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Dominance in Visual Space of ASD Children Using Multi-Robot Joint Attention Integrated Distributed Imitation System

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ABSTRACT The focus of this research is to study: 1) the distribution of joint attention of autistic (ASD) children in their left and right visual space, 2) the corresponding dominance of either left or right hemisphere of brain using electroencephalography (EEG), and 3) the relationship between the dominance of visual space and hemisphere of brain. The proposed multi-robot system includes sequential and simultaneous actuations of robots dealing with single and multi-robot communication. Results indicate that most of the autistic children initiate joint attention from right to left vision space. Similarly, for imitation, robot at right visual space is imitated and focused more. These findings are also supported by the results obtained from the dominance of brain and number of eye contacts. Eight participants, five males and three females, participated in this research. Six participants belong to minimal while two belong to mild case on autism spectrum. Minimal cases of autism indicated proper dominance of either left or right visual space and hence the respective dominance of hemispheres of brain too. While mild cases of autism showed balanced performance in visual space but distinguishable dominance of hemispheres of brain. The overall average followed imitation accuracy for robot at right visual space is 83.49 % while for robot at left visual space is 61.53 %. Similarly, overall average eye contacts with robot at right visual space are 16.47 and for robot at left visual space are 14.95 per minute. Power spectral density (PSD) values of EEG data also indicate the dominance of right hemisphere of brain. F value is 2.93, F-critical value 4.60, and p-value is 0.108.

INDEX TERMS Joint attention, imitation, multi-robot therapy, ASD children, autism matrices, perception, joint attention distribution.

I. INTRODUCTION

Autism is a neurodevelopment disorder which affects different social skills of ASD children. A part from social skills, autism also affects the different parts of brain and hence their performance too. Joint attention and imitation are two important social skills present in human being and they vary from person to person. Joint attention and imitation skills of TD children are better than ASD children. The imitation signatures of TD and ASD children are quite different from each other [1], [2] and this difference leads us to identify the type of child. Joint attention enables human being to perceive the surroundings and act accordingly. In imitation, repeatability is involved and it is also coupled with joint attention because if someone has not seen the actions (did not pay attention), then he / she will not be able to imitate properly. Robots are also being used in imitation interventions [3]. With the advancement in technology, robots are being used as mediator in different therapies [4], [5], and designed according to the need and type of social impairments [6].

Research has proved that robots, particularly those resembling with human being, have more effect as compare to visually simple robots [7], [8]. In other words, features of robot are also important in ASD interventions [9]. External stimuli (either given from environment or from robotic agent) are also important while designing robotic interventions related

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to joint attention for ASD children [10]. In order to capture the joint attention of a human, an external stimulus is needed. These stimuli can be divided in to three different types with respect to agent, which includes visual, speech and motion-based cues [11], [12]. Shifting of joint attention from one stimulus to another stimulus and joint attention fixation time are also important parameters. A comparison between ASD and TD children has been presented in which the shifting of joint attention of ASD and TD from one type of stimulus to another type of stimulus and the joint attention fixation duration are studied [13]. Shifting of joint attention is difficult for ASD children as compare to TD children while joint attention fixation duration of TD is less than ASD children. In [14], different static and dynamic matrices for evaluating social engagement of humans while interacting with robots have been presented. Another set of different matrices (kinetic energies, body and head movements, direction of gaze and magnitude of gazing) has been presented in [15] for the assessment of autism in children and ensuring the use of robots as autism assessment tool. Moreover, in [16], comparison of mind perception of ASD and TD children has also been presented using agency and experience parameters of different objects like, God, robot, human etc. A comparison between a robot and human being is presented to see the effectiveness of robot and human as a joint attention initiator in ASD and TD children [17], [18] and robots are reported as a good joint attention initiator.

Gesture production and learning have also been compared using robot and human mediators and it has been reported that there is no significant difference between these two groups [19]. Joint attention based interventions have different types of effects if they are being taught by robots, teachers, and parents depending upon the familiarity and ease in interaction [20]. In establishing eye contact, partner's role as reinforcer is also important [21], [22]. Teaching and intervention programs are now being conducted using humanoid robots [23]. Early gaze following responses of ASD children in their early ages (infants) are also important as they depend upon the situational constraints and partner's individual characteristics [24]. Infants have different frequency, quality and behaviors of joint attention and it has been found that siblings of such infants are also affected due to interaction with same ASD sibling [25]. The extent of engagement of the human with robot varies based on the type of participants. Social referencing in ASD children is also important and it is governed by behavior analytic conceptualization. It is also linked with different types of stimuli either being provided by familiar or unfamiliar persons/entities [26].

Joint attention is also linked with another social impairment called visual perspective taking (VPT) in autism [27], [28]. It consists of two different levels in which the same things are observed from different points in space by TD and ASD children and hence have different perspectives. VPT can also be linked with body awareness and comparison has been reported in [29] in which ASD children are reported to have deficit related to body awareness. Superior visual search has been reported in ASD children irrespective of combination of feature [30]. Associative, recognition, and visuospatial working memories are three different types of important memories in autism. Reference [31] presented the inter comparison of these memories in ASD and TD children and reported the deficiency in recognition memory in ASD. Weakness of visual working memory in autism has also been reported by [32]. Moreover, visual perception in autism is not following the Weber's Law [33]. Zooming out leads towards orientating deficit in ASD children [34].

Autism also has different effects on different parts of brain [35]. During the interaction with human or a robot partner, the study of states of brain's different parts and bands of ASD child is also important [36]. Alpha-mu, beta and gamma waves have been considered for this purpose and [36] found synchronization between alpha-mu band of both interactors. Theo observation of different actions effects the human mirror neuron system (HMNS). Robots are usually mechanical structures whose motions are also mechanical. In [37] the impact of speed of the actions of robot on HMNS is presented using electroencephalography (EEG) study of occipital and sensorimotor regions. The results show that activation of HMNS is higher in occipital region as compare to sensorimotor region while later one is more robust [38]. Motion of objects and humans have different effects on both hemispheres of brain [39]. In case of motion of humans, the power spectral density (PSD) of Centro-parietal regions of both hemispheres decreased. Moreover, study of linking between both hemispheres, due to finding differences in left and right visual half systems, has also been reported in [40]. In case of perception, both left and right hemispheres are responsible for different types of actions and information processing [41]. This perception is further related with types of stimuli being presented and also the writing hand [42].

Functional magnetic resonance imaging (fMRI) based study reported interesting facts regarding the expression estimation using only the gaze of person [43]. Orbito-frontal cortex (OFC), superior temporal gyrus (STG) and amygdala's activity was observed in TD and ASD children. STG and amygdala showed increased activity as compare to OFC in TD while in case of ASD, OFC showed increased accuracy. In case of joint attention and imitation, mirror neurons are also important and [44] has presented a circular reactions for imitative behaviors (CRIB), a neural model, which explains that gaze following, joint attention, and imitation social skills of ASD children to whom they learn through inter-personal circular reactions. Superior temporal sulcus (STS) region and the intraparietal sulcus (IPS) are reported to be specifically activated during the passive observation of shifts in eye gaze. Posterior part of the STS region and the cuneus are specifically involved in extracting directional information from the eyes of another person to redirect one's own gaze and establish joint attention [45]. A comparison between ASD and schizophrenia (SZ) patients have been presented in [46] in which face emotion recognition (FER) and abnormal motion processing have been compared using visual cortex. Associated visual perception and sensorimotor learning are reported to be linked with each other in TD children but not in ASD children [47].

Functional near infrared spectroscopy (fNIRS) has also being used to study development of functional connectivity and brain activation under different tasks like joint attention, working memory, face processing and resting state of ASD children [48], a systematic review. Many fNIRS studies reported atypical brain activation in the prefrontal cortex, inferior frontal gyrus, middle and superior temporal gyrus.

A. CONTRIBUTION / NOVELTY

Following are the novel points of this research.

Based on Designed System Architecture:

I. The devised system can tell the distribution of joint attention of any child irrespective of his / her type (we used it for autistic children). It is further linked with joint attention initiation mechanism of children. Most of the ASD children initiate joint attention from right visual space and then shifts it towards left visual space ($R_1 \rightarrow R_2$), while other children initiate joint attention from left visual space and then shifts it towards right visual space ($R_2 \rightarrow R_1$).

II. The system incorporates the capability of both single robot and a multi-robot based imitation system.

III. The proposed system is capable of noticing the imitation accuracies in single and multi-robot imitations.

IV. It measures the joint attention of participant via number of eye contacts and duration of each eye contact in both visual spaces i.e., left and right.

II. MATERIALS AND METHODS

In this study, we are studying the distribution of joint attention in visual space and imitation skills of ASD children in joint attention integrated distributed imitation system using multi-robot. Moreover, we are also studying the dominance of left and right visual space of participant and relevant dominance of left and right hemisphere of brain of participant [36], [40], [42], using EEG analysis. Two types of actuations are being considered: sequential and simultaneous. In sequential actuation, participant can only actuate one robot at time. After the actuation of robot, if participant shifts his / her attention towards the other robot, it will not be activated till the completion of task by first robot and vice versa. While in case of simultaneous actuation, child can actuate both of the robots via paying attention without any restriction. Integrated joint attention module continuously records the joint attention of participant and hence actuates the corresponding robot being focused. After actuation, robot performs few imitation actions and invites the participant to perform those which are evaluated using Kinect sensor. Imitation actions consist of two different steps delayed by 20 seconds. During these 20 seconds, participant can shift his / her joint attention towards the other robot, resulting the actuation of second robot and hence the imitation actions too. Depending upon the performance of participant, a reward (calling child's name XYZ, good job!) is given by robot. In case of poor performance of the participant, no response is given by the robot so to avoid any kind of discouragement for the ASD child.

A. HYPOTHESES

We devised two different hypotheses H_1 and H_0. H_1 deals with simultaneous actuation of robots while H_0 deals with sequential type of actuation of robots in joint attention integrated distributed imitation system.

H_1 : Autistic children can perform simultaneous actuations of robots and have right vision space dominance. Moreover, visual space dominance is linked with brain's hemisphere dominance. (Alternate hypothesis)

H_0 : Autistic children can only perform sequential actuations of robots and have left vision space dominance. Moreover, visual space dominance is not linked with brain's hemisphere dominance. (null hypothesis)

Which hypothesis will sustain? This information can be extracted from designed intervention, data processing and performing statistical analysis. Moreover, we are also trying to find out the general trend of initiating joint attention and shifting of joint attention in case of multi-robot imitation / communication system along with dominance of either left or right visual space. We are also finding the relationship between dominant visual space and hemispheres of brain and writing hand (if any).

B. SUBJECTS AND TRIALS' FREQUENCY

Eight participants, five males and three females, from mild and minimal autism categories, took part in this research. Average age of all participants is 8.275 years, Table 1. The experimentation has been approved by the ethical committee of university and director of Autism Resource Center Islamabad (ARCI). A written consent has been taken from the parents of participants. Each participant participated in eight different trials. The frequency of experimentation for each participant was one experiment per week while for researcher, its eight experiments per week. This intervention was carried out for two months (eight weeks).

C. JOINT ATTENTION MODULE

Joint attention module is an important part of our devised distributed imitation system. This module is responsible for controlling the actuations of both robots and also telling us about the distribution of participant's attention with in the visual space. This module runs on both robots as separate thread and each one is also integrated with transmission control protocol (TCP) client. It notes the number of eye contacts made with each robot and duration of each eye contact. Joint attention module is supervised by corresponding TCP server. Target hit, abbreviated as ''TH'', is the signal which is an output of this module and acts as an input for imitation module.

TABLE 1. Participants' details.

Subject	Sex	Age (Years)	Autism Category
S1	M	10	Minimal
S2	M	7.5	Mild
S3	F	10.4	Minimal
S4	M	4.3	-do-
S5	M	8.5	-do-
S6	F	8	Mild
S7	M	9	Minimal
S8	F	8.5	-do-
Average	***	**8.275**	***

D. DISTRIBUTED IMITATION MODULE

Imitation module is another important module of our system. This module is responsible for controlling imitation actions on both robots and also reacting according to the distribution of participant's attention with in the system [11]. This module runs on both robots as separate thread and each one is also integrated with transmission control protocol (TCP) client. It is also linked with Kinect sensor which measures the accuracy of imitation being performed by participant and hence giving reward (calling child's name "X", and saying "good job") as well. Imitation module is supervised by corresponding TCP server. Imitation complete, abbreviated as "IC", is the signal which is an output of this module. Since, imitation module runs as separate threads on both robots, they are not linked with each other. Whole system will be having only two possible types of actuations of robots. They are sequential and simultaneous actuations.

1) SEQUENTIAL IMITATION

The sequential type of imitation is the one in which both robots are not allowed to activate simultaneously even both are receiving attention from child. At any given instant of time, only one robot will be activated based on the joint attention of the child and other one will remain inactive till the completion of imitation task of first robot.

2) SIMULTANEOUS IMITATION

The simultaneous type of imitation is the one in which both robots are allowed to activate simultaneously. At any given instant of time, which robot will be activated, it is based on the gaze response (distribution of attention) of the child. Here, completion of imitation task from initially actuated robot is not necessary for the activation of second robot.

E. EEG

Electroencephalography (EEG) has also been used to measure the dominance of hemispheres of brain and to find its linkage with dominant visual space of a participant. In the beginning and ending of each experiment, EEG for 25 seconds duration has been recorded using Emotive EPOC EEG neuroheadset with 128 samples per seconds sampling rate. PSD analysis has been used and the duration of analyzed EEG signals is 15 seconds (truncating initial and last 5 seconds data). For left hemisphere, AF3, F3, and O1 and for right hemisphere, AF4, F4, and O2 channels have been used. These selected channels belong to frontal and occipital lobes of brain. A second order band pass filter with $f_1 = 8Hz$ and $f_2 = 12Hz$ as cutoff frequencies has been used to extract alpha band. Average PSDs of left and right hemispheres are compared and dominance of relevant

hemisphere is calculated. Further, its relation with the dominance of visual space has also been studied.

F. SYSTEM'S STATE MACHINE

State machine is used to completely describe the states of whole system under different conditions at different instants of time and transitions among those. At hierarchy level one, there are three different states through which distributed imitation system traverse. They are: initialization, execution, and termination, Fig. 1, equation (1).

$$HL_1 = \{Init., Exec., \ Term.\} \tag{1}$$

Execution and termination are controlled by signals $S1, \ S2, \ S3 \ \& \ S4$. These signals are as under:

$S1$: Is_Person_Available_R1.

$S2$: Is_Person_Available_R2.

$S3$: Is Signal (for termination of process).

$S4$: TH (Target hit, an output from joint attention module).

At hierarchy level two, there are three different states under execution state. They are: idle, sequential, and synchronous, Fig. 1, equation (2). The transition among these states will depend upon different conditions. These conditions are linked with the states of robots at given time.

$$HL_2 = \{Idle, Seq., Sync.\} \tag{2}$$

We will be explaining these transition sequences under different given conditions described in mathematical model.

G. MATHEMATICAL MODEL

At the start, distributed imitation system will move from initialization state to idle state, that can be represented as $T_{Init \to Idle}$, Fig. 1. In this transition, both robot $R1$ and robot $R2$ will be ready, equation (3). After this, the system's behavior depends upon the interaction of participant. If system is not changing the current state, then following are the possible conditions which will be set.

$$T_{Init \to Idle} = Activate \ (R1 \& \ R2) \tag{3}$$

$$T_{idle \to idle} = if \, (\sim R1 \ \& \sim R2) \tag{4}$$

Interpretation: if the system is in idle state and robot one and two are not working or actuated by the participant, then system will remain in idle state until or unless robots are actuated.

$$T_{Seq. \to Seq.} = if \ ((R1 \ \& \ \sim R2) \ || \ (\sim R1 \ \& \ R2)) \tag{5}$$

Interpretation: if the system is in sequential state and either robot one or two is working or actuated by the participant at

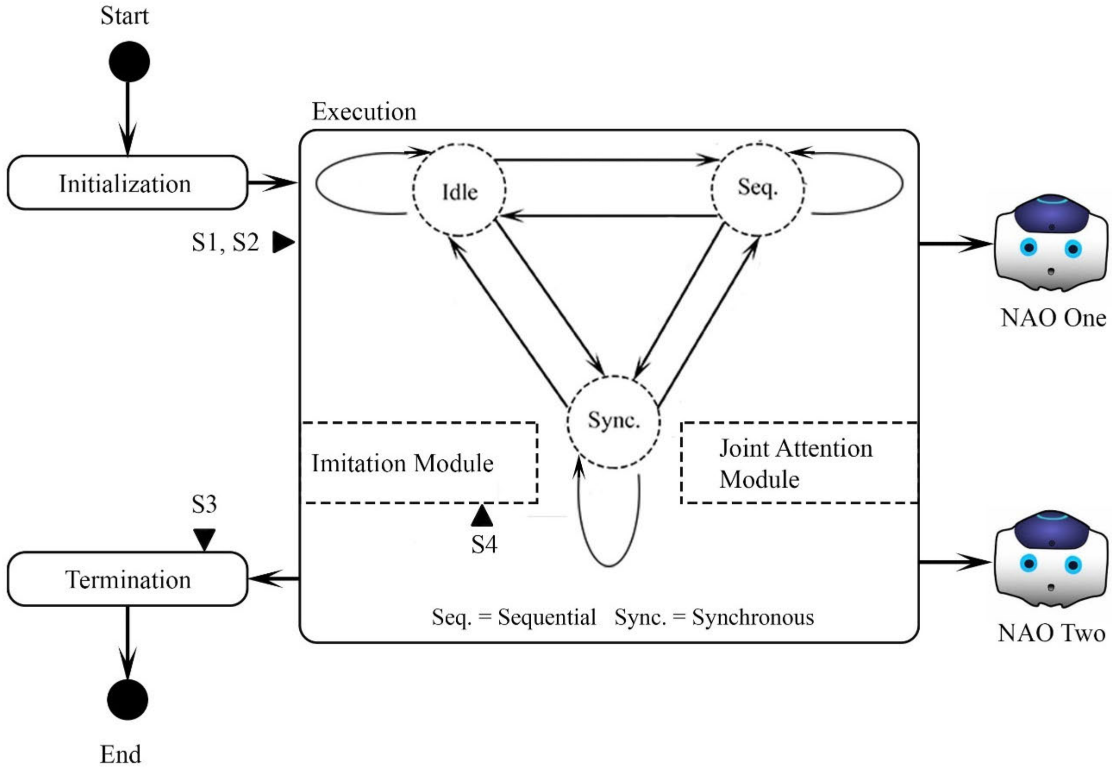

FIGURE 1. Harel state machine diagram of joint attention integrated distributed imitation system.

a time, then system will remain in sequential state.

$$T_{Sync.\to Sync.} = if\ (R1\ \&\ R2) \quad (6)$$

Interpretation: if the system is in synchronous state and both robots are actuated by the participant at a time, then system will remain in synchronous state until or unless robots' actuation sequence is changed. Equations (4)-(6) are representing the repetition of current states. It is also possible that these states will also change among themselves.

$$T_{Idle\to Seq.} = if\ ((R1\ \&\ \sim R2)\ ||\ (\sim R1\ \&\ R2)) \quad (7)$$

Interpretation: if the system is in idle state and either robot one or two is actuated by participant at a time, then system will move to sequential state until or unless robots' actuation sequence is changed, equation (7).

$$T_{Seq.\to Idle} = if\ (\sim R1\ ||\ \sim R2) \quad (8)$$
$$T_{Seq.\to Sync.} = if\ (R1\ \&\ R2) \quad (9)$$
$$T_{Sync.\to Seq.} = if\ ((\sim R1\ \&\ R2)\ ||\ (R1\ \&\ \sim R2)) \quad (10)$$
$$T_{Sync.\to Ideal} = if\ (\sim R1\ \&\ \sim R2) \quad (11)$$
$$T_{Idle\to Sync.} = if\ (R1\ \&\ R2) \quad (12)$$

In similar way, these states will change their self, equation (8)-(12). Here, $T_{X\to Y}$ is representing the transition between two states, where X is representing the current state while Y is representing the future state. ||, &, and $\sim$ are representing the OR, AND, and NOT operations respectively. Joint attention integrated distributed imitation system can terminate the whole process / intervention at any stage while residing at any state. Irrespective of the current state, whole system will move towards termination state and robots, $R1$ and $R2$ will be deactivated, equation (13).

$$T_{(Idle\ ||\ Sync.\ ||\ Seq)\to Ter\min ation} = Deactivate\ (R1\ \&\ R2) \quad (13)$$

Since we are utilizing two different robots, $R1$ and $R2$, so the imitation tasks are also different. We are defining these imitation tasks as a piece wise function.

$$IM_{R1} = \begin{cases} Raise\ hands \\ Hands\ down \end{cases} ;\ if\ (JAT_{R1}^{[i]} \geq 5\ Sec) \quad (14)$$

Here, IM_{R1} is representing the imitation task of robot $R1$, equation (14). $JAT_{R1}^{[i]}$ is representing the joint attention time for i^{th} eye contact with robot $R1$. The condition of activation of robot $R1$ is: seeing towards robot $R1$ or maintaining an eye contact with robot $R1$ for at least 5 seconds. After activation, robot will perform two actions. They are: raising hands and then hands down. There is a delay of 20 seconds between these two actions. Similarly, for robot $R2$, we have imitation equation (15).

$$IM_{R2} = \begin{cases} Move\quad forward \\ Move\quad backward \end{cases} ;\ if\ (JAT_{R2}^{[i]} \geq 5\ Sec) \quad (15)$$

Here, only actions for robot $R2$ will be different from $R1$. A part from these separate imitation modules, IM_{R1} and IM_{R2}, we have another module called joint attention recording module which runs on both robots to note the attention of participant and gives details regarding number of eye contacts made along with duration of each eye contact, equation (16).

$$JA_{Rx} = \sum_{i=1}^{n} \left(JAT_{Rx}^{[i]} \right) = \sum_{i=1}^{n} \left(\int_{t=0}^{m} dt \right);$$
$$i, m, n \in \Re; x = \begin{cases} 1 \, for \ Robot \ 1 \\ 2 \, for \ Robot \ 2 \end{cases} \quad (16)$$

$JA_{Rx}^{[i]}$ is representing the joint attention module running on robot x while i is representing the index of eye contact. where x can either be 1 or 2. i is denoting number of eye contacts being made and integral part is noticing the duration of each eye contact.

Iteration 1:

In this iteration, system deals with robot one only present at right vision space. i.e.,

$x = 1;\ i = 1, 2, 3, \ldots$ so,

$$JA_{R1} = JAT_{R1}^{[1]},\ JAT_{R1}^{[2]},\ JAT_{R1}^{[3]}, \ldots$$

where, $JAT_{R1}^{[1]}, JAT_{R1}^{[2]}$, and $JAT_{R1}^{[3]}$ are representing the eye contact readings of participant. These readings will be noted till we get an eye contact of 5 seconds duration.

Iteration 2:

In this iteration, system deals with robot two only present at left vision space. i.e.,

$x = 2;\ i = 1, 2, 3, \ldots$ so,

$$JA_{R2} = JAT_{R2}^{[1]},\ JAT_{R2}^{[2]},\ JAT_{R2}^{[3]}, \ldots$$

where, $JAT_{R2}^{[1]}, JAT_{R2}^{[2]}$, and $JAT_{R2}^{[3]}$ are representing the eye contact readings of participant. These readings will be noted till we get an eye contact of 5 seconds duration. Also, if we talk about the sequential and simultaneous imitation system, then above two iterations run in sequential manner in case of sequential imitation. While in case of simultaneous imitation, they run in parallel manner. The overall control of the system can be represented using equation (17), and equation (18)-(21).

$$DIM = \begin{cases} AND\,(X_1, Y_1)\,; Sync.\ state \\ OR\,(X_2, Y_2)\,; Seq.\ state \end{cases} \quad (17)$$

where,

$$X_1 = AND\,(IM_{R1}, JA_{R1}) \quad (18)$$
$$Y_1 = AND\,(IM_{R2}, JA_{R2}) \quad (19)$$
$$X_2 = AND\,(IM_{R1}, JA_{R1}) \quad (20)$$
$$Y_2 = AND\,(IM_{R2}, JA_{R2}) \quad (21)$$

Here, *DIM* is representing distributed imitation system. *DIM* is written in piece wise function representing the working of both robots under synchronous and sequential states. In synchronous state, both robots have to operate simultaneously, hence using AND operation to ensure the running of both robots. Similarly, in sequential state, at least one robot should run at a time, hence using OR operation, ensuring at least one robot runs at a time. Moreover, irrespective of the state of system, i.e., synchronous or sequential, imitation and joint attention modules will be running in parallel manner hence using AND operation. These Boolean operations are dealing with associated flags of modules.

H. NETWORKING

In joint attention integrated distributed imitation system, we have different modules which are linked with each other. For example, actuation of robots is linked with joint attention of the parson. So, it is necessary to establish connection between these modules. For information exchange, we used the concept of shared memory and for real time communication, we used transmission control protocol (TCP). Communication is governed by two different entities called TCP server and TCP client. These servers and clients are connected with each other with respect to nature of module and also write information in shared memory (robot memory). The convention used in networking is presented in equation (22), and (23).

$$S_{JA} \Leftrightarrow \begin{cases} C_{JAR1} \\ C_{JAR2} \end{cases} \quad (22)$$

&

$$S_{IM} \Leftrightarrow \begin{cases} C_{IMR1} \\ C_{IMR2} \end{cases} \quad (23)$$

Here, S_{JA}, C_{JAR1}, and C_{JAR2} are representing joint attention server, robot one joint attention client and robot two joint attention client. Similarly, S_{IM}, C_{IMR1}, and C_{IMR2} are representing imitation server, robot one imitation client and robot two imitation client.

1) PSEUDO CODE AND FUNCTIONS DESCRIPTION

Pseudo code consists of three different states named initialization, execution, and termination. Initialization state consists of initialization of different Boolean variables which are being used by different function in execution state. Execution state is further divided in to two different steps while termination state consists of only one step. A part from different states, steps and functions, we have event related signals too, Table 2 Pseudo code used different functions. The description of each used function is given in Table 3.

III. INTERVENTION'S ARCHITECTURE

Experimental room has been divided into two different parts named control area and intervention area. Both are separated from each other with the help of a wooden partition. We have two robots in our designed system which are one meter apart from each other as well as from the chair placed for participant to sit in, Fig 2, and Fig. 3. Joint attention integrated imitation modules are loaded on each robot and they are being controlled by researcher, sitting in control area. The imitation accuracy of the participant is being recorded. Each participant had been participated in eight different experiments and we were having eight different participants. EEG has also been

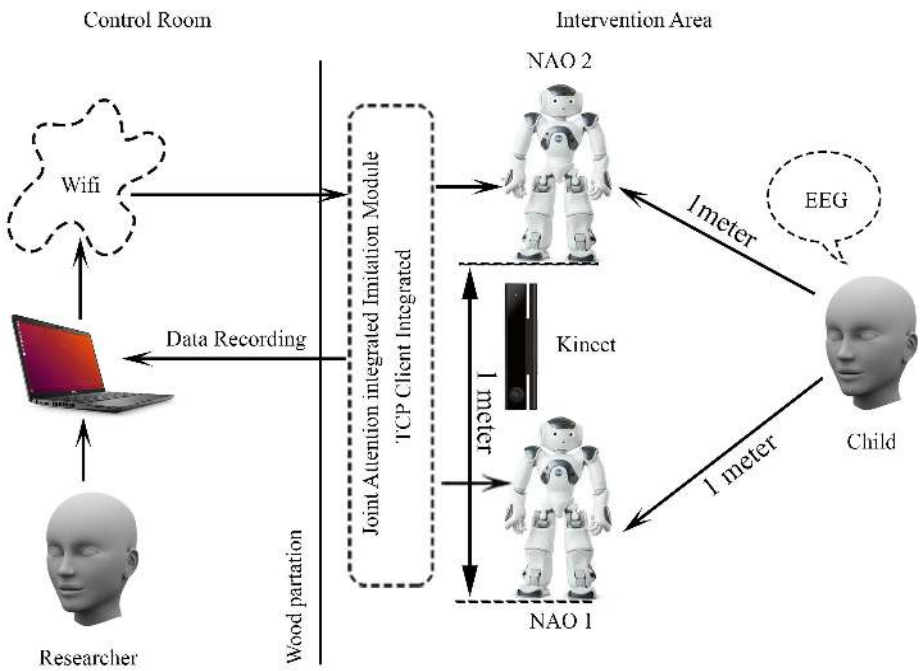

FIGURE 2. Architecture of the system.

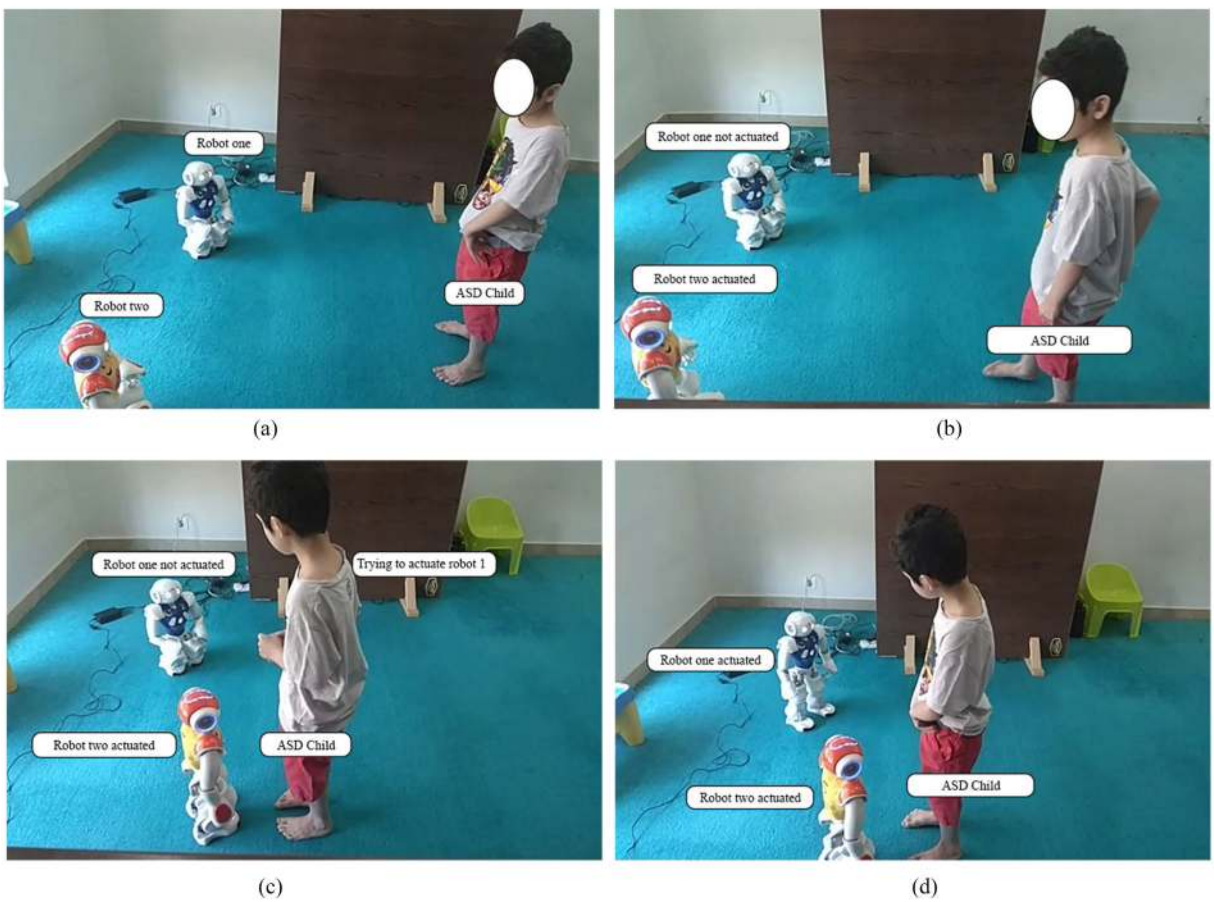

FIGURE 3. Participant in joint attention integrated distributed imitation systems.

recorded for 20 seconds at the beginning and ending of each experiment. State of the system depends upon the nature of the participant, particularly the distribution nature of joint attention. Imitation is noticed with the help of Kinect sensor.

TABLE 2. Algorithm of intervention.

```
Robot_Action_List={ ["Move Forward", "Move Backward"] ,
["Raise hands", "Hands down"] };
Joint_Attention_List [2]; // Two lists to store joint attention of
both robots separately.
Initialization:
Is_Person_Available_R1, Is_Person_Available_R2,
Is_Imitation_Done, Is_Signal;
Execution:
Step 01:
If (Is_Person_Available_R1 || Is_Person_Available_R2)
{
    [Robot , Value]=Joint_Attention();
    If (Robot==R1 && Value >4)
    {
        Robot_Behavior(Robot_Action_List[0]);
        Is_Imitation_Done =Imitation Kinect();
        Joint_Attention_List [0].Push(Value);
    }

    If (Robot==R2 && Value >4)
    {
        Robot_Behavior(Robot_Action_List[1]);
        Is_Imitation_Done =Imitation_Kinect();
        Joint_Attention_List [1].Push(Value);
    }
}
If (Is_Signal)
   Go To step 03;
Step 02:
If(Is_Imitation_Done)
   Reward();
Go To step 01;
Termination:
Step 03:
Terminate();
```

A reward (calling child's name "X" and saying "good job") is given on good performance while on low performance, no reward is given just to avoid any kind of hyper activity in participant. All participants are able to actuate both robots simultaneously while subjects 1, 2, 5, 6 and 8 were able to perform well, Fig 10. In case of simultaneous actuation, participant's joint attention is instantly changing between left and right visual spaces.

While in case of sequential actuations, it's not so. Five participants were more deviated towards right visual space while others three were more deviated towards left visual space, Fig. 4.

TABLE 3. Functions' description used in algorithm.

Function	Description
Joint_Attention()	This function extracts information of joint attention of participant and return two parameters, value of eye contact and robot number.
Imitation_Kinect()	This function tells us whether imitation has been done by participant?
Push()	This function appends the value of joint attention at the end of list (Joint_Attention_List).
Reward()	If imitation has been performed by child and it is accurate too, then verbal appreciation will be given via robot.
Terminate()	This function stops all threads and whole system.

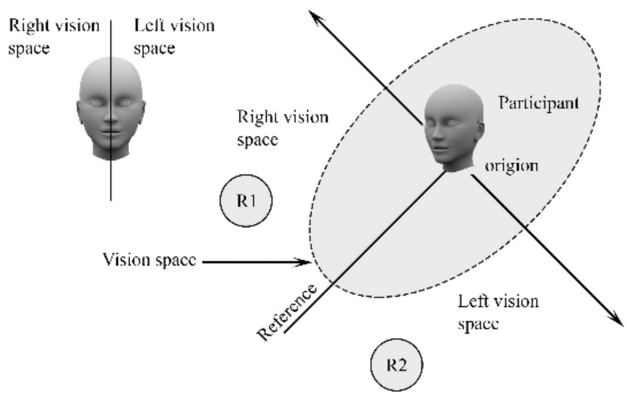

FIGURE 4. Division of visual space of a participant.

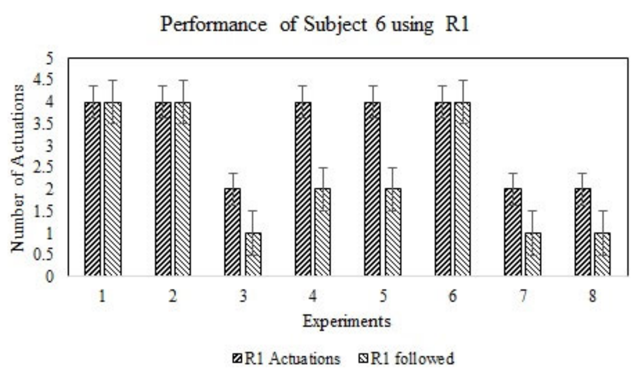

FIGURE 5. Actuated and followed imitations of subject 6 using robot one.

IV. RESULTS

Different parameters have been considered for evaluation purpose of this research. We are sharing the individual as well as collective performance of participants. Initially, Fig. 5, and Fig. 6 are presenting the number of actuations of both robots along with actually followed number of actuations of subject 6. These plots are actually giving the comparison between the willing of participant to actuate the robots and then to imitate them as well. Comparing Fig. 5, and Fig. 6, we can conclude that in sequential actuations, subject 6 was actuating and following the robot two more as compare to robot one. Moreover, imitation performance in sequential actuations of all subjects in 1st, 4th, and 8th week are given in Table 4. The performance of ASD children in imitation system completely depends upon their interest as the system can only be actuated by joint attention of ASD children. We also noted the number of eye contacts made by each participant in each intervention with robot one and two. Fig. 7 is representing the number of eye contacts with robot one and

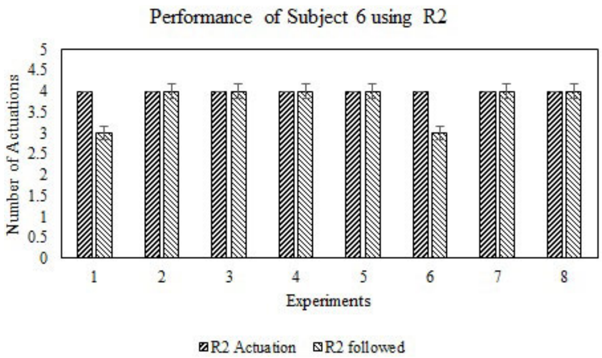

FIGURE 6. Actuated and followed imitations of subject 6 using robot two.

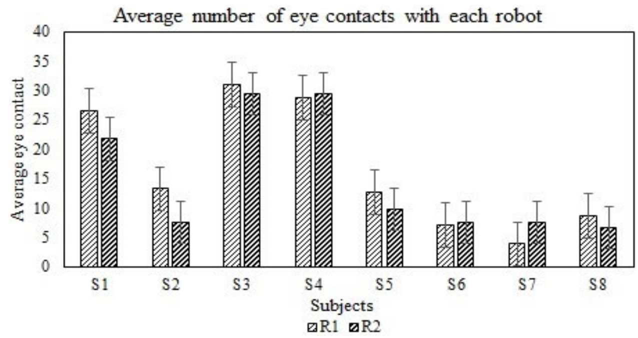

FIGURE 9. Average number of eye contacts of each subject with robot one and robot two.

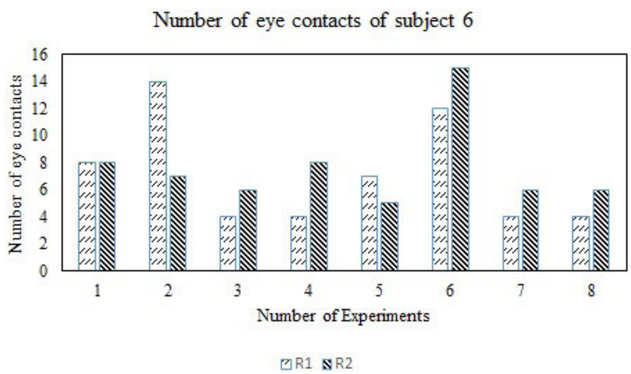

FIGURE 7. Number of eye contacts of subject 6 with robot one and two in each experiment.

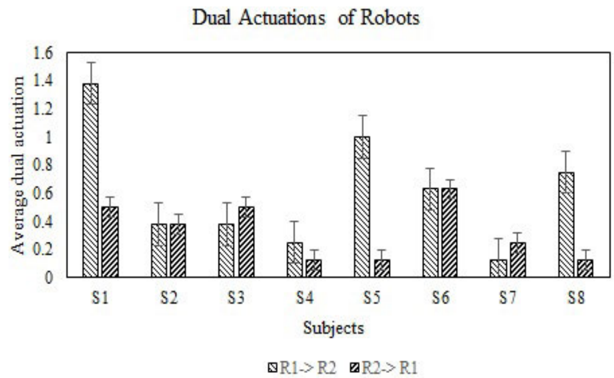

FIGURE 10. Number of dual actuations of each subject.

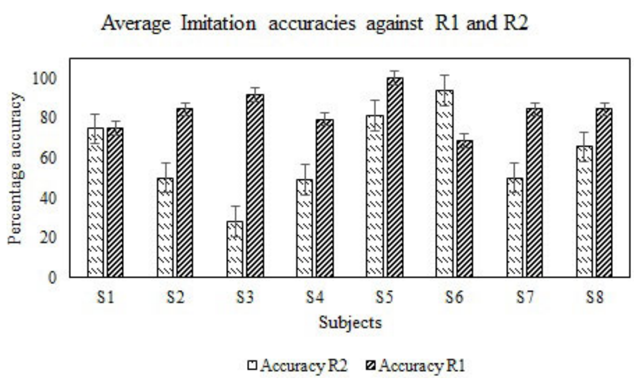

FIGURE 8. Average imitation accuracies of each subject against robot one and robot two.

two made by Subject 6 during each intervention session. We can see that in many intervention sessions, the number of eye contacts with robot two are dominating over number of eye contacts with robot one. Average imitation accuracies of all participants with respect to robot one and robot two are also calculated. These average accuracies are calculated on the basis of number of actuations done and number of actual followings. Seeing Fig. 8, we can say that most of the participants have robot one dominance, which is present in right visual space of participant, so overall right visual space is dominating and hence the right hemisphere of brain

A part from average imitation accuracies, we have also calculated the average number of eye contacts of all participants with robot one and robot two. Each column is an average of eight experiments. Most of the data is showing that number of eye contacts with robot one is greater than robot two, Fig. 9. Dual actuation of robots has also been noted. There are two different orders of dual actuations. First order of dual actuation is related with actuation of robot one followed by actuation of robot two. In second order of dual actuation, the sequence is opposite. Fig. 10 is representing the comparison between these two orders. Here, again first order, i.e., actuation of robot one first followed by actuation of robot two, is dominating over second order and hence also conveying the information that right visual space dominates for most of the participants.

In general, results are indicating that robot one, present at right visual space of the participant, is dominating the robot two, present at left visual space in terms of joint attention and imitation. In both types of imitations, sequential and simultaneous, robot at right vision space has been focused more. For most of ASD children, joint attention initiation pattern starts at right visual space first and then shifts towards left visual space. Moreover, these two dominances are also verified by the number of eye contacts of the participants with robots and the dominance of hemisphere of brain using EEG signals.

TABLE 4. Imitation performance of each subject in sequential imitation.

Subjects	Imitation accuracies in experiments		
	1st week	4th week	8th week
S1	100	75	75
S2	100	100	100
S3	100	83	75
S4	75	100	100
S5	100	100	100
S6	100	50	50
S7	100	50	100
S8	100	75	75
Average	97 %	79 %	84 %

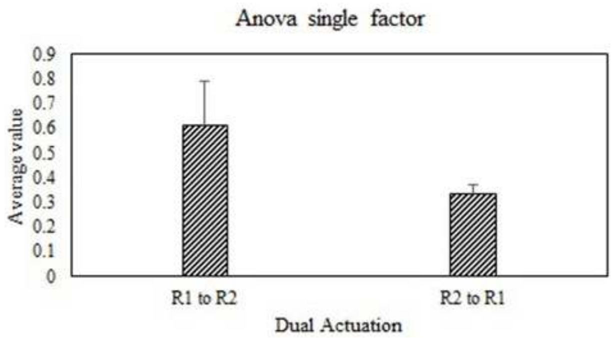

FIGURE 11. ANOVA single factor.

TABLE 5. Visual spaces and eye contacts dominance of subjects.

Subjects	Dominant visual space		Eye Contact Dominance		Writing hand	
	Left	Right	Left	Right	Eval.	Actual
S1	--	*	--	*	Right	Right
S2	*	*	--	*	Right	Right
S3	*	--	--	*	Left	Left
S4	--	*	*	--	Right	Right
S5	--	*	--	*	Right	Right
S6	*	*	*	--	Left	Right
S7	*	--	*	--	Left	Left
S8	--	*	--	*	Right	Right

(* = *Yes* ; -- = *No*)

TABLE 6. Brain's dominance using EEG and PSD analysis.

Subjects	Hemispheres' average PSD Values		Dominance	
	Left	Right	Hemisphere	Visual Space
S1	14.66	19.08	Right	Right
S2	6.61	4.2	Left	Right
S3	6.55	4.81	Left	Left
S4	9.07	9.65	Right	Right
S5	8.87	8.99	Right	Right
S6	3.4	0.12	Left	Left
S7	9.49	7.35	Left	Left
S8	11.228	11.325	Right	Right

V. STATISTICAL ANALYSIS

We used ANOVA single factor statistical analysis on distribution of joint attention of participants, Fig. 11. In case of dual actuations of robots, we found that diversion from $R1$ to $R2$ ($R1 \rightarrow R2$) is higher as compare to diversion from $R2$ to $R1$ ($R2 \rightarrow R1$) means that for most of ASD children, joint attention initiation starts from right visual space and then shifts towards left visual space. F value is 2.94 while $F_{Critical}$ value is 4.60 with 0.10 as P value. This shows that ASD children can also handle the simultaneous actuations of robots.

A part from ANOVA single factor statistical analysis, we have also presented results related to the dominance of visual space of each participant. This dominance of visual space is calculated on the basis of number of imitations performed in sequential and simultaneous actuations and the of number of eye contacts establish with in each visual space (if imitation performance is balanced) Table 5. Moreover, using PSD analysis of EEG signals, we studied the dominance of hemisphere of brain too, Table 6. Further, we have also gathered the information related to writing hand of ASD participants and compared it with dominance of visual space and eye contacts.

Depending upon the focus of ASD children, dominance of brain's hemisphere has also been noticed using PSD analysis of EEG signals [40], [42], [49]. Depending upon the distribution of joint attention initialization, joint attention shifting manner, and performance, four subjects showed the right visual space dominance and right hemisphere dominance. This is verified using number of eye contacts too. Moreover, it is also linked with the writing hand which is again right in these cases. Two subjects showed the left visual space dominance and hence left hemisphere dominance. Similar to above cases, it is also linked with the writing hand which is left in these cases. Remaining two participants showed the equal dominance in both visual spaces. Six participants belong to minimal case of autism while remaining two belong to mild case of autism. Minimal cases of autism showed proper dominance of either left or right visual space (distinctive), along with the dominance of respective hemisphere of brain too. While mild cases of autism showed a balanced performance between left and right visual space but distinguishable dominance of brain's hemisphere.

VI. DISCUSSION

Autism spectrum disorder is a neurodevelopment disorder which affects different parts of brain and results in lack of different social skills. Joint attention and imitation are two important social skills which are utilized by every ASD child in daily life. Improvement in joint attention skill of an ASD child helps to respond timely, accurately, and properly toward different intrinsic and extrinsic reinforcement stimuli. The situation becomes more challenging when one has to deal with multiple persons simultaneously as for children with ASD, social skills are weak as compare to TD children.

Autistic children have different deficits in their social skills. These deficits include joint attention, imitation, verbal, non-verbal and many other skills which are important in daily life activities. Lack of important communication skills result in inconvenience for different surrounding people and incompletion of different daily routine life activities. Autism affects different parts of the brain and hence their associated social skills as well. Curing autism depends upon condition of the child. Possible ways of curing include medication, therapies for specific social skills either by experts or by robots. Humanoid robots are able to provide open and closed loop based interventions for autism [6], [11]. There are different factors which can effect robotic interventions and physical appearance of robot is one among those [7], [8].

VII. CONCLUSION

In this research, we have investigated the imitation skills and joint attention distribution patterns of ASD children in joint attention integrated distributed imitation system using multi-robot. Many imitation interventions have been reported with single robot as mediator in literature [1], [3]. Introduction of multi-robot based concept is to see the multi-person communication in ASD children [11]. The testing hypotheses for this research are:

H_1 : Autistic children can perform simultaneous actuations of robots and have right vision space dominance. Moreover, visual space dominance is linked with brain's hemisphere dominance. (Alternate hypothesis)

H_0 : Autistic children can only perform sequential actuations of robots and have left vision space dominance. Moreover, visual space dominance is not linked with brain's hemisphere dominance. (null hypothesis)

A part from these hypotheses, we have also studied the distribution pattern of joint attention of ASD children in left and right visual space. This leads us towards the dominance of either left or right visual space and it is further linked with the dominance of brain's hemispheres and with writing hand [36], [40], [42].

Five males and three females participated in this research with an average age of 8.275 years. Imitation actions of both robots are different from each other. The overall average imitation followed accuracy of all children for robot one, present at right visual space, is 83.49 % while for robot two, present at left visual space is 61.53 %. The overall average eye contacts of all children for robot one is 16.47 and for robot two is 14.95. In statistical analysis (single factor ANOVA) F value of gathered data is 2.93 which is less than F-critical value: 4.60 with p-value 0.108 and threshold 0.05.

The results also confirmed that ASD children can perform simultaneous imitations in our designed system and hence are capable of dealing with multi-robot communication. The right visual space has been found as joint attention initiator and then shifting joint attention towards left visual space. The corresponding brain's hemisphere dominance has also been noticed using PSD analysis of EEG signals which is further linked with writing hand of participants. In sequential and simultaneous imitations, robot at right vision space has been focused more. These visual space dominances have also been verified using number of eye contacts with both robots. We have also found the interesting facts regarding the categories of autism. Minimal cases of autism showed proper dominance of either left or right visual space along with the dominance of respective hemisphere of brain. Whereas mild cases of autism showed a balanced performance between left and right visual space.

REFERENCES

[1] S. Boucenna, S. Anzalone, E. Tilmont, D. Cohen, and M. Chetouani, "Learning of social signatures through imitation game between a robot and a human partner," *IEEE Trans. Auton. Mental Develop.*, vol. 6, no. 3, pp. 213–225, Sep. 2014.

[2] S. Boucenna, D. Cohen, A. N. Meltzoff, P. Gaussier, and M. Chetouani, "Robots learn to recognize individuals from imitative encounters with people and avatars," *Sci. Rep.*, vol. 6, Feb. 2016, Art. no. 19908.

[3] 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. Social Robot.*, vol. 3, no. 4, pp. 349–357, Nov. 2011.

[4] S.-S. Yun, J. Choi, S.-K. Park, G.-Y. Bong, and H. Yoo, "Social skills training for children with autism spectrum disorder using a robotic behavioral intervention system," *Autism Res.*, vol. 10, no. 7, pp. 1306–1323, 2017.

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

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

[7] 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.

[8] B. Robins, K. Dautenhahn, R. Te Boerkhorst, and A. Billard, "Robots as assistive technology—Does appearance matter?" in *Proc. RO-MAN 13th IEEE Int. Workshop Robot Hum. Interact. Commun.*, Sep. 2004, pp. 277–282.

[9] 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.

[10] D. O. David, C. A. Costescu, S. Matu, A. Szentagotai, and A. Dobrean, "Developing joint attention for children with autism in robot-enhanced therapy," *Int. J. Soc. Robot.*, vol. 10, no. 5, pp. 595–605, 2018.

[11] S. Ali, F. Mehmood, D. Dancey, Y. Ayaz, M. J. Khan, N. Naseer, R. De Cassia Amadeu, H. Sadia, and R. Nawaz, "An adaptive multi-robot therapy for improving joint attention and imitation of ASD children," *IEEE Access*, vol. 7, pp. 81808–81825, 2019.

[12] 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-Mach. Syst.*, vol. 48, no. 2, pp. 125–135, Apr. 2017.

[13] S. Mo, L. Liang, N. Bardikoff, and M. A. Sabbagh, "Shifting visual attention to social and non-social stimuli in autism spectrum disorders," *Res. Autism Spectrum Disorders*, vol. 65, pp. 56–64, Sep. 2019.

[14] S. M. Anzalone, S. Boucenna, S. Ivaldi, and M. Chetouani, "Evaluating the engagement with social robots," *Int. J. Social Robot.*, vol. 7, no. 4, pp. 465–478, Aug. 2015.

[15] S. M. Anzalone, J. Xavier, S. Boucenna, L. Billeci, A. Narzisi, F. Muratori, D. Cohen, and M. Chetouani, "Quantifying patterns of joint attention during human-robot interactions: An application for autism spectrum disorder assessment," *Pattern Recognit. Lett.*, vol. 118, pp. 42–50, Feb. 2019.

[16] K. Gray, L. Young, and A. Waytz, "Mind perception is the essence of morality," *Psychol. Inquiry*, vol. 23, no. 2, pp. 101–124, 2012.

[17] W. Cao, W. Song, X. Li, S. Zheng, G. Zhang, Y. Wu, S. He, H. Zhu, and J. Chen, ''Interaction with social robots: Improving gaze toward face but not necessarily joint attention in children with autism spectrum disorder,'' *Frontiers Psychol.*, vol. 10, p. 1503, Jul. 2019.
[18] M. Ishikawa, M. Yoshimura, H. Sato, and S. Itakura, ''Effects of attentional behaviours on infant visual preferences and object choice,'' *Cogn. Process.*, vol. 20, no. 3, pp. 317–324, 2019.
[19] W.-C. So, M. K.-Y. Wong, W.-Y. Lam, C.-H. Cheng, S.-Y. Ku, K.-Y. Lam, Y. Huang, and W.-L. Wong, ''Who is a better teacher for children with autism? Comparison of learning outcomes between robot-based and human-based interventions in gestural production and recognition,'' *Res. Develop. Disabilities*, vol. 86, pp. 62–75, Mar. 2019.
[20] E. A. Jones, E. G. Carr, and K. M. Feeley, ''Multiple effects of joint attention intervention for children with autism,'' *Behav. Modification*, vol. 30, no. 6, pp. 782–834, 2006.
[21] V. J. Carbone, L. O'Brien, E. J. Sweeney-Kerwin, and K. M. Albert, ''Teaching eye contact to children with autism: A conceptual analysis and single case study,'' *Educ. Treat. Children*, vol. 36, no. 2, pp. 139–159, 2013.
[22] J. Kourassanis-Velasquez and E. A. Jones, ''Increasing joint attention in children with autism and their peers,'' *Behav. Anal. Pract.*, vol. 12, no. 1, pp. 78–94, 2019.
[23] E. Y. Chung, ''Robotic intervention program for enhancement of social engagement among children with autism spectrum disorder,'' *J. Develop. Phys. Disabilities*, vol. 31, no. 4, pp. 419–434, 2019.
[24] T. Del Bianco, T. Falck-Ytter, E. Thorup, and G. Gredebäck, ''The developmental origins of gaze-following in human infants,'' *Infancy*, vol. 24, no. 3, pp. 433–454, 2019.
[25] M. Franchini, T. Hamodat, V. L. Armstrong, L.-A. R. Sacrey, J. Brian, S. E. Bryson, N. Garon, W. Roberts, L. Zwaigenbaum, and I. M. Smith, ''Infants at risk for autism spectrum disorder: Frequency, quality, and variety of joint attention behaviors,'' *J. Abnormal Child Psychol.*, vol. 47, no. 5, pp. 907–920, 2019.
[26] L. Cornew, K. R. Dobkins, N. Akshoomoff, J. P. McCleery, and L. J. Carver, ''Atypical social referencing in infant siblings of children with autism spectrum disorders,'' *J. Autism Develop. Disorders*, vol. 42, no. 12, pp. 2611–2621, 2012.
[27] A. Pearson, D. Ropar, and A. F. de C. Hamilton, ''A review of visual perspective taking in autism spectrum disorder,'' *Front. Hum. Neurosci.*, vol. 7, p. 652, Oct. 2013.
[28] J.-A. Little, ''Vision in children with autism spectrum disorder: A critical review,'' *Clin. Exp. Optometry*, vol. 101, no. 4, pp. 504–513, 2018.
[29] L. Russo, F. Craig, M. Ruggiero, C. Mancuso, R. Galluzzi, A. Lorenzo, I. Fanizza, and A. Trabacca, ''Exploring visual perspective taking and body awareness in children with autism spectrum disorder,'' *Cogn. Neuropsychiatry*, vol. 23, no. 4, pp. 254–265, 2018.
[30] M. A. O'Riordan, K. C. Plaisted, J. Driver, and S. Baron-Cohen, ''Superior visual search in autism,'' *J. Exp. Psychol. Hum. Perception Perform.*, vol. 27, no. 3, p. 719, 2001.
[31] S. Semino, M. Zanobini, and M. C. Usai, ''Visual memory profile in children with high functioning autism,'' *Appl. Neuropsychol., Child*, pp. 1–11, Apr. 2019.
[32] Y. Funabiki and T. Shiwa, ''Weakness of visual working memory in autism,'' *Autism Res.*, vol. 11, no. 9, pp. 1245–1252, 2018.
[33] B.-S. Hadad and S. Schwartz, ''Perception in autism does not adhere to Weber's law,'' *eLife*, vol. 8, Mar. 2019, Art. no. e42223.
[34] L. Ronconi, M. Devita, M. Molteni, S. Gori, and A. Facoetti, ''Brief report: When large becomes slow: Zooming-out visual attention is associated to orienting deficits in autism,'' *J. Autism Develop. Disorders*, vol. 48, no. 7, pp. 2577–2584, 2018.
[35] M. Asada, K. Hosoda, Y. Kuniyoshi, H. Ishiguro, T. Inui, Y. Yoshikawa, M. Ogino, and C. Yoshida, ''Cognitive developmental robotics: A survey,'' *IEEE Trans. Auton. Mental Develop.*, vol. 1, no. 1, pp. 12–34, May 2009.
[36] G. Dumas, J. Nadel, R. Soussignan, J. Martinerie, and L. Garnero, ''Interbrain synchronization during social interaction,'' *PLoS ONE*, vol. 5, no. 8, 2010, Art. no. e12166.
[37] T.-J. Luo, J. Lv, F. Chao, and C. Zhou, ''Effect of different movement speed modes on human action observation: An EEG study,'' *Frontiers Neurosci.*, vol. 12, p. 219, Apr. 2018.
[38] G. W. Humphreys and M. J. Riddoch, *Visual Object Processing: A Cognitive Neuropsychological*. Evanston, IL, USA: Routledge, 2017.
[39] S. Cochin, C. Barthelemy, B. Lejeune, S. Roux, and J. Martineau, ''Perception of motion and qEEG activity in human adults,'' *Electroencephalogr. Clin. Neurophysiol.*, vol. 107, no. 4, pp. 287–295, 1998.
[40] M. S. Gazzaniga, J. E. Bogen, and R. W. Sperry, ''Observations on visual perception after disconnexion of the cerebral hemispheres in man,'' *Brain*, vol. 88, no. 2, pp. 221–236, 1965.
[41] E. Goldberg and L. D. Costa, ''Hemisphere differences in the acquisition and use of descriptive systems,'' *Brain Lang.*, vol. 14, no. 1, pp. 144–173, 1981.
[42] Y. Pinto, D. A. Neville, M. Otten, P. M. Corballis, V. A. F. Lamme, E. H. F de Haan, N. Foschi, and M. Fabri, ''Split brain: Divided perception but undivided consciousness,'' *Brain*, vol. 140, no. 5, pp. 1231–1237, 2017.
[43] S. Baron-Cohen, H. A. Ring, S. Wheelwright, E. T. Bullmore, M. J. Brammer, A. Simmons, and S. C. R. Williams, ''Social intelligence in the normal and autistic brain: An fMRI study,'' *Eur. J. Neurosci.*, vol. 11, no. 6, pp. 1891–1898, 1999.
[44] S. Grossberg and T. Vladusich, ''How do children learn to follow gaze, share joint attention, imitate their teachers, and use tools during social interactions?'' *Neural Netw.*, vol. 23, nos. 8–9, pp. 940–965, 2010.
[45] S. Materna, P. W. Dicke, and P. Thier, ''Dissociable roles of the superior temporal sulcus and the intraparietal sulcus in joint attention: A functional magnetic resonance imaging study,'' *J. Cogn. Neurosci.*, vol. 20, no. 1, pp. 108–119, 2008.
[46] A. Martínez, R. Tobe, E. C. Dias, B. A. Ardekani, J. Veenstra-VanderWeele, G. Patel, M. Breland, A. Lieval, G. Silipo, and D. C. Javitt, ''Differential patterns of visual sensory alteration underlying face emotion recognition impairment and motion perception deficits in schizophrenia and autism spectrum disorder,'' *Biol. Psychiatry*, vol. 86, pp. 557–567, Oct. 2019.
[47] S. J. Hayes, M. Andrew, N. C. Foster, D. Elliott, E. Gowen, and S. J. Bennett, ''Sensorimotor learning and associated visual perception are intact but unrelated in autism spectrum disorder,'' *Autism Res.*, vol. 11, no. 2, pp. 296–304, 2018.
[48] F. Zhang and H. Roeyers, ''Exploring brain functions in autism spectrum disorder: A systematic review on functional near-infrared spectroscopy (fNIRS) studies,'' *Int. J. Psychophysiol.*, vol. 137, pp. 41–53, Mar. 2019.
[49] D. Kimura, ''The asymmetry of the human brain,'' *Sci. Amer.*, vol. 228, pp. 70–80, Mar. 1973.

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