with pre-defined questions for the participants such as

Useful teaching methods for children with ASD/DS,
Their observation capability,

Indirect teaching methods and their usefulness,

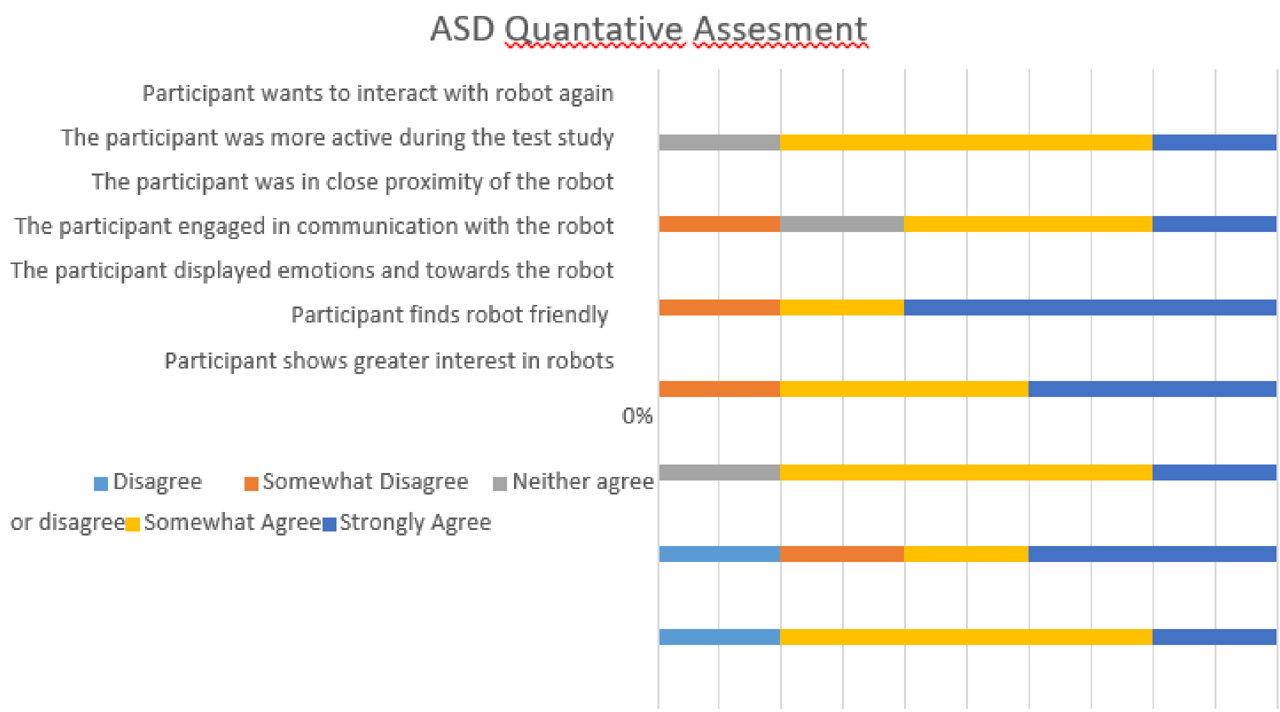
Children with ASD/DS and their bond with robot.

Closed format-questionnaire with the same above participants using a 5-level 'Likert scale' format ranging from strongly disagree to strongly agree

Table 4.1: Closed format Questionnaire

Question-ID	Description
Q1	Participant shows greater interest in robots
Q2	Participant finds robot friendly
Q3	The participant displayed emotions and towards the robot
Q4	The participant engaged in communication with the robot
Q5	The participant was in close proximity of the robot
Q6	The participant was more active during the test study
Q7	Participant wants to interact with robot again

Figure 4.1: ASD and DS Quantitative Assesment



4.2 Future Work

Following upgradations are possible in our designed interventions.

1) Wide range of activities can be employed to measure more traits and HRI markers in children with Down syndrome. There is potential of introducing mounted screens on mobile platforms for higher interaction.
2) Use of software's like the observer XT (www.noldus.com) to devise coding schemes for behaviors.
3) The scope of educational robotics is ever expanding and children with DS are more flexible to learning and interaction with humanoid robot that exhibit childlike emotions and corporeal movements as compared to children with autism
4) Use of Kinect to accurately measure motions and create an automated system to carry out seamless therapy based on feedback and prompt without human intervention

4.3 Acknowledgement

We acknowledge all the contributions and collaborations from Picture Autism Islamabad and Down Syndrome Club Islamabad, Pakistan. This research was conducted because of mutual collaboration between RISE Lab, dept of robotics and intelligent machine Engineering (RIME), SMME, National University of Sciences and Technology (NUST) Islamabad, Pakistan and Picture Autism and Down Syndrome Club. We thank all the members who were involved in this project either directly or indirectly.

APPENDIX A

Subject's Details

Table A-1 Details of all subjects participated in interventions

Down Syndrome

Child	Age (y)	Gender	Diagnosis	Group
P1	3	Male	DS	1
P2	7	Male	DS	2
P3	4.5	Female	DS	1
P4	5	Female	DS	1
P5	14	Female	DS	3
P6	8	Female	DS	2
P7	15	Female	DS	3

ASD

Child	Age (y)	Gender	Diagnosis
P1	5	Male	ASD
P2	7	Male	ASD
P3	3.5	Male	ASD