Receptive Language Development Intervention and Assessment in Conversational Interactions with QTrobot for Autism

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Abstract

Delays in language development in early childhood are usually the first hints that motivate parents to initiate autism diagnostics. While expressive language can be easily observed, assessment of receptive language development is more difficult and prone to misjudgement. Robot-assisted autism interventions offer a potential solution. This article describes the results of long-term use of QTrobot for autism at home by multiple families. The setup is non-experimental and thus, the results are ecologically valid. The results of this exploratory analysis show that playful interactions with QTrobot for autism help to perform a more accurate assessment of the child's receptive vocabulary. The results also suggest that QTrobot for autism supports autistic children in receptive language learning.

1 Introduction

Language development delays are frequently a key concern for parents seeking a diagnosis related to neurodevelopmental disorders such as Autism (Gernsbacher et al., 2016). It has been shown that improving communication skill of autistic children can improve their long-term prognosis and improve their chances for independent living and skill acquisition in other areas of development (Hendricks, 2010; Gray et al., 2014). Hence, improving their child's communication abilities is one of the primary goals for parents seeking support.

Numerous studies indicate that autistic children experience delays in both expressive (language production) and receptive (language comprehension) language skills (Gernsbacher et al., 2016). They tend to have a smaller vocabulary and struggle with understanding and using language effectively. Speech therapy can improve language development, but it is expensive and sometimes inaccessible for families. In addition, inaccurate evaluation of the child's language leads to resource overuse in terms of budget and time.

While it is observable which words a child can say, personalized interventions targeting receptive language skills can pose challenges due to assessment accuracy in which parents become a proxy to evaluate their children's language skills using tools like the MacArthur Bates (Luyster et al., 2007) or Vineland Adaptive Behavior Scales (VABS) assessments (Sparrow and Cicchetti, 1989). However, studies indicate that parents frequently misjudge their child's receptive language skills (Feldman et al., 2000; Akhtar and Gernsbacher, 2007). Further challenges for assessment of receptive language skills include difficulties to differentiate between lack of skills and lack of motivation and long waiting periods for professional assessment.

To overcome these barriers in assessment and to support autistic children in developing better receptive language skills, one effective approach is to involve and empower parents in interventions. Numerous approaches focus on educating parents to deliver parent-led interventions, such as parent-driven Early Start Denver Model (P-ESDM) (Abouzeid et al., 2020), which emphasizes supporting parents to bridge the gap in accessibility of autism interventions. However, parent-led interventions often necessitate professional-led training, supervision, and significant effort from parents to be effective, particularly in enhancing children's receptive language development skills.

Robot-assisted interventions represent a relatively new field that aims to enhance the accessibility, evidence-based nature, and reliability of standard interventions (Salimi et al., 2021; Kouroupa et al., 2022). These interventions can effectively support parents in contributing to their child's education with reduced effort and improved outcomes. QTrobot for autism is one such technology.

The objective of this article is to evaluate the outcome of the QTRobot for Autism in receptive language assessment at the start of its use as compared to parents' judgement, and the receptive lan-

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guage skill development after $6 - 12$ months of use by five families who were Beta-testers of the platform. The next section describes QTrobot for Autism curriculum including the method for receptive language development. Further, we explain the data and present the analysis results regarding receptive language assessment and development in the selected user's population. Finally, we draw conclusions and outline future research directions.

2 QTrobot for Autism

QTrobot for Autism incorporates a humanoid, expressive robot programmed with a curriculum with over 400 activities targeting various skill areas, including social, emotional, self-regulation and cognitive skills, and receptive and expressive language development. The curriculum is based on neurodevelopmental milestones in pediatrics and integrates evidence-based methods such as social narratives, Discrete Trial Training, prompting, reinforcement, visual supports, and video modeling. Each milestone is used as a unique unit, practicing the tasks that help the child to achieve that milestone. For example, a 2-years old child is expected to be able to point to minimum 2 body parts when they are named, therefore the curriculum includes a unit focused on identification of body parts in it's level 2 covering the developmental age of 12 to 24 months.

2.1 Skill Assessment at Baseline

At start, parents are asked to complete a placement quiz and conservatively rank their child's skills from 1 (the child cannot do that) to 3 (the child can always do this). Based on the quiz results, a set of educational activities is suggested as the starting point in the curriculum. Conservative ranking ensures that areas of doubt are evaluated later using the robot. This approach minimizes the risk of overlooking early developmental milestones. Examples of assessment units are: "My child can point to a particular color if I name it" and "My child can discriminate between big and small items, when presented in real life or in pictures".

2.2 QTrobot Curriculum Use Procedure

During each session, parents use the Educator tablet to select the activities identified through the parent quiz. The robot then leads the activity, providing instructions, age-appropriate questions, and visual stimuli to support learning. For receptive language skills, the robot presents stimuli on the Learner tablet, and the child responds by selecting provided options. Figure 1 shows the triadic set-up of the interaction.

Figure 1: The triadic setup in interactions with QTrobot for Autism: Child, parent and robot.

In case of a corrrect response, the robot provides positive feedback using facial expressions, gestures, and language. If the response is incorrect, the robot provides structured prompts to help the child find the correct answer, then presenting a distractor trial using the skills from lower developmental age, followed by a repetition of the original question. Structured prompting ensures systematic teaching and prevents trial-and-error learning, while the error correction procedure without negative feedback ensures that challenging instructions are reinforced after the child successfully responds with guidance. Once a skill has been practiced with over 90% success rate for three consecutive practices, the robot marks it as mastered, prompting parents to introduce a new skill from the same category. The robot collects data on task performance in a privacy-preserving way, and maintains a record of each child's progress. These data serve as a reliable source for objective evaluation, i.e. in assessing the child's receptive language repertoire.

As part of the intervention, parents receive training sessions, support calls, video and written resources and instructions on how to create additional practice opportunities outside of robot interactions, helping their children generalize skills to natural environments and maintain acquired skills over time.

2.3 Receptive Language Curriculum

Also in the receptive language curriculum, each unit is connected to one particular developmental

milestone in terms of how language is developed in neurotypical children. For example, at certain points in the development, experts in language development expect children to understand certain words, adjectives, prepositions and verb-noun combinations. We have used these developmental milestones as the guideline for the curriculum units and tasks and in the placement questionnaires. Using this method of arrangement of units, we can create an individual educational plan for each child.

QTrobot supports receptive language development in several ways. Direct interaction with QTrobot and practicing receptive language questions improves a child's language comprehension. Second, parents learn how structured receptive language training is organized and delivered, and how to replicate them without the robot. In addition, by observing the robot sessions and participating actively in them, parents are informed about their child's receptive language ability. In this way, parents are better informed when it comes to answering parental questionnaires to evaluate a child's receptive language ability.

3 Procedure and Results

To evaluate the expected impact, an exploratory post market analysis has been conducted on five families who purchased the robot in 2021 as Beta-testers, when QTrobot for Autism was released for parents for the first time. All on-boarded families already received therapy for their children. The minimum physical age of children was 4 and the maximum was 11 years, and the developmental age of 18-24 months. We use the single subject study method evaluating the progress of each child based on their baseline when starting the intervention according to their parents ranking of receptive language in the placement quiz. The goals during the Beta-testing phase, in which families were granted free of charge use of QTrobot for six months, included

1. Feasibility evaluation of at home implementation of robot-assisted interventions;
2. Parents ability to follow instructions and deliver the intervention with fidelity;
3. Monitoring of skill acquisition and generalisation by children;
4. Monitoring for undesired behaviours and any negative side effects related to the robot;
5. Monitoring the long-term effectiveness after the novelty effect decreases.

ID	Av. Q	Av. RL Q
P01	398	122
P01	423	116
P03	1071	237
P04	579	188
P05	454	152
TT	585	163

Table 1: ID: learner ID; Av. T Q: monthly average number of non-unique questions played by the earner from the entire curriculum; Av. RL Q: monthly average number of receptive language questions played. Last row: total average over selected learners.

In addition to these set goals, the platform enabled a more accurate assessment of language development by both robot and parents, as our analysis here shows.

We evaluated of the data collected by the robot from the sessions with children conducted by their parents at home. In addition, video statements submitted by parents after a duration of use between 6 and 12 months, have been used to evaluate parents perception of impact on various levels. Appendix A provides links to the videos.

The total use of QTrobot for each family was more than 12 months. Each unit includes eight questions which can be repeated if a child cannot reply correctly and independently for the first time, according the the methodology explained in Sec. 2.2. Table 1 shows average use of QTrobot curriculum and receptive language curriculum in 2021. The data shows that each family has played in 2021 in average 163 questions of receptive language development per month, and in average 585 questions on all skills, including emotional, social, expressive and cognitive. Because the families followed the methodology described in Section 2, they played more advanced questions after they mastered the preceding ones. By the end of 12 months of use, all five subjects mastered the level 3, and four subjects also mastered level 4. Thus, the developmental age of all the kids in terms of receptive language has evolved to up to 4 years, as compared with the developmental age of about 2 years at start. Figure 2 shows and example of a lerner's answer history. Figure 3 shows how a learner's success can be measured over time.

In addition to the learner data, video reports from parents were analyzed and annotated according to three categories: ease of use, effectiveness on child's learning from parents perspective and ef-

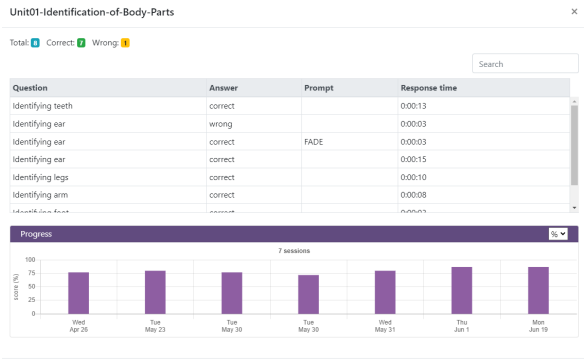

Figure 2: A learner answers a question with error. The question is simplified. The answer is then correct. The material is rehearsed.

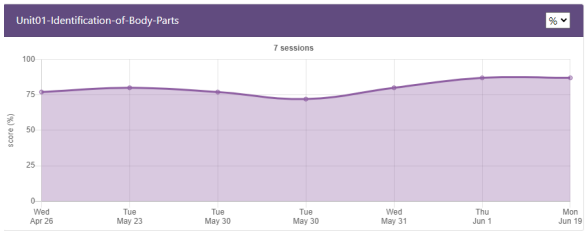

Figure 3: Skill development with QTrobot over time.

fectiveness on improving parents knowledge of the child's developments.

We found evidence in our data confirming earlier findings in literature that parents tend to misjudge their children's receptive language skills (Feldman et al., 2000; Akhtar and Gernsbacher, 2007). For example, one of the parents mentions in the video that she thought that her child is already good at understanding words, but she followed the recommendation from LuxAI team to start with earlier levels of curriculum, and realized that the child's actual developmental level in receptive language was actually lower.

The analysis of the data and the parents videos with respect to the receptive language development shows that:

1) All children have mastered receptive language skills, showing progress compared to their baseline evaluation. We can conclude that children can learn effectively from the robot, and they can show progress in terms of increased developmental age in receptive language development area.

2) The robot can generate reliable data related to the children's receptive language ability, which can be used for intervention planning.

3) Parents tend to misjudge their child's receptive language skills (over- and underestimation).

4) By involving parents in the sessions and allowing them to observe their children in concrete language tasks, they would be able to have a more accurate understanding of their child's strengths and weaknesses and therefore they can be a more reliable proxy for evaluation of the child's language for purposes such as intervention planning.

All parents found the robot effective in supporting them to deliver interventions and in gaining a deeper knowledge about their child's educational and developmental status.

4 Conclusions and Future Work

This article focused on receptive language assessment and development in autistic children, and presented the results of non-experimental long-term Beta-use of QTrobot for Autism in families. Data collected by the robot from sessions with children and customer feedback videos have shown that even parents without technical backgrounds can easily utilize the robot at home to provide structured interventions and support their child's development. Beyond its educational role, parents have reported that QTrobot indirectly enhances their knowledge of their child's developmental progress and increases their understanding of evidence-based interventions for receptive language skills. By observing their child's performance in each task and witnessing how the robot delivers simple instructions, reinforcement, and structured prompts, parents gain valuable insights. Consequently, QTrobot empowers parents, enabling them to reliably participate as proxies in assessments by better understanding their child's strengths and needs.

Additionally, QTrobot provides reporting and progress monitoring features, capturing data on task performance and maintaining a record of each child's progress. This data serves as a reliable source for objective evaluation, such as assessing a child's receptive language repertoire. Professionals and speech therapists can use this information to accurately evaluate a child for individually tailored interventions. Even though that the robot is still expensive, it is far more affordable and accessible solution than speech therapy and it can bring several added benefits including improving parents ability to teach speech/communication skills, developing a better understanding of the child's ability and perform better as a proxy, and as a consequence, minimizing inaccurate resource allocation caused by imprecise evaluation for the child.

However, there are certain limitations to consider regarding the interventions provided by QTrobot for autism, as well as the presentation of data to parents and professionals. Currently, QTrobot employs a set of stimuli designed to address specific areas of receptive language development, randomly presenting eight stimuli during each activity session. To enhance effectiveness, future iterations should aim to develop an automated recommendation system that considers each child's previous performance to select more relevant stimuli to further individualize the educational interaction. For instance, in an activity focused on discrimination of size adjectives, the algorithm could prioritize presenting more stimuli related to identifying small items if a child struggles in that area.

Furthermore, the robot currently presents data in the form of the percentage of correctly answered questions during interactions, generating progress reports based on this percentage. It also provides detailed reports that include the stimuli presented to the child and their responses. While this enables evaluation of a child's receptive language skills and creates profiles of nouns, verbs, adjectives, and prepositions they comprehend accurately, it would be advantageous to align QTrobot's data reporting with standardized language assessment tools commonly used in speech therapy and other interventions. The manufacturer plans to conduct clinical studies aiming at direct evaluation of child language using standardized language development tests and develop an algorithm that maps QTrobot's raw data to these standardized measures.

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Limitations

The results described in this article come from a non-experimental setup and need further validation in a clinical study.

Ethics Statement

The data used for this article were obtained and analysed with informed consent based on the QTrobot for autism terms of use and a separate agreement with the parents.

A Parents' Reports

https://youtu.be/ufJI2rnCAxE
https://youtu.be/DwLBI5vtuC0
https://youtu.be/f8RURWsANbI
https://youtu.be/jgspU4QV_7M
https://youtu.be/Lhzx9qo4sN4