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ABA-Based Interventions: A Study on Learning Speed in Robotics-Mediated Interventions for Children on the Autism Spectrum

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ABSTRACT

Background: The present study aims to investigate the effects of a robotics-mediated intervention on the learning speed within habilitative treatments based on Applied Behavior Analysis (ABA) principles for children diagnosed with Autism Spectrum Disorder (ASD).
Methods: The study considered as dependent variables the skills in certain verbal operants, such as echoic, Tact, mand, listener, visual-perceptual skills, and imitation, while the independent variable was the use of the NAO robot as a mediator in the intervention. The participants in the study were six children, aged between 3 and 6 years (5 male and one female), divided into an experimental group and a control group. For both groups, we run a pre-test measurement without using robotics. Then, we recorded the number of trials required to reach the acquisition criterion for each item.
Results: The study revealed a functional relationship between using robotics to repeat items (echoic), labeling (Tact), and visual-perceptual tasks.
Conclusions: The research findings demonstrate that the initial hypothesis of using robotics within habilitative interventions led to practical results in some areas of learning (echoic, Tact, and visual-perceptual skills). Further investigation into the potential of this tool in various learning domains could be valuable.

*Keywords***:** autism spectrum disorder, ASD, robot-mediated intervention, Applied Behavior Analysis

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Introduction

As of today, the Ministry of Health reports that in Italy, the prevalence of autism spectrum disorder (ASD) is 1 in 77 children aged 7-9 years and 1 in 54 in the United States (CDC, 2016). The main features of this neurodevelopmental disorder are difficulties in social communication, eye contact, restricted social skills, engagement in self-injurious behaviors, limited or repetitive behaviors (CDC, 2022; Rylaarsdam & Guemez-Gamboa, 2019), restricted or non-functional play skills, difficulty adapting to changes in routine, and challenges in understanding emotions. The severity of these changes and symptoms varies from person to person.

Although ASD is a lifelong disorder, there is significant evidence that early interventions are more effective than those provided at older ages. Teaching strategies to children with ASD often involves strengthening desired skills and behaviors through individualized instruction, intensive training, repeated instructions, and generalization across different environmental contexts (Ruble et al., 2012).

In the context of rehabilitative pathways, the guidelines of the National Autism Observatory (OssNA) indicate that an effective practice in early intensive behavioral rehabilitative interventions is Applied Behavior Analysis (ABA) and its associated techniques. ABA offers evidence-based treatments to address communication, social, and behavioral deficits to reduce problematic behaviors in these populations (Cooper et al., 2007), teach communication, social, play, academic, and daily living skills, and achieve better therapeutic outcomes. For these reasons, educators should administer ABA-based treatments during early childhood, between the ages of 1.5 and 6 (Zhang and Cummings, 2020).

In recent years, research has provided evidence of the effectiveness of interventions using digital interfaces, including robotics-mediated interventions. The literature analysis revealed that the use of such tools has contributed to increased motivation for learning, enhanced imitative skills (Robins et al., 2005; Greczec et al., 2014), improvement in social skills (e.g., turn-taking in conversation, shared attention, eye contact, greetings) (Bekele et al., 2014; Pop et al., 2013), reduction in problematic behaviors (Andreae et al., 2014; English et al., 2017), improvement in emotion recognition (English et al., 2017; Pioggia et al., 2005), increased intraverbal communication skills (Korneder et al., 2021), and listening comprehension skills (Louie et al.).

Compared to other digital interfaces, the use of humanoid robots has the potential to overcome the limitations of other digital interfaces, such as the inability to generate natural reinforcement and the need to interact with a screen. Unlike digital interfaces, humanoid robots have humanoid features that allow them to establish eye contact, communicate verbally through gestures, occupy the same physical space, and provide personalized strategies similar to those used in human interactions. These characteristics can serve as stimuli to facilitate the generalization of learning from robot interaction to human interaction through antecedents (e.g., eye contact followed by words) and reinforcements (e.g., verbal and gestural social reinforcement) provided during therapy.

The study by Hujnen et al. (2019), in its review of the use of robotics in interventions for children with ASD, investigates the roles, strengths, and weaknesses of using robots with children on the spectrum based on the use of a humanoid robot. This research focuses on six roles of the robot: the humanoid robot as: a) Stimulator, b) Reinforcer, c) Mediator, d) Trainer, e) Prompter, and f) Provider of diagnostic information. Hujnen et al. (2019) highlight the strengths of the humanoid robot, including its ability to be customizable and multifunctional, its playfulness, its capacity to demonstrate action-reaction effects, its neutrality, its ability to implement consistent and repetitive applications, and its unique feature of modifying reality in a controlled manner. Hujnen et al. (2019) also discuss the difficulties that may arise when using robots, which they identify in four points: a) limited reaction possibilities, b) some children may be frightened by the robot, c) generalization/transfer, where some children may struggle with generalizing to real-life contexts, and d) dependency on the robot.

From the analysis of the studies considered, a predominant use of humanoid robots, specifically NAO, developed by Aldebaran Robotics (now SoftBank Robotics), can be observed in research on robotics-mediated interventions. These studies specifically examine the use of robots for the following purposes: development of intraverbal skills (Korneder et al., 2021), improvement of joint attention skills (Zheng et al., 2018; Zheng et al., 2020), enhancement of social skills (Ali et al., 2020; Ghiglino et al., 2020), improvement of gestural communication (Louie et al., 2021), imitation skills, and recognition and production of emotional expressions (Lecciso et al., 2021). In all these cases, the results showed positive outcomes both in terms of learning and learning speed. However, these studies also revealed limitations, such as the absence of control groups, the limited number of participants, and the need to replicate and expand the demonstrated evidence.

The use of robotics as a therapeutic support for children with Autism Spectrum Disorder (ASD) is emerging as a promising area of research and application.

Brighenti et al. (2022) highlight the launch of a project that aims to integrate specialized facial emotion recognition (FER) software, with the goal of developing personalized solutions for children with ASD. Robotic interventions have also proven to be effective tools for enhancing imitation skills. For instance, Alnafjan et al. (2024) present a human action recognition system designed to improve imitation abilities in children with ASD. Using the NAO robot, the authors demonstrate that robotics can promote social and emotional integration, thus contributing significantly to the cognitive and social development of children with ASD.

In line with this evidence, Holeva et al. (2024) emphasize the effectiveness of robot-assisted psychotherapy for children with ASD. They suggest that the use of validated tools and a rigorous methodology are essential for evaluating outcomes. The authors argue that the integration of artificial intelligence can further enhance therapeutic practices. Di Cara et al. (2025) explore another application of robotics, showing that NAO-assisted therapy is particularly effective in improving verbal communication and communicative initiative in children with limited verbal skills. Their findings indicate that robot-assisted therapy provides significant improvements over traditional approaches, addressing the need for adaptable and engaging interventions that can meet the diverse needs of children with ASD.

Based on the reported evidence, the present study aims to investigate whether using robotics as a mediator in habilitative therapies based on ABA for children with ASD can enhance verbal operants, visual-perceptual skills, and imitation skills. Furthermore, it examines whether this enhancement leads to a faster learning speed than using the same techniques in direct interaction with the therapist.

Method

Participants and procedures

Six children aged between 4 and 6, all diagnosed with ASD based on DSM-5 criteria, attended the study. All participants attended a center specializing in ABA to improve their functional skills. Participants were assigned to the experimental or control group based on organizational and contextual factors, such as family preferences and scheduling compatibility, rather than random assignment. Despite the lack of randomization, group composition was balanced by selecting children with similar language and social skill profiles according to their VB-MAPP scores. Before the study began, we obtained informed consent from the families.

Among the six participants, four attended preschool (four in the second year and one in the third year), while one attended the first year of primary school. All participants had completed the first level of the VB-MAPP (Verbal Behavior Milestones Assessment and Placement Program, Sundberg, 2012, Giunti) for language development and social skills. Participants were selected based on their VB-MAPP assessment scores to ensure they had similar objectives across the dependent variables. Participants in the control group included Participant 1, who attended the first year of primary school for 25 hours per week and participated in the center's activities for 3 hours per week. Participant 2 attended the second year of preschool and received the center's services for 2 hours per week. Participant 3, also in the second year of preschool, spent 25 hours per week in school and 2 hours at the center.

In the experimental group, Participant 4 attended the second year of preschool for 25 hours per week and participated in the center for 4 hours per week. Participant 5, also in the second year of preschool, attended the center for 4 hours per week. Participant 6, enrolled in the third year of preschool, attended the center for 2 hours per week.

The VB-MAPP scores also guided participant inclusion, helping ensure that the children shared similar targets across intervention areas.

Materials and Setting

We conducted the sessions in a room equipped with various toys and a child-sized table in a habilitative center for neurodevelopmental disorders in Northern Italy. Each participant completed the pre-test and treatment phases individually, maintaining a therapist-to-client ratio 1:1.

The robotic mediator used in the intervention was NAO, a humanoid robot (58 cm tall) capable of head, arm, and leg movements. NAO was programmed using Robomate software (Behavior Labs) and controlled via a tablet and Wi-Fi. The robot provided verbal prompts, social reinforcement, and gestures as part of the intervention. For data collection, we used paper-based grids to record scores for each dependent variable. During each session, we presented 10 items per objective.

Experimental Design

We implemented a between-group A-B design to compare learning speed across five dependent variables. We recorded the number of correct responses in word repetition tasks to assess Echoic. For Tact, we evaluated the number of correct responses in labeling tasks. Listener performance depended on the number of correct responses in understanding verbal requests, while VPMTS (Visual Perception and Matching to Sample) involved counting the correct responses in visual-perceptual tasks. Lastly, we measured imitation by tracking the number of correct responses in replicating gestures or movements. Participants demonstrated skill acquisition by achieving 100% accuracy over three consecutive trials. Each task was considered mastered following three consecutive correct probes. The study examined using robotics as a mediator in ABA treatments as the independent variable. The aim of the study is to investigate whether the use of robotics facilitates faster attainment of learning objectives (learn units to criterion), thereby enhancing skill acquisition in a shorter time compared to children receiving traditional ABA interventions. Learning speed was measured using the learn units to criterion parameter, and the mean number of repetitions was calculated for the 10 baseline and post-test items for each dependent variable.

Measures

We assessed baseline and post-treatment measures using the VB-MAPP test, which evaluates 170 developmental milestones related to language and social skills. We measured learning speed as the number of trials required to reach the mastery criterion. We recorded scores using a 0 (incorrect) to 1 (correct) system, except for "echoic" and "imitation" responses, where partially correct responses received a score of 0.5.

Pre-test Phase

We assessed each participant individually using the VB-MAPP test. The test was administered across five scales (echoic, Tact, listener, VPMTS, and imitation) to determine baseline performance and set intervention objectives.

Intervention Phase

Participants in the experimental group received a robot-mediated ABA intervention, while those in the control group received a traditional ABA intervention led by a therapist. Both interventions followed the same structured protocol for presenting stimuli, reinforcing correct responses, and managing errors. However, in the experimental group, a humanoid robot mediated these tasks, whereas in the control group, the therapist directly implemented all the tasks.

In Echoic tasks, the child had to repeat a verbal stimulus (word or sound) provided by the robot or therapist. If the child produced the correct response, he received consequences such as verbal praise (e.g., "Great job!", "Excellent!") or social gestures such as applause. If the response was incorrect or partially correct (e.g., mispronounced but recognizable), a partial score (0.5) was assigned. We used a zero-second prompt in case of an incorrect response, where the robot or therapist immediately repeated the correct model. The child was then given another opportunity to respond. If errors persisted, additional support was provided, such as exaggerated mouth movements or visual cues to guide pronunciation. The goal was gradually reducing prompting until the child could produce the sound or word independently.

For Tact tasks, the child was shown an image and prompted to name it. If the child correctly labeled the object, then he received praise. If the response was incorrect, a four-step prompting procedure was applied.

1. Prompt phase – The correct answer and question repetition were immediately provided.
2. Transfer phase – The question was asked again without the answer being provided.
3. Distraction phase – A neutral distraction (e.g., introducing an unrelated word or movement) was used before retesting.
4. Test phase – The child was asked the original question again to assess retention. This method ensured that the child received appropriate support while minimizing dependency on prompts.

In Listener tasks, the child was instructed to hand over a specific card upon request. Correct responses were reinforced verbally or socially. If an error occurred, the therapist or robot named the object without taking it and repeated the request. If the error persisted, the correct card was shown as a model before asking the child to try again. If the child responded correctly on the second attempt, he received reinforcement, but the response was marked as incorrect for scoring purposes.

For VPMTS tasks, the child was given a card and instructed to match it to a corresponding stimulus. If the response was correct, reinforcement was delivered. If the child made an error, the correction procedure involved silently re-presenting the card, giving the child another chance to make the correct selection without immediate verbal correction.

In Imitation tasks, the child was asked to replicate a demonstrated movement. If the child performed the movement correctly, reinforcement was given. If the response was incorrect, the model was repeated a second time without additional verbal prompting. In the control group, the therapist could provide physical prompting (e.g., gently guiding the child's hands or body through motion) and gradually fade assistance until the child performs independently.

While the overall structure of the intervention was identical in both groups, in the experimental group, these processes were automated and controlled via the robot, which delivered verbal prompts, gestures, and reinforcements. In contrast, the therapist manually executed these steps in the control group, adapting physical and verbal prompting as needed and recording response accuracy throughout the sessions.

Post-test Phase

Learning speed was measured again by assessing the number of trials required to reach the mastery criterion using 10 items per dependent variable.

Interobserver Agreement

In this study, data were collected by the experimenter and by appropriately trained individuals. By dividing the number of agreements by the sum of agreements and disagreements, and multiplying by 100 (Cooper et al., 2007), we computed the Inter-Observer Agreement (I.O.A.) using the data collected by two independent observers for 45% of the sessions. In the baseline session, the I.O.A. was 100% of agreement. During the training phase, the I.O.A. was 98% (95% to 100%).

Results

The results obtained in the pre-test and test phases are presented in Table 1, divided into the control group (P1, P2, P3) and the experimental group (P4, P5, P6). After recording the number of probes required to reach the acquisition criterion for each item within each variable, the arithmetic mean of these values was calculated. This mean represented the average number of probes needed to master the 10 items of each variable during both the baseline and post-test measurements. The table shows the average number of probes required to reach mastery criteria, divided by the dependent variables.

Table 1. Pre-test and test phases

	CONTROL GROUP						EXPERIMENTAL GROUP					
	P1		P2		P3		P4		P5		P6	
	Baseline	Post Test	Baseline	Post Test	Baseline	Post Test	Baseline	Post Test	Baseline	Post Test	Baseline	Post Test
ECHOIC	7,2	7	5,7	6	4,5	4,3	4,5	3,4	5,6	3,6	4,9	3,9
TACT	3,7	3,7	6,2	5,9	4	3,7	4	3,4	7,4	5,3	4,6	3,7
LISTENER	4,9	4,6	3,2	3	3,4	4,5	3,1	3,1	3	3	3,1	3
VPMTS	3,6	3,8	4,1	4	3,4	3,3	4,3	3,2	5,9	3,6	3,4	3,1
IMITATION	4,5	4,7	4,6	4,3	3,9	4,1	3,5	3,8	3,4	3,8	3,2	3,1

In Figures 1.a and 1.b, the results for the dependent variable "echoic" are displayed. Participants in the control group reached the mastery criterion in the test phase with an average difference in correct trials for each item of -0.2 for P1, +0.3 for P2, and -0.2 for P3, compared to the pre-test phase. Participants in the experimental group (with robot) reached the mastery criterion in the test phase with an average difference in trials for each item compared to the pre-test phase of -1.1 for P4, -2 for P5, and -1 for P6.

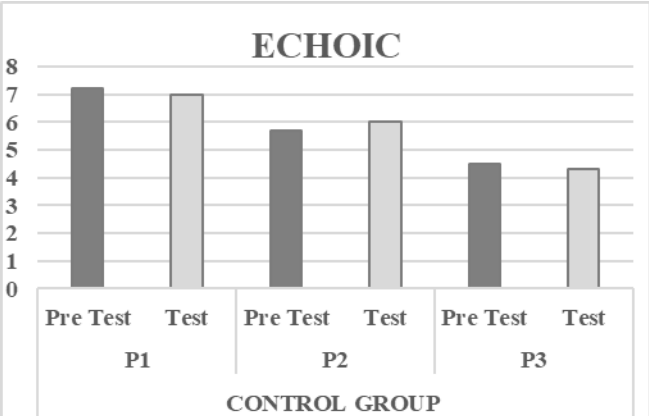

Figure 1.a *Control Group: comparison of Echoic trials Pre Test and Test*

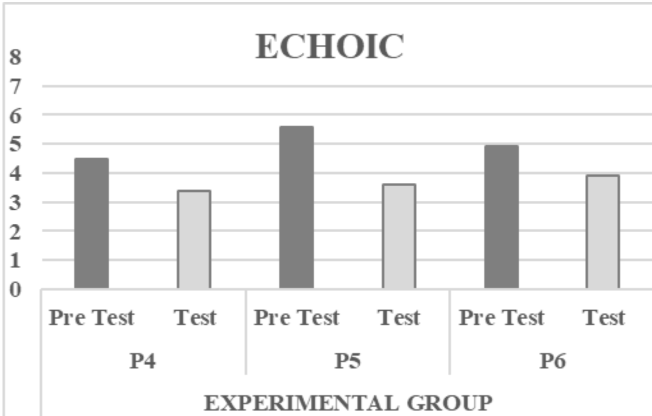

Figure 1.b *Experimental Group: comparison of Echoic trials Pre Test and Test*

Figures 2.a and 2.b present the results for the dependent naming variable, "tact,". In this case, participants in the control group reached the mastery criterion in the test phase with an average difference in correct trials for each item of 0 for the first participant, -0.3 for the second, and -0.3 for the third, compared to the pre-test phase. Participants in the experimental group reached the mastery criterion with an average difference in trials for each item of -0.6 for the fourth participant, -2.1 for the fifth participant, and -0.9 for the sixth participant, compared to the pre-test phase.

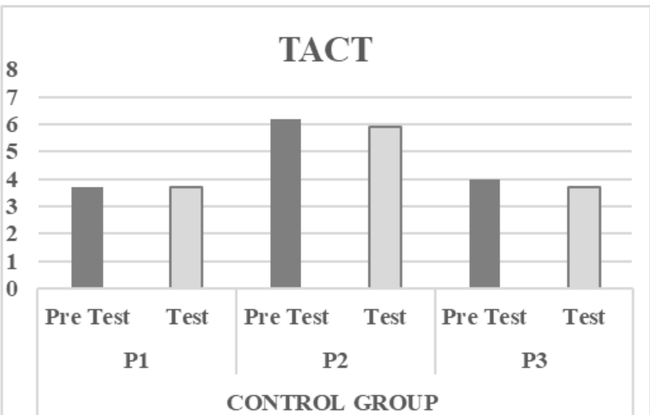

Figure 2.a *Control Group: comparison of Tact trials Pre Test and Test*

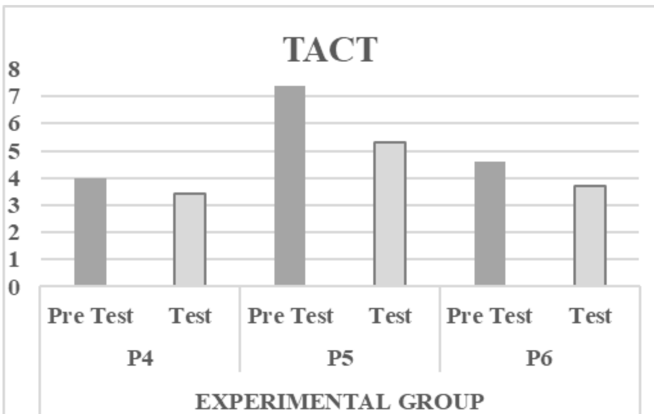

Figure 2.b *Experimental Group: comparison of Tact trials Pre Test and Test*

In Figures 3.a and 3.b, the data for the dependent variable of listening skills, "listener," are presented. The graph shows that participants in the experimental group reached the mastery criterion with an average difference in correct trials for each item in the test phase of -0.3 for the first participant, -0.2 for the second participant, and +1.1 for the third, compared to the pre-test phase. On the other hand, the children in the control group showed an average difference of -0.1 for the sixth participant, while the values remained the same for the fourth and fifth participants. It is important to note that the values for Participants 2, 4, 5, and 6 were equal to the minimum required trials for reaching the criterion (values = 3), indicating that they immediately understood the instruction and correctly learned the command in all the proposed trials.

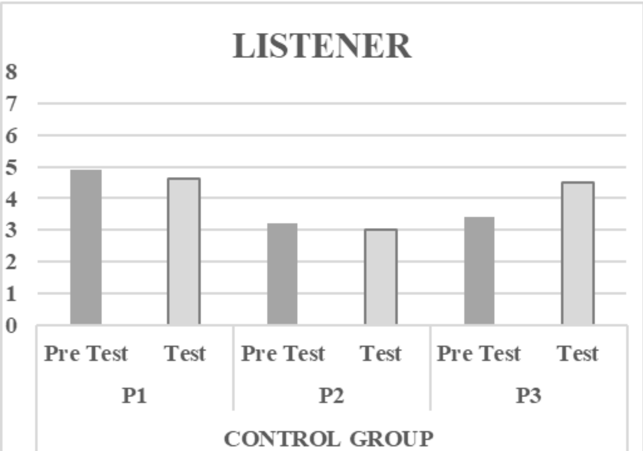

Figure 3.a *Control Group: comparison of Listener trials Pre Test and Test*

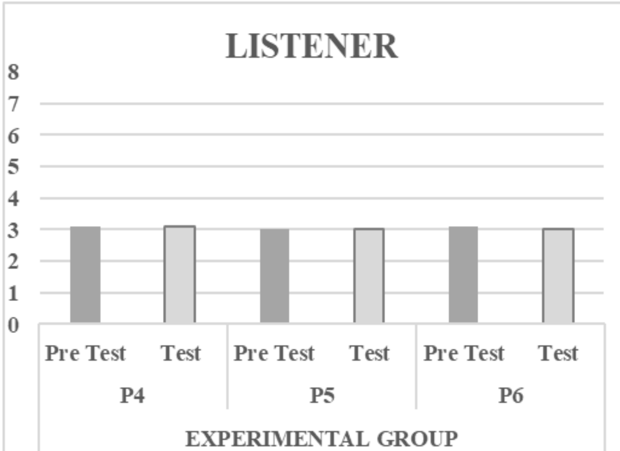

Figure 3.b *Experimental Group: comparison of Listener trials Pre Test and Test*

Figures 4.a and 4.b show the values for the dependent variable related to visual-perceptive skills, "VPMTS,". For the control group, the average difference incorrect trials for each item in the test phase is +0.2 for Participant 1 and -0.1 for Participants 2 and 3. In the experimental group, the difference in the test phase is -1.1 for Participant 4, -1.3 for Participant 5, and +0.3 for Participant 6 (*who reached the minimum value of trials for mastering the criterion).

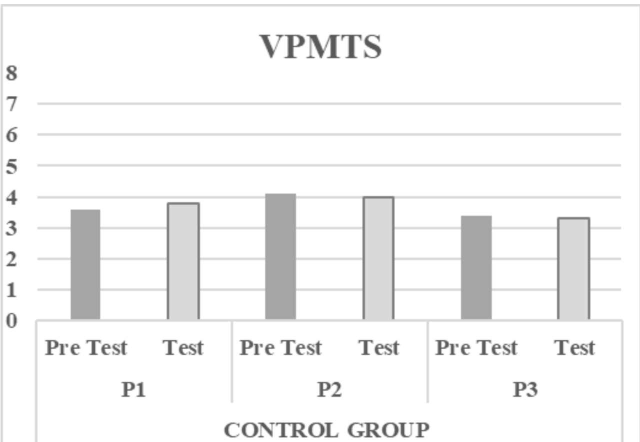

Figure 4.a *Control Group: comparison of VPMTS trials Pre Test and Test*

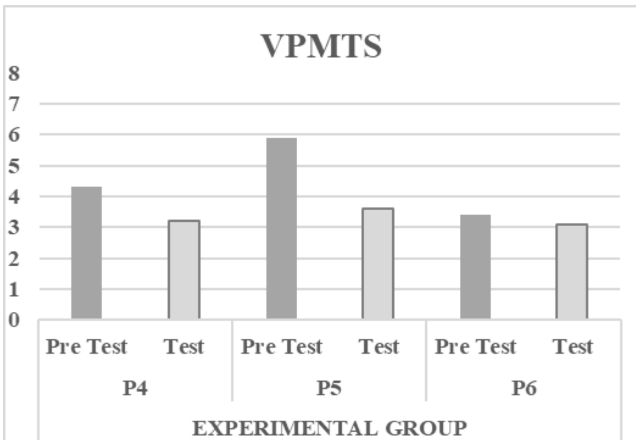

Figure 4.b *Experimental Group: comparison of VPMTS trials Pre Test and Test*

Figures 5.a and 5.b present the values for the dependent variable related to imitation skills. For the control group participants, the average difference in trials for each item in the test phase is +0.2 for Participant 1, -0.3 for Participant 2, and -0.2 for Participant 3 compared to the pre-test phase. Meanwhile, in the experimental group, the difference in the test phase is +0.3 for Participant 4, +0.4 for Participant 5, and -0.1 for Participant 6. The minimum criterion for acquisition is 3 trials per item, which equals 30 trials per phase (pre-test and test).

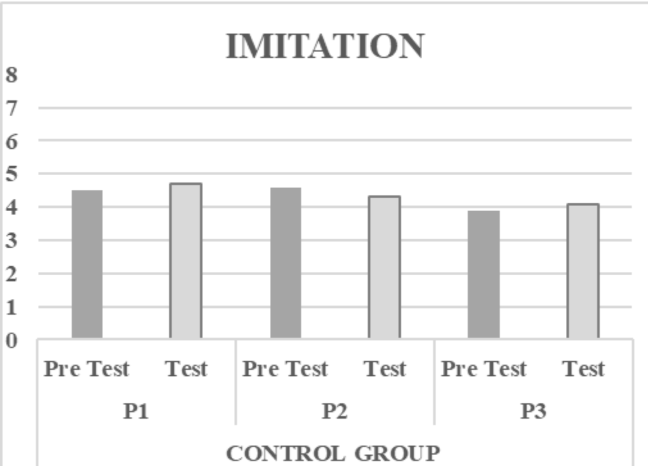

Figure 5.a *Control Group: comparison of Imitation trials Pre Test and Test*

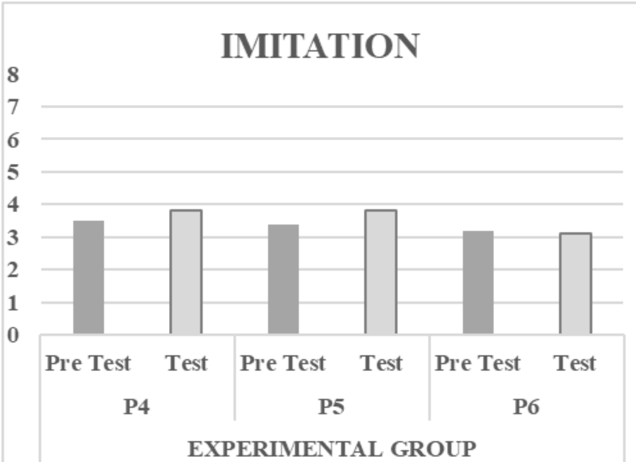

Figure 5.b *Experimental Group: comparison of Imitation trials Pre Test and Test*

Discussion

The study aimed to investigate the effects of robot-mediated interventions within ABA-based habilitative programs for children with ASD aged 3 to 6 years, focusing on echoic, Tact, and listener responses, visuoperceptual abilities, and imitation. The primary objective was to determine whether using robotics in habilitative interventions reduces the number of trials required to reach the acquisition criterion for an item.

In the tests on the echoic, tact, visuoperceptual, and listener variables, the control group showed sufficiently homogeneous values between the pre-test and post-test phases, with only a minimal decrease. However, the data from the experimental group's test sessions indicate that all three participants significantly reduced the number of trials in the echoic and Tact variables. This suggests a functional relationship between using robotics as a mediator and the speed of learning new items. The results also show that, concerning visuoperceptual items, two out of three participants in the control group experienced a significant decrease in the number of trials required to meet the acquisition criterion. The third participant also showed a decline that brought them closer to the minimum trials threshold. According to these results, the relationship between the use of robotics and the reduction in trials required for criterion achievement may be functional even for this skill.

No significant differences were observed regarding the listener variable, as participants had already reached the maximum learning speed in the pre-test phase. Consequently, it was impossible to observe a functional relationship between the use of the robot and the speed of criterion acquisition.

In the data related to the speed of learning imitation items, contrary to findings reported in the examined literature, the experimental group showed an increase in trials, although this was not highly significant compared to the control group. A more specific qualitative analysis of the items used (five items involving imitation of non-communicative movements and five items involving imitation of communicative movements – such as waving, blowing a kiss, clapping, hands in front of eyes, and raising one arm in celebration) revealed that, qualitatively, participants were more motivated by the imitation of movements related to communication than by the decontextualized movements of simple imitation. Furthermore, the robot's mechanical movements seemed significantly slower than the child's.

It is suggested that this item be further investigated by modifying the timing of the robot's movements and the latency between the movement and the instruction provided by the robot. This observation, which is currently qualitative, may also open up a new research opportunity involving the use of robotics in learning communicative pragmatic gestures and patterns.

The present study has several limitations. First, the small sample size restricts the generalizability of the findings. Additionally, the lack of an initial, detailed investigation of latency times in the imitation task limits a deeper understanding of the temporal dynamics involved in the intervention. Future studies should aim to include larger and more heterogeneous samples to enhance external validity. They should incorporate precise measures of response latency better to explore its role in imitation and treatment efficacy.

A further limitation concerns the non-random assignment of participants to the experimental and control groups. We determined group allocation by organizational and contextual factors, such as family preferences and scheduling constraints, rather than through randomization. Although the groups were balanced based on VB-MAPP profiles, this method introduces potential bias and may compromise internal validity.

Finally, the study did not include statistical analyses to assess the significance of differences observed between groups. Future research should incorporate appropriate inferential tests to strengthen the interpretation of results and support the robustness of conclusions.

Conclusion

The findings of this study support the initial hypothesis that integrating robotics into ABA-based habilitative programs may enhance learning efficiency in children with ASD. Specifically, the intervention was associated with a reduction in the number of trials required to reach criterion in echoic, tact, and visual-perceptual skills. These outcomes suggest that robotics, when used as mediators, may function as effective antecedents or reinforcing stimuli within behavior-analytic procedures, aligning with ABA principles that aim to increase socially significant behaviors through evidence-based strategies.

While these findings are promising, future studies with larger and more diverse samples are needed to assess the replicability of these effects and better explore the generalization of learning outcomes. Further investigation into the impact of robot-mediated interventions on other verbal operants and functional skills would also contribute to refining their educational and therapeutic applications.

Additionally, research could examine whether robotics can enhance motivation, engagement, and generalization across contexts — elements central to ABA-based interventions. Given that ABA relies on individualized instruction, consistent reinforcement, and data-driven decision-making, the integration of robotics may provide a valuable complement to traditional human-delivered teaching, especially in early habilitation programs.

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Declaration of Interest statement

Declarations of interest: none

Authors' contribution

All authors contributed to and have approved the final manuscript.

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