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Teaching Psychomotor Skills to Autistic Children by Employing a Robotic Training Kit: A Pilot Study

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Abstract Autism spectrum disorder is becoming a global challenge as the number of children affected by it increases drastically. Autistic children suffer from impairments such as social interactions, language and communication skills, cognitive skills and psychomotor skills. A number of technological systems have been put to use for training children with autism. The children's attraction towards robot and robot like features promotes the use of assistive technology in rehabilitating autistic children. This paper focuses on teaching psychomotor skills to autistic children by employing a robotic training kit. The scope of the training includes learning the concept of directions and the ability to operate a joystick so as to manipulate the robot as per given instructions. Training and trials were conducted under the supervision of a speech therapist. The study demonstrated the positive response of employing the robotic kit in imparting the knowledge of directions, hand–eye coordination and palmar grasp.

Keywords Psychomotor skills · Robotic training · Hand–eye coordination · Knowledge of directions · Palmar grasp

1 Introduction

Autism spectrum disorder (ASD) statistics from the United States Centers for Disease Control and Prevention (CDC) identifies 1 in 68 American children on the autism spectrum, which is a ten-fold increase in prevalence over 40 years. Research shows that this increase is partly explained by improved diagnosis and awareness [1]. The UK reported in 2012, an increase of 56 % of children with autism in the last five years [2].

A child with ASD is known to have the triad of impairments i.e. challenges in social interactions, language & communication and cognitive skills. In addition, they also have deficiency in psychomotor skills [3]. In case of social interactions, the child mostly seems to be uninterested in people and finds it difficult to develop relationships with them [4]. Ming, et al. carried out a cohort study and found that motor deficits prevailed to a large extent in children with ASD which includes delayed gross motor milestone, reduced ankle mobility, toe-walking, motor apraxia and hypotonia [5]. These children also show significant developmental delay in gross/fine motor skills in addition to challenges in verbal & nonverbal communication and social interactions [6]. Gross motor skills involve large-scale coordinated activities such as walking, movement of arms, which include holding an object, throwing a ball, etc. Fine motor skills involve detail-oriented activities such as writing, drawing or playing a musical instrument. The stereotypical, self-stimulatory behaviour in autistic children is one of the major issues, as it tends to interfere with the motor activities, thus making it difficult to concentrate and complete any given task. Jasmin et al. found that sensory avoidance or excessive reaction to sensory stimuli and fine motor skills are correlated with daily life skills. As sensori-motor deficits have an impact on the autonomy of the child, there has to be more interventions on supporting and improving the development of sensori - motor skills [7]. The early childhood physical educators should create a learning environment that supports and provides an opportunity for the children with autism to master their motor skills [8].

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As studies show, treating ASD has become a global challenge with the drastic increase in the number of children affected by it. Some measures have to be taken to train and treat the children diagnosed with it. Treating ASD is not a simple task; it needs sustained effort over a long period to make them learn social interaction and necessary daily life skills. The seamless advancements in Science and Technology could be leveraged to teach and train the children with autism, who are attracted towards robot and robot like features [9,10]. It was found during an experiment that children with ASD respond better to technological programs with more interactive features such as voice, sound, animation displays, etc. [11]. A global positive attitude towards the use of robots in training, of therapists specialized in the treatment of intellectual disabilities has been demonstrated in a recent study by employing the Unified Theory of Acceptance and Use of Technology (UTAUT) model [12].

Numerous robots have been developed explicitly for interaction with children as a part of research in the field of embodied interaction. Social robots, designed to administer nonverbal interactions with children are used in rehabilitation and therapy to predominantly develop social interaction skills through turn passing, sharing, imitation, etc. A few examples of interactive robots used to improve social interactions in autistic children are NAO, Robota, Kismet, Keepon, etc. [13]. NAO and Robota are the most commonly used humanoid robots for academic research worldwide. In a pilot study involving NAO it was observed that there was suppression in the child's autistic behaviour and increase in eye contact with the robot. This confirms that humanoid robots such as NAO serve as a potential platform to initiate interaction with autistic children [14]. Robota is a doll-shaped robot, which helps children learn to use vision and speech processing, including interpretation of gestures and recognition of speech. It is also used by educators to systematically evaluate an autistic child's social competences. As Robota makes use of vision based learning, it makes it a more natural and less constraining setup for children with autism [15]. Probo is a robot that targets both cognitive interaction and physical interaction with the children. It is a huggable robot developed predominantly for children but also serves as a very useful robotic research platform for Human–Robot Interaction (HRI) [16]. Kismet is a face robot, which engages children using several varied social cues like facial expression, gaze direction and vocalization, making it convenient to be used with autistic children to teach them social skills [17]. Another similar robot is Keepon, a small creature-like robot designed for natural, simple and nonverbal interaction with children. Kozima et al. observed an increase in interactive behaviour in children with ASD after training with Keepon, suggesting its design to be effective in eliciting a motivation to share mental states [18].

RoDiCa project uses interactive robots in virtual environments so as to accomplish HRI for treatment of children with ASD. This is done by using Zeno robot to teach facial expression & speech to improve social interactions and body language like hand & arm motion to improve motor skills. The motions of Zeno and that of the child are recorded simultaneously and compared for further studies [19]. AuRoRA project (Autonomous Robotic platform acts as a Remedial tool for children with Autism) employs KASPAR robot [20] in the triadic collaborative play involving pairs of children with ASD, as it is capable of providing high degree of expressiveness and also to carry out interactive games [21]. Boccanfuso et al. have developed a simple interactive robot, CHARLIE (CHild-centred Adaptive Robot for Learning in an Interactive Environment) which has a hand and face tracking mechanism equipped with a camera. It was used for engaging autistic children during therapy involving imitation and turn taking [22]. In recent times, a Robo Parrot was developed to screen autistic children based on parameters from DSM IV criteria like eye contact, social interaction, stereotypical behaviour, etc. [23]. Another technology that has the potential to help people with autism is Collaborative Virtual Environments (CVEs) using which basic emotions have been taught to children and found to have shown positive results [24].

Taking note of the fact that most of the researches already reported were focused more on the enhancement of facial expressions, social interactions, etc. and not much on enhancement of psychomotor skills, this paper focuses on imparting psychomotor skills to autistic children to cope with daily life activities.

2 Impairments in Psychomotor Skills in Autistic Children

As already mentioned in the previous section one of the universal problems that most autistic children face is weak motor skills [25]. The cerebellum, which controls fine motor skills and the frontal lobe of the cerebrum that organizes voluntary body movements are responsible for motor skill development. When these areas are impaired, children cannot perform tasks with the coordination that is expected [26]. Motor difficulties influence academic, social and adaptive functioning of an autistic child [27]. Even the simplest tasks seem to be like herculean task due to lack of hand–eye coordination. For example, when a typically growing child learns "playground politics" at preschool, an autistic child has too many motor or sensory challenges to tolerate the same [28]. Due to this, these children are not able to perform day-to-day tasks.

They also have problems during large muscle activities like walking, marching, crawling and rolling [29]. A child with impaired gross motor skills has poor motor coordination, which leads to being clumsy while moving around furniture in a crowded room or in a busy playground. She/he has problem while climbing stairs, avoiding obstacles on the path, handling playground equipments and so on. On the other hand, impairments in fine motor skills causes difficulties in doing tasks like drawing, writing, buttoning, opening snack packages, eating using utensils, etc. A child with such impairments also has difficulties in using both the eyes together, tracking moving objects, poor hand–eye coordination, etc. [29]. Lips and jaw movements are required to articulate words, hence motor impairments may also affect language skills [30]. The behaviour of an autistic child with psychomotor impairments should be viewed as such and not as described as escape, non-compliment or attention seeking [31].

The objective of this work is to employ a simple, robotic system that would have continuous visual movement to capture the attention of the children with autism and train them in performing smooth pursuits with a focus on the enhancement of palmar grasp, hand–eye coordination and knowledge of directions.

3 Development of Robotic Training Kit

As general humanoid robots like NAO, Robota, etc. were employed for training autistic children to improve social interactions and cognition, in this work an OWI-535, a general pick and place robotic arm [32] has been customised to teach palmar grasp and manipulation of joystick towards enhancing psychomotor skills. The robotic training kit is a 4 Degree of Freedom (DOF) pick and place robot made out of durable plastic polymer with a lifting capacity of 100 g. The four joints of the robot are actuated by four servomotors, to provide a base rotation of 270 °, base tilt motion of 180 °, elbow range of 300 ° and a wrist rotation of 120 °. The robot is fitted with a two-finger gripper that can open and close. The home position is such that the base motor is aligned exactly at the centre using the pointer on the base and all the other motors are aligned in a straight line and is perpendicular to the base. The overall reach of the robot is 0.38 m vertically and 0.32 m in the horizontal direction. The dimensions of the robot is 0.228 m × 0.16 m × 0.38 m (L × W × H), it weighs 658 g and is powered by 4 “D” batteries. The robot is controlled using a five switch wired joystick.

A preliminary trial using this setup was done with two autistic children below 10 years of age, from a special school in Chennai, Tamilnadu, India. No specific action or tasks were given to them; they were only asked to randomly manipulate the robot using the joystick. Both the children found it very difficult to use the joystick, as the levers were too hard for them to push or pull with their fingers. Due to their already existing motor skill deficits and cognitive challenges, it was difficult for them to coordinate all the five motors that were actuated. Hence, three significant changes were made to the kit. The number of DOF was reduced to two, by actuating only the base rotation and the elbow motors. The base rotation is used to turn the robot clockwise and anti-clockwise while the elbow extension is used to move the arm up and down. Using the two DOF, the arm could be moved to any desired position within its workspace. Also, the 5-bidirectional lever joystick was replaced with a classic arcade style joystick. It is a four way micro switch joystick lever with a smooth spring return to the centre. It was also found that the children had a tendency to spin the spherical top of joystick, which is used to hold and manipulate. This hampered the focus of the children and was found_to be a distraction. Hence, the spherical top was replaced with a cubical holder of 0.035 m × 0.035 m size, made out of aluminium block covered with bright colours to induce positive behaviour in children with autism [33–35]. The edges were filed to prevent the children getting hurt while using it and to avoid tactile defensiveness [13]. The two motors are connected to the joystick in such a way that when the joystick is pushed away from the user, the corresponding motor moves the arm up and when the joystick is pulled towards the user the motor moves the arm down. Similarly, when the joystick is moved left or right, the other motor moves the arm to left or right correspondingly. The robot arm and the joystick are fixed on an appropriately sized wooden plank for easy usage and portability. The footprint of the entire kit is 0.44 m × 0.32 m (L × W). It is placed in such a way that the joystick is at a reachable distance on the board. The picture of the setup is shown in Fig. 1.

4 Training Using Robotic Kit

A pilot study on training autistic children using the above-mentioned setup was conducted in one of the physical therapy centres in Thanjavur, Tamil Nadu, India under the supervision of a speech therapist. The scope of the training includes acquaintance with the robotic kit, teaching the concept of different directions *‘up, down, right and left’* and imparting the ability to operate the joystick so as to manipulate the robot. Even though the robotic kit is employed, human interaction and communication are very much part of the training. The kit is just a tool for the therapist to use, which would help children learn better. The unique feature of the training is that the child is taught to operate the robot using joystick physically, which ensures active participation of the child while learning.

The objective of the training is to,

1. Enable the subjects to learn directions
2. Improve the subjects’ capacity to associate with the correct directions
3. Enhance palmar grasp and
4. Improve hand–eye coordination.

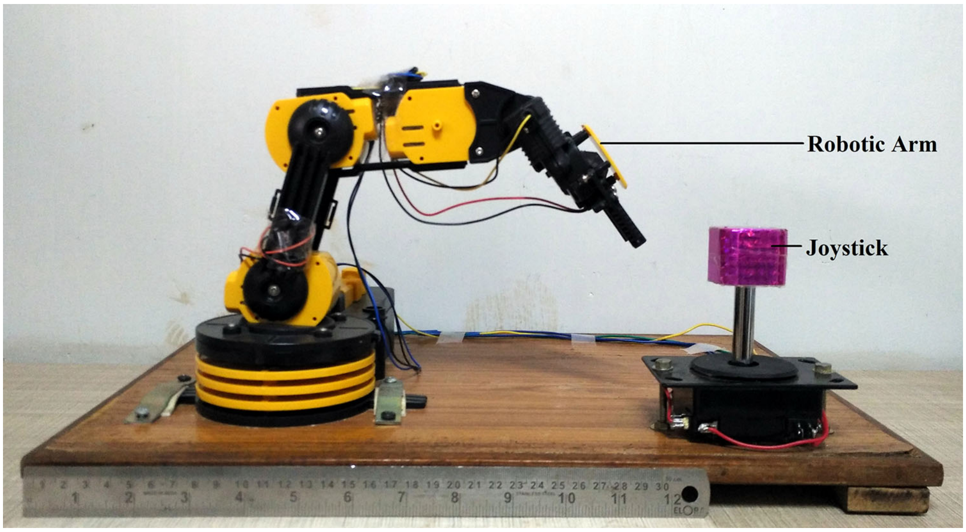


Fig. 1 Robotic training kit

Five autistic children in the age group of 4 to 10 years who were undergoing speech therapy in the centre, were considered for this pilot study with due consent from their parents. All the five subjects were previously diagnosed to be autistic by 'Child Trust Hospital', in which a team of paediatricians, psychologists and psychiatrists work together. They referred these children for occupational and speech therapies. These children did not have any idea of relative directions such as up, down, right and left.

The children were taught the directions by training to move the robot '*up, down, right* and *left'* by operating the joystick as shown in Fig. 2. The training procedure followed for every subject was the same and is as follows: first, the subject was taught how to move the robot using the joystick by the therapist. Then the subject was asked to move the robot by the therapist. The directions were taught in a language that could be understood by the subject. Initially only one action was made to do by the subject. A number of repeated commands were given to the subject to perform the same action. Only when the subject has learnt to do a particular motion properly, the next motion was taken up. Depending on the mood, cooperation, focus & attention of the child and the appointment with the therapist, the training sessions were approximately 20–30 min each, one session per week. But, the total duration of training varied with subjects based on their regularity. Every session was structure oriented to make it easier for the subject to adapt and learn. In every session, the learning of the previous session was practiced before moving on to the next one. Repeated commands were given until the subject got that action right and was able to move the arm correctly with minimal assistance. The intention of giving repeated commands was to increase the familiarity with the commands (directions) and most importantly reduce delayed perception. All the activities in general help the children pay attention to the command and follow it.

The first task out of the four directions was taken to be *'up'* and then followed by *'down, 'right' and 'left'*. The children were taught the directions by moving the robot towards a particular intended direction by manipulating the joystick appropriately. Repeated practice on a particular command improves the attention and retention ability of the subject and makes the subject remember the direction and follow the direction subsequently. The important part of the training is that with enough practice the subjects would acquire palmar grasp, which is primary to enhance their motor skills. Further, as the movement of the robotic arm in the intended direction involves manipulation of joystick, the training enables the subjects acquire the skill of exerting 'push or pull' in addition to holding the joystick. *'Stop'* command was used to check if the subject was able to stop the current work when asked to do so. The way the trials were conducted for the five subjects is explained below:

Initially, the robot was placed in front of the subject facing him/her. The subject was trained to identify the robot and taught to hold the joystick. If the subject was not able to do it correctly, then the therapist or the caregiver assisted the subject physically to hold the joystick until the subject was able to do it without any assistance. After the basic step, the directions were introduced. If the subject was already aware of the *'up'* direction, then the command was directly given, if not the therapist taught the subject by holding the hand of the subject over the joystick and moving it in the upward direction, simultaneously saying the word *'up'*. Then the command was repeated for the subject to follow it. Again, if the subject did not respond, the same procedure was repeated until the subject could do it individually. If the subject succeeded without any assistance then a tick ✓ was marked in the *'Up'* cell of

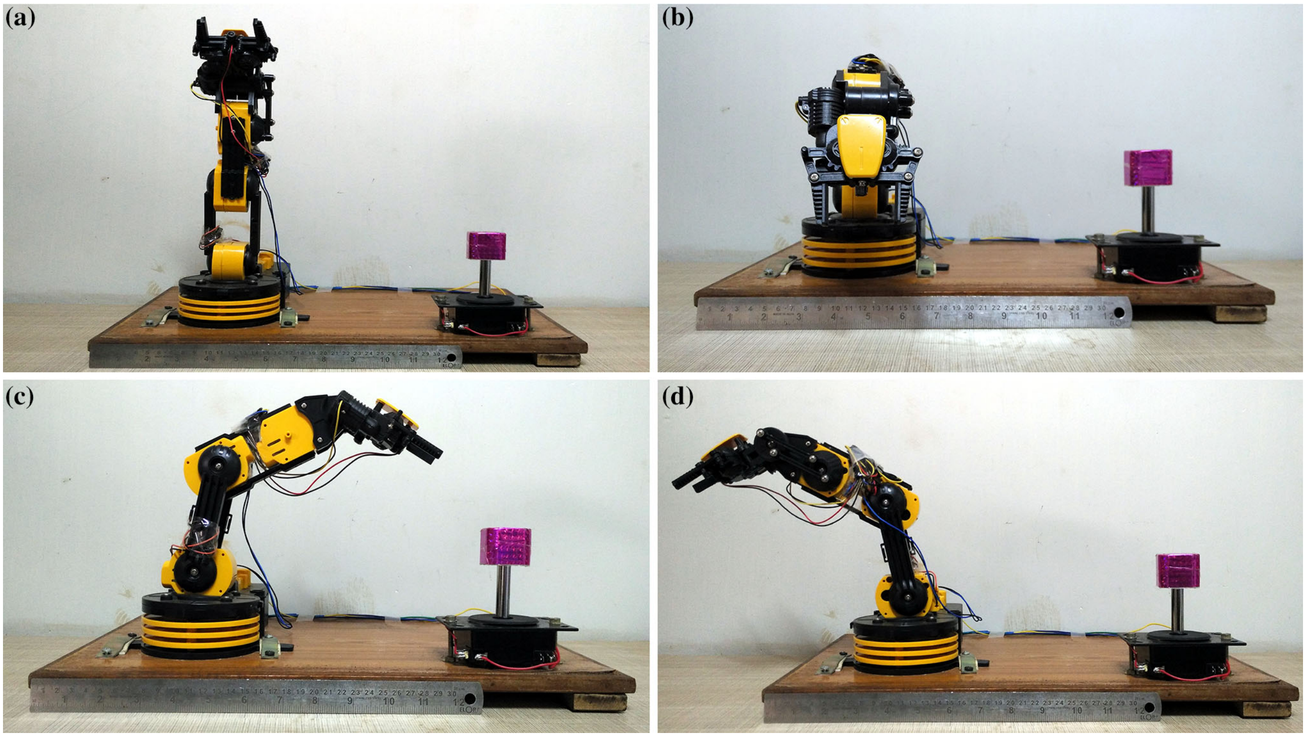


Fig. 2 Position of robotic arm in different directions. **a** Up, **b** down, **c** right, **d** left

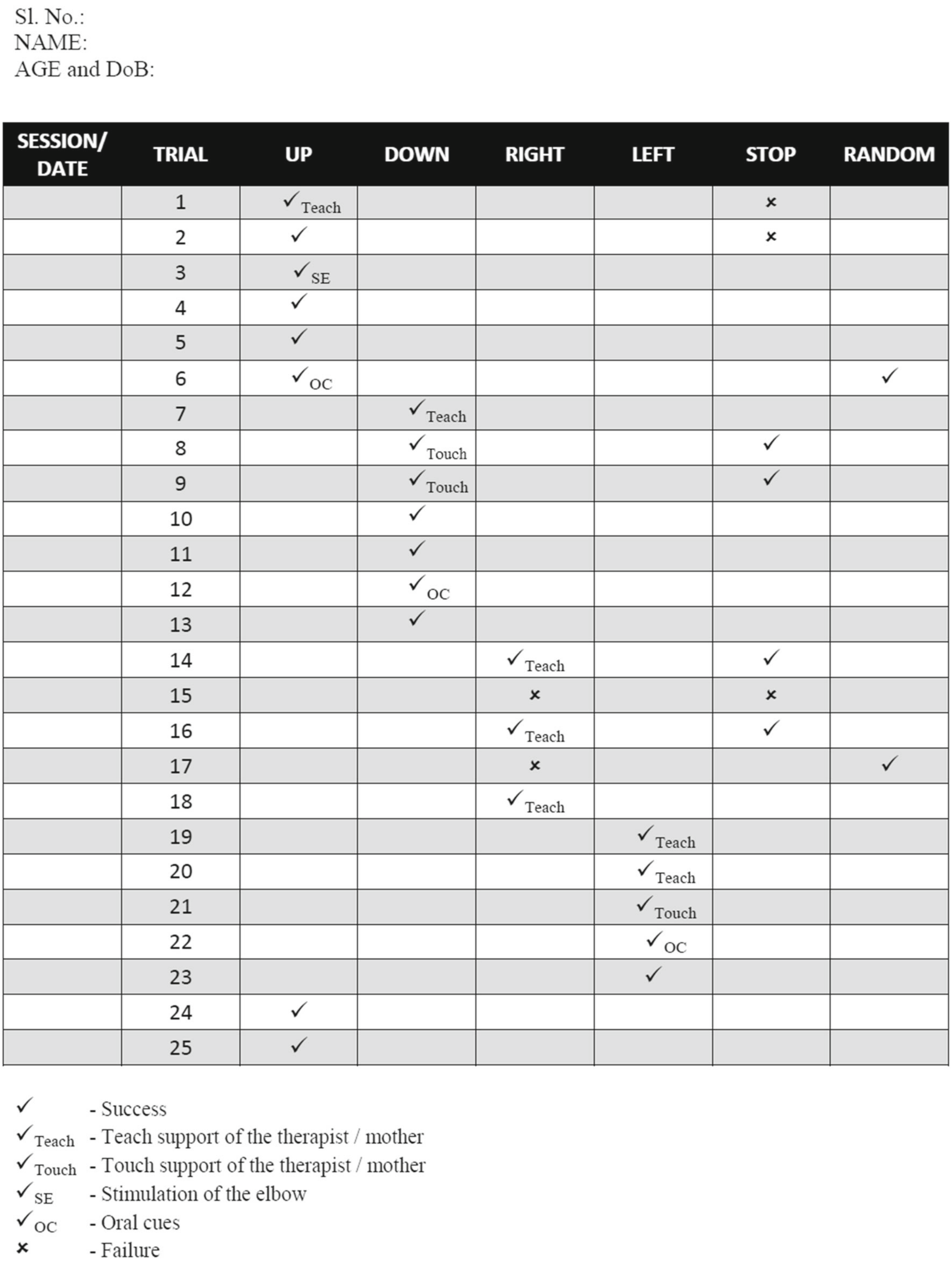
the trial sheet else it was marked it with a ×. If the subject needed teach support from the therapist / caregiver, where the subject's hand is held over the joystick physically and moved then the cell was marked with $\checkmark_{\text{Teach}}$. If it was touch support that was needed, where the subject just needs a touch by therapist/parent then the cell was marked with $\checkmark_{\text{Touch}}$. If the assistance provided was stimulation of the elbow or oral cues then the respective cell was marked with $\checkmark_{\text{SE}}$ or $\checkmark_{\text{OC}}$. If the subject moved the joystick randomly, then it was noted in the 'Random' cell in a similar fashion. As the subjects succeeded in doing one direction, next direction was taught. The same procedure was carried out with each of the five subjects individually and all the outcomes were tabulated for further studies. Specific particulars of observations on the behaviour of subjects were noted down for reference purposes. A sample trial sheet shown in the Fig. 3, consists of a table used to record the outcomes of all the tasks created for the subjects using the robotic arm. Each subject has one dedicated trial sheet and the outcomes are tabulated for all the sessions conducted.

5 Results and Discussions

From the observations recorded in the trial sheets of the subjects, the progress of learning by each subject is measured in terms of percentage of total number of successful trials. The success percentage of each subject in every session was calculated to measure the learning progress of the respective subject in each session. The trial data has been furnished in Table 1 and is shown graphically in Fig. 4.

As can be seen from Table 1, the number of trials per session varied with subjects as it depended on the mood, response, task and learning rate of a subject. The number of trials per task also varied with each subject. Figure 4 shows the success percentage of trials performed by different subjects in different sessions. The success percentage considered here includes the successful trails with assistance as well. The success percentage plotted in the graph includes the result of all the directions that were taken up in the respective sessions; this explains the dips in the graph as they attribute to the new learning in that respective session. By the seventh session all the subjects have learnt all the four directions and needed only minimal assistance, hence it was decided to stop the trials at that point.

Subject 1 initially responded with 80 % success in session 1and had 86 % at the end of the training session. This 86 % success includes all the four directions and indicates the assessment of summative learning. Subject 2 did not respond to training in the first session but from subsequent training sessions, she was able to attain close to 96 % success in all the four directions put together. Subject 3 had 67 % success in the first session and by the end of seventh session he had learnt all the directions and achieved a 96 % success rate with minimal assistance. Subject 4 started with a success rate of 93 % and by the end of seventh session had a success rate of



Sl. No.:
NAME:
AGE and DoB:

SESSION/ DATE	TRIAL	UP	DOWN	RIGHT	LEFT	STOP	RANDOM
	1	✓$_{\text{Teach}}$				×	
	2	✓				×	
	3	✓$_{\text{SE}}$					
	4	✓					
	5	✓					
	6	✓$_{\text{OC}}$					✓
	7		✓$_{\text{Teach}}$				
	8		✓$_{\text{Touch}}$			✓	
	9		✓$_{\text{Touch}}$			✓	
	10		✓				
	11		✓				
	12		✓$_{\text{OC}}$				
	13		✓				
	14			✓$_{\text{Teach}}$		✓	
	15			×		×	
	16			✓$_{\text{Teach}}$		✓	
	17			×			✓
	18			✓$_{\text{Teach}}$			
	19				✓$_{\text{Teach}}$		
	20				✓$_{\text{Teach}}$		
	21				✓$_{\text{Touch}}$		
	22				✓$_{\text{OC}}$		
	23				✓		
	24	✓					
	25	✓					

✓ - Success
✓$_{\text{Teach}}$ - Teach support of the therapist / mother
✓$_{\text{Touch}}$ - Touch support of the therapist / mother
✓$_{\text{SE}}$ - Stimulation of the elbow
✓$_{\text{OC}}$ - Oral cues
× - Failure

Fig. 3 A typical trial sheet

96 % with decline in assistance required. Subject 5 recorded a 100 % success from the third session onwards though she required some assistance until the end.

In order to study the learning outcome of each subject towards a particular directional task the response of the subject is studied activity wise. This data is furnished in Table 2, which records the number of successes and failures under each direction for each subject. The same has been captured graphically in Fig. 5, which helps to study the percentage of successful trials of the subjects in each of the four tasks. Sim-

Table 1 Session wise trial data

No. of Sessions	Subject 1			Subject 2			Subject 3			Subject 4			Subject 5		
	TT	TS	S (%)	TT	TS	S (%)	TT	TS	S (%)	TT	TS	S (%)	TT	TS	S (%)
Session 1	16	13	81	2	0	0	21	14	67	32	30	94	16	14	88
Session 2	36	35	97	26	20	77	20	16	80	69	57	83	13	12	92
Session 3	16	13	81	22	18	82	30	27	90	30	28	93	27	27	100
Session 4	24	24	100	31	29	94	14	11	79	55	54	98	18	18	100
Session 5	44	37	84	28	21	75	26	23	88	33	31	94	31	31	100
Session 6	35	33	94	48	44	92	37	30	82	17	16	94	26	26	100
Session 7	34	29	85	71	68	96	48	46	96	25	24	96	19	19	100

TT Total trials, *TS* successful trials, *S* % success percentage

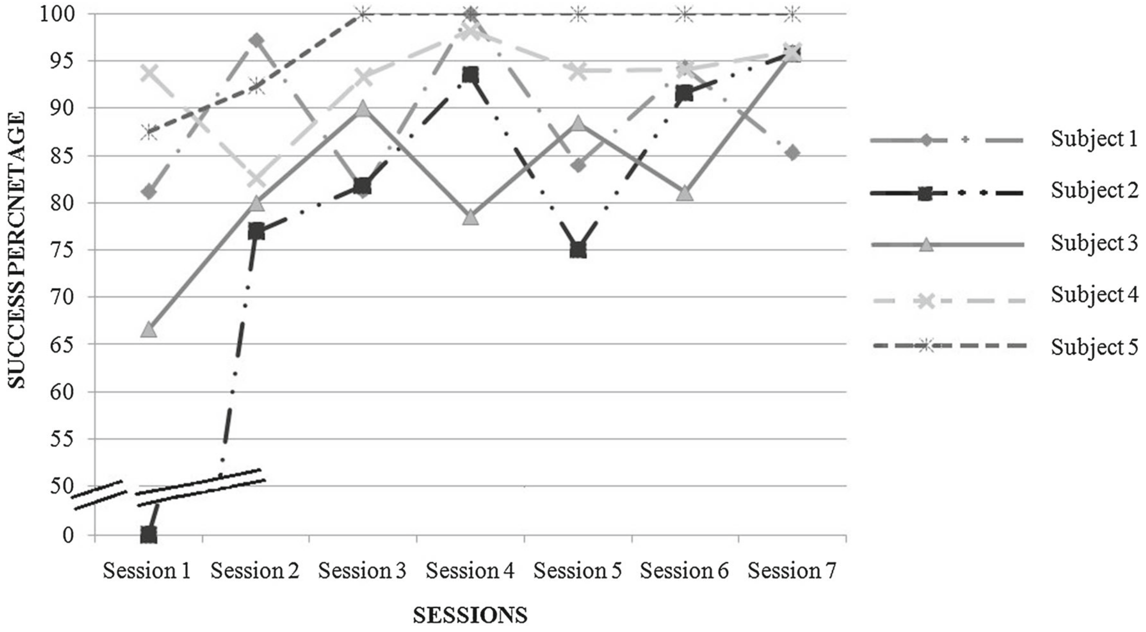


Fig. 4 Success of the subjects in different sessions

Table 2 Task wise trial data

Subject	Age	Move up			Move down			Move right			Move left		
		TT	TS	S%	TT	TS	S%	TT	TS	S%	TT	TS	S%
Subject 1	4 years	66	61	92	52	46	88	50	44	88	36	32	89
Subject 2	6 years	81	71	88	65	54	83	39	38	97	43	37	86
Subject 3	5 years	74	63	85	60	51	85	40	34	85	22	19	86
Subject 4	7 years	59	58	98	39	39	100	77	74	96	86	69	80
Subject 5	10 years	51	48	94	46	46	100	33	33	100	20	20	100

TT Total trials, *TS* successful trials, *S* % success percentage

ilar to Fig. 4, the success percentage in each task also includes the success achieved with assistance. As can be seen from the histogram, the minimum success achieved by a subject was 80 % in a particular task (LEFT) and the average success achieved by all the subjects in all the tasks put together crossed 91 %.

5.1 Assistance Needed During Trials

During trials, if a subject did not respond to the given command or found it difficult to do so, the therapist or the caregiver provided the subject with the required assistance. This could be in the form of teaching once again or just

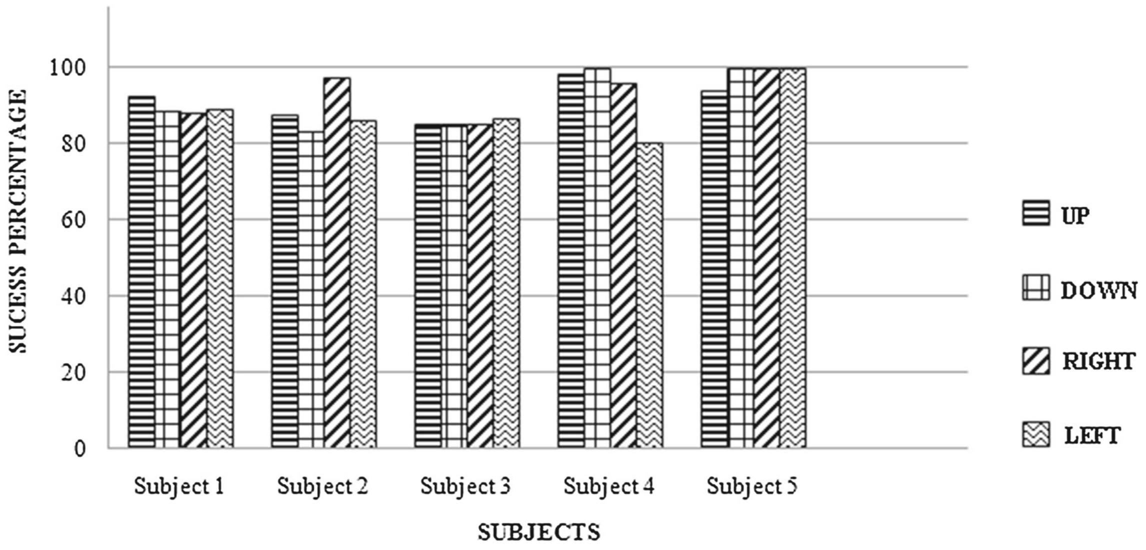


Fig. 5 Success of the subjects in different tasks

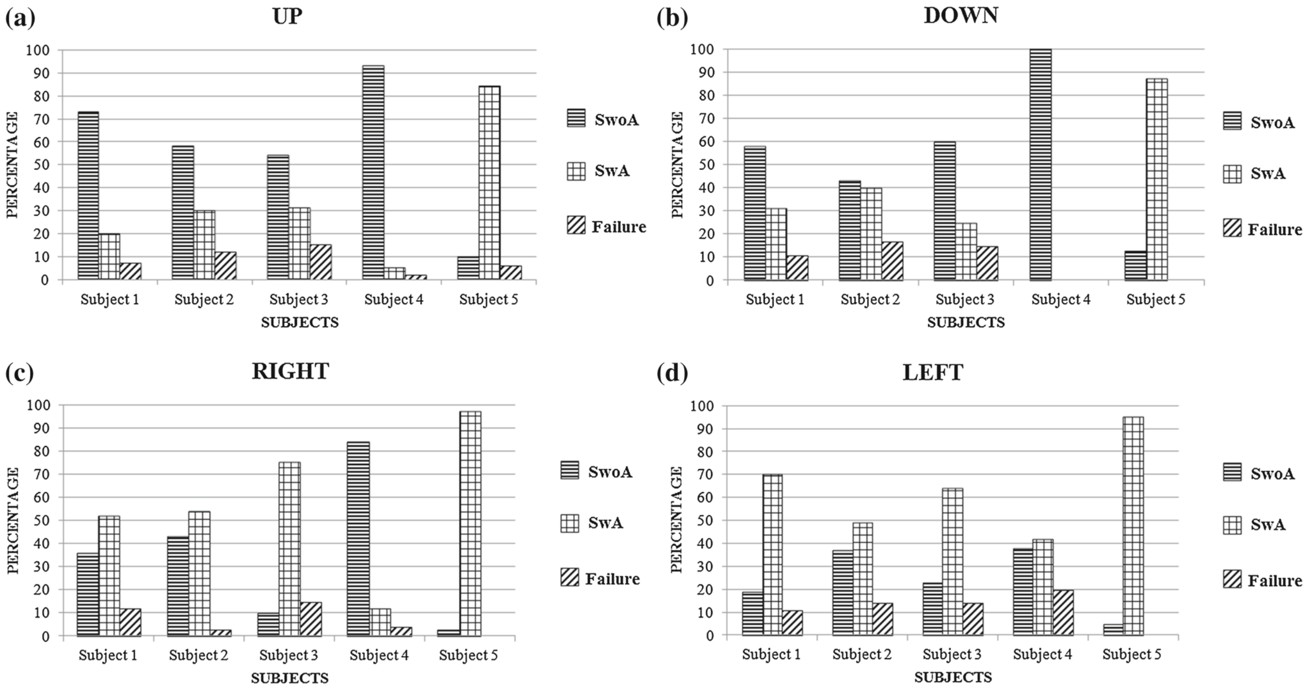


Fig. 6 Performance of the subjects with and without assistance

touching the subject's hand, or stimulation of the elbow or giving oral cues. Assistance was given to the subject until he/she was able to carry out the task individually. In order to study the extent of assistance required by different subjects for different tasks in different sessions, the assistance provided by the parents and therapists were also noted down. Using the data from the trial sheet, percentage of success without assistance (SwoA), success with assistance (SwA) and failure were calculated individually for each of the four directions. Performance of subjects with and without assistance was plotted task wise as shown in the Fig. 6. It can be seen from the graphs that 'up' and 'down' motions were executed by the subjects easily without much assistance. The maximum success in the 'up' direction could be because of the fact that it is always easier to push the joystick away from the body, than moving it in any other direction. The second easiest would be naturally, pulling the joystick towards the body. Thus, 'right' and 'left' motions needed more assistance than 'up' and 'down'. This may be understood in the light of the fact that distinguishing between right

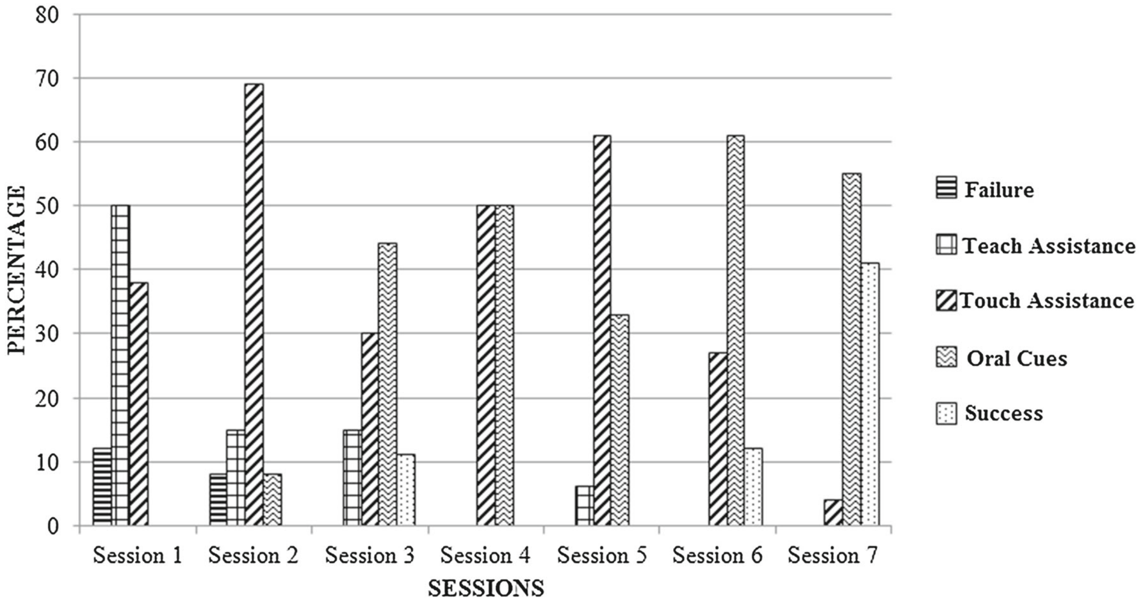


Fig. 7 Breakup of assistance required by subject 5

and left starts only at the age of 5 years even by a normal child [36].

However, towards the end of the training, it was seen that the subjects were capable of performing the tasks without much prompts from the therapist or the caregiver. Even though the subject 5 needed more assistance until the end as shown in Fig. 6, the quality of assistance needed gradually reduced. Figure 7 provides a break-up of assistance required by subject 5 for further detailed study. The decline in the extent of assistance required can be seen from the Fig. 5, which shows only oral cues and very minimal touch assistance in the seventh session. Elbow stimulation was not required throughout the training, but teach assistance of 50 % required in the first session reduced to 15 % by the third session and completely vanished after the fifth session. Teach assistance transformed into 4 % of touch assistance and 55 % of oral cues towards the end. The success rate i.e. without any assistance was zero in the first session, and reached a remarkable 41 % on the seventh session. Subject 5 was able to achieve 96 % success rate on the seventh session, without any physical assistance but only with oral cues. Thus, the use of robotic training kit helps in improving lateralization in children with autism as they were able to improve from total dependence to minimal assistance.

5.2 Positive Response of Training Using the Robotic Kit

The usefulness of employing the robotic kit in teaching psychomotor skills is evident from the graphs and is further ascertained by the observations of the therapist and the parents. Usually Autistic children have problems of sustaining attention for extended period. They also cannot shift attention appropriately between several tasks [37]. After the training sessions, the therapist observed that there was increase in the children's attention and response even in the speech therapy sessions. This observation is in line with the findings that there is increase of attention in children with autism spectrum due to perceptual-motor trainings [38–40].

She also observed that there was a definite decrease in the unwanted stereotypical behaviours in all subjects and increase in adaptive behaviour, as they were found to be working with the kit for longer periods towards the end of the training. This also correlates well with the previous study results that use of perceptual and motor training decreases the behavioural disorders in children with autism [41]. The therapist also noted that using the robotic training kit improved their ocular-motor skills, which includes both hand–eye coordination and hand motor skills to an appreciable extent. The subjects were able to work with the robot perfectly even after a few weeks break, through a confirmation trial.

A physician who was consulted after the trails for reconfirmation, after watching the trial videos, pointed out that the children are able to retain their learning gained through the training due to active participation during training sessions. Learning by doing and reflecting on the results from the training, helps children to create a concrete understanding and connect that experience with daily life [34,42]. The learning process through physical manipulation of the joystick with corresponding physical movement in the robot, provides an opportunity for the child to experience a visual learning process, which helps them in long term retention of the learnt activity.

One common observation from the parents of all the children was that the children started to respond better at

Table 3 Learning assessment and behavioural improvement

Subject	Age	Progress during training	Assessment by therapist during training session	Observations by parents in everyday life
Subject 1	4 years	Initially moved joystick using single finger and in discontinuous motion but gradually developed the palmar grasp and was able to move the joystick continuously	Increase in attention span	Handling TV remotes and remote control cars, etc
		Absence of random movement at the end of the training which was present at the beginning	Increase in response to the commands	Increase in response to commands
			Increase in adaptive behaviour	
			Decrease in stereotypical behaviours	
Subject 2	6 years	Improvement in visual tracking and hand– eye coordination followed the robot’s continuous movement at the end of training	Increase in adaptive behaviour	Started to hold plates and tumblers
		Only aware of “up” and not any other directions, but at the end of the seventh session, was able to clearly distinguish between the four directions and associate it to the commands	Increase attention span	Increase in response to commands
		Initially pushed joystick using palm but gradually developed the palmar grasp	Increase in response to the commands	
Subject 3	5 years	Obeyed commands and there was reduction of prompts at the end of the training	Improvement in the two-hand coordination	Started to hold plates and tumblers
		Reduction in hyperactivity and increase in adaptive behaviour	Increase in adaptive behaviour	Handling TV remotes
		Was able to clearly distinguish between the four directions and also was able to visually track the robot without distractions	Increase in attention span	Increase in response to commands
			Decrease in stereotypical behaviours	
Subject 4	7 years	Enjoyed working with the robot	Improvement in hand–eye coordination and not only did he promptly respond to the given command directions but also started placing the robot by coordinating both the DOF of the robot using the joystick	Started to use both his hands (lateralization) to hold things
		Used single finger to push the joystick but later on learnt the palmar grasp	Increase in adaptive behaviour	Started to insert his legs in the correct shoes
		Initially had difficulty with right and left; was able to differentiate between the directions towards the end	Increase in attention span	Increase in response to commands
Subject 5	10 years	Used two fingers to push the joystick but later on learnt the palmar grasp	Increase in hand–eye co ordination and motor skills	Started to hold plates and tumblers
		Was able to differentiate between the directions towards the end of the session	Increase in attention span	Handling TV remotes
			Increase in adaptive behaviour	Increase in response to commands
			Decrease in stereotypical behaviours	

home. They also noted that a few additional skills related to their daily living activities such as ability to hold plates and tumblers, using remote control devices, inserting their legs correctly into the corresponding shoes, etc. improved after the training sessions. Further to the common improvements observed amongst all the subjects, specific improvements concerned with individual subjects are tabulated in Table 3.

6 Conclusion

A number of robotic systems have been deployed to train children with autism in different types of emotions & facial expressions [17,18] and to enhance eye contact & social interactions [14,19,22]. However, not many attempts have been made towards enhancement of psychomotor skills using robotic systems. Thus, the robotic kit developed in this work is novel as it addresses specific skills such as palmar grasp and hand–eye coordination. Teaching psychomotor skills to autistic children by employing this robotic training kit is found to be working and the results are encouraging. After the training sessions, the children learnt all the four directions, acquired the skill of palmar grasp and were able to manipulate the joystick appropriately. Thus, the use of robotic training kit helps in improving lateralization in children with autism, as they were able to improve from total dependence to minimal assistance. Apart from the results, the feedback from the parents, the therapist and the physician led to conclude that the robot based training helps the children with autism to improve their attention span, reduce unexpected stereotypical behaviour and most importantly increase hand–eye coordination. Encouraged by these findings, the authors are motivated to take the research further and develop more comprehensive training systems to enhance the psychomotor skills of autistic children in order to accomplish day-to-day activities.

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