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# Improving the social communication skills of preschoolers with autism spectrum disorder: robot-based intervention on Picture Exchange Communication System use

Shumeng Hou<sup>a</sup>, Pengpeng Cai<sup>a</sup>, Lingling Yu<sup>b</sup>, He Cui<sup>b</sup>, Jiajia Hu<sup>b</sup> and Zhen Wei<sup>b</sup>

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## ABSTRACT

**Objectives:** Children diagnosed with autism spectrum disorder (ASD) often exhibit challenges in social communication. Picture Exchange Communication System (PECS) is effective in enhancing the social skills of children with ASD, and interventions using social robots are potentially beneficial training tools. However, it is uncertain whether robots can facilitate more effective training for children with ASD compared to human therapists.

**Methods:** In the present study, we compared the effectiveness of robot-based and human-based interventions on enhancing the social communication behaviors in young children diagnosed with ASD. The feasibility and efficacy of integrating the PECS in robotic systems were evaluated using a single-case design. Eight children with ASD were randomly assigned to either a robot-based group ( $N=4$ ) or a human-based group ( $N=4$ ). Participants in the two groups underwent phases I–III of the PECS protocol facilitated by either a human therapist or a robot therapist. Changes in social communication behaviors were assessed in each child after intervention using a single-case design.

**Results:** Half of the participants in the robot-based intervention group showed significant improvement in both verbal and nonverbal communication behaviors after a two-month PECS intervention. A higher proportion of children in the robot-based intervention group showed significantly enhanced social communication skills encompassing both verbal and nonverbal behaviors than in the human-based intervention group.

**Conclusions:** This study demonstrates the effectiveness of robot-based PECS intervention in enhancing verbal and nonverbal communication behaviors in young children with ASD. These findings present novel intervention tools for early intervention educators engaged in supporting children with ASD.

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## KEYWORDS

Children with ASD; PECS;  
robot-based intervention;  
human-based intervention

## Introduction

### **Impairment of social communication skills in children with ASD**

Autism spectrum disorder (ASD) is the most prevalent and rapidly increasing developmental disability (Alakhzami and Huang 2023; Dunlap and Filipek 2020). The Centers for Disease Control and Prevention (CDC) of America reports that approximately 1 in 54 children in the U.S. have been identified with ASD (Centers for Disease Control and Prevention 2020). Global incidence estimates indicate that approximately 3–5 million children in China are diagnosed with ASD (Zhou, Ma, and Wang 2022). Children with ASD typically exhibit two main

symptoms: persistent challenges in social communication and interaction, and engaging in restricted and repetitive behaviors (American Psychiatric Association 2013).

The diagnostic and statistical manual of mental disorders – 5th edition (DSM-5) highlights social communication deficits as a key symptom of ASD. DSM-5 categorizes the social communication impairments into three severity levels: Level 1, where individuals require support due to difficulties in initiating interactions and often display atypical responses to others; Level 2, marked by significant verbal and nonverbal communication impairments even with support; and Level 3, characterized by severe communication impairments that significantly affect daily functioning (American

Psychiatric Association 2013). Numerous studies indicated that subsets of children with ASD, particularly those with Level-2 and Level-3 severity of social communication deficits, may encounter behavioral and social challenges due to communication variations (Bhat 2021; Christensen and Zubler 2020; O'Keeffe and McNally 2023). Therefore, it is imperative to develop effective techniques to enhance the communication skills of children with ASD at an early age to ensure long-lasting and significant impact on their lives (Fletcher-Watson et al. 2016; Silvera-Tawil, Bradford, and Roberts-Yates 2018).

### ***Intervention of the PECS on social communication skills for young children with ASD***

Extensive research has been conducted to explore intervention strategies for enhancing the social communication skills of children with ASD, especially at an early age. Recent research has demonstrated the significant impact of the Picture Exchange Communication System (PECS) in addressing the communication deficits in children with ASD. The PECS developed by Frost and Bondy (2002), is a structured communication system based on picture exchange, initially designed to aid with limited spoken language or communication skills in initiating requests. The PECS is widely used in early interventions for children with ASD and other developmental disabilities characterized by severe delays in language development and impairments in social communication skills. The PECS has six phases designed to train individuals on communicating using pictures (Flippin, Reszka, and Watson 2010). In Phase I, children are trained to present a picture representing something they desire to a communication partner in exchange for the corresponding item. Phase II involves advancing the difficulty levels by requiring the children to exchange pictures from a distance. In Phase III, children are taught to distinguish between pictures of preferred and nonpreferred items, enabling them to independently exchange multiple pictures with a communication partner. In Phase IV, children learn to construct a simple sentence using an 'I want' card and a corresponding picture. Phases V and VI involve teaching children how to use the PECS to respond to questions such as requesting an item or labeling objects they observe (Cummings, Carr, and LeBlanc 2012).

Recent studies have consistently demonstrated the effectiveness of PECS in enhancing both verbal and nonverbal communication skills for young children with ASD at an early age (Bateman et al. 2023; Kruger 2022; Safi, Alshamsi, and Opoku 2022). Some

studies have highlighted the efficacy of PECS implementation in enhancing social interactions and vocal speech, even in children with limited verbal skills (Daniolou, Pandis, and Znoj 2022; Greenberg, Tomaino, and Charlop 2014; Paden et al. 2012). Previous findings indicate that the PECS is effective and appropriate for children with ASD at an early age or for those with limited verbal abilities during social interactions (Ganz et al. 2012; Lerna et al. 2014; White et al. 2021).

### ***Application of the PECS in human-computer interactive systems***

Several traditional interventions are being adapted to repeatable, user-friendly, and easily accessible human-computer interactive systems owing to advances in artificial intelligence technology. The integration robotics and digital devices in human-computer interactive systems can simplify and improve the efficiency of operating the PECS (Hasan, Islam, and Choudhury 2023). The conventional PECS relies on compiling pictures, photographs, words, sign language and gestures, which can be time-consuming and labor-intensive (Barnes et al. 2021; Khowaja and Salim 2013). Therefore, human-computer interactive systems offer a more efficient approach for repetitive practice while reducing the manpower, time, and costs (McCoy and McNaughton 2019). In addition, researchers have proposed that electronically implementing the PECS could be an effective communication method for children with ASD, given its intrinsic simplicity, reduced demands, built-in reinforcers, and adaptability (Syriopoulou-Delli and Gkiolnta 2022). Previous research demonstrated the feasibility of designing PECS applications using augmented reality (AR) or other advanced technologies to enhance communication skills in children with ASD (Astalini et al. 2018; Taryadi and Widiyono 2018). A recent study proposed that adapting the PECS into the Kaspar robot makes it easier to record the preferred rewards of children with ASD compared to traditional interventions (Syrdal et al. 2020).

### ***Application of intervention and education programs in social robotic systems for children with ASD***

Several artificial intelligence techniques, such as social robots, have been developed to enhance communication skills in children with ASD. Although previous studies report that children with ASD face challenges

when interacting with humans (Anzalone et al. 2014), recent studies indicate that children with ASD are attracted to social robots. These studies demonstrated that children with ASD exhibit specific positive social behaviors during interactions with robots that are not typically observed during interactions with peers, caregivers, and therapists (Amirova, CohenMiller, and Sandygulova 2022; Arent et al. 2022). Children with ASD are more inclined to engage in activities involving robots than typically developing children (TD) (Costescu, Vanderborght, and David 2015; So et al. 2020). This preference can be attributed to the perception of robots as being more secure and manageable than humans by children with ASD (Dautenhahn and Werry 2004; Huijnen et al. 2019). A recent study using functional near-infrared spectroscopy indicated that fewer selective attention resources are required when children with ASD interact with robots than when they interact with humans. This could be due to improved understanding of communication with robots compared to humans (Hou et al. 2022).

Interventions or educational programs implemented with social robots can offer distinctively attractive social cues for children with ASD through standardized interactions compared to the conventional human-based interventions (So et al. 2020; Soares et al. 2019). This approach guarantees operational simplicity, which is a crucial factor for the engagement of children (Bharatharaj et al. 2017). The replicability of a social robot is advantageous for children with ASD, as it allows for the necessary repetitive practice of social skills in a controlled and predictable manner, leading to significant improvements in training joint attention and verbal communication (Taheri et al. 2018). Furthermore, the versatility of social robots enables them to be tailored to a various therapeutic and educational settings, meeting the evolving needs of children with ASD as their skills progress (Cabibihan et al. 2013). As a result, social robots have become a promising tool for enhancing the treatment and education of children with ASD to cultivate complex social skills (Soares et al. 2019). Limited research has been conducted to evaluate the feasibility of using social robots to train social interactive behaviors in children with ASD (Cabibihan et al. 2013; Dewey, Cantell, and Crawford 2007). Ghiglino et al. (2021) observed significant improvements in behavioral requests, responses, joint attention, and both verbal and nonverbal communication skills following robot-based interventions. However, the efficacy of robot-based interventions compared to human-based intervention has not been

fully elucidated. Most previous studies only compared the effects before and after robot-based intervention, without including a human-based intervention group for comparative analysis (Ghiglino et al. 2021). In addition, studies on use of robot-based PECS intervention for children with ASD, especially in young children, are limited. Consequently, the superiority of PECS application in social robots over other modalities (e.g. human-based intervention) in young children with ASD remains unclear.

### **This study**

In recent decades, several studies explored the feasibility and effectiveness of various interventions for improving communication skills in children with ASD. However, as artificial intelligence techniques evolve, researchers should assess whether interventions based on human-computer interactive systems have equal or superior effects in young children with ASD compared to conventional intervention methods. Researchers often use the single-case design to assess interventions or treatments for special groups such as children with ASD, comparing performance across different study phases (Desideri et al. 2018; Maggin et al. 2014; Ray 2015). The present study comprised two groups: one receiving intervention from a human therapist and the other from robots. In this study, we used a single-case design analysis to evaluate the intervention effects in each group and compared the differences between the two groups.

This study aimed to address two research questions. Firstly, using a single-case design, we explored whether robot-based interventions can effectively enhance the social and communicative abilities of children with ASD from a longitudinal perspective using a single-case design. We hypothesized that social communication behaviors would be improved after robot-based intervention. Secondly, adopting a group comparison design, we assessed whether robot-based interventions are as effective as or more effective than human-based interventions. The hypothesis for this section was that the robot-based intervention would significantly enhance the communicative abilities of children with ASD compared to the human-based intervention. Additionally, we sought to explore the feasibility and effectiveness of implementing traditional intervention techniques such as the PECS into social robot-based interventions.

## Methods

### Participants

Eight children with ASD, including six males and two females, were recruited from Shenzhen Maternity & Child Healthcare Hospital, China. The participants were randomly and evenly assigned to the robot-based intervention group and the human-based intervention group. The inclusion criteria for the participants in this study were as follows: (1) aged between 4 and 6, (2) a Childhood Autism Rating Scale (CARS) score above 30, and (3) meet the criteria outlined in the Autism Diagnostic Observation Schedule, 2nd Edition (ADOS-2), Modules 1 and 2, including a total score  $\geq 12$ , a communication score  $\geq 4$ , and a social interaction score  $\geq 7$ . [Tables 1](#) and [2](#) showed the demographic and basic information of participants in robot-based and human-based intervention group.

### Research design and measurements

Single-case design and group compression between robot-based intervention and human-based intervention were adopted to answer the research questions. The effectiveness of treatment within each group was evaluated using a single-case design ([Desideri et al. 2018](#); [Hersen 1990](#)). In the present study, the verbal and non-verbal communicative behaviors of the participants were recorded during a free-play task after each intervention. The communicative performance for each participant was subsequently coded and compared during the post-intervention free-play sessions to assess the changes before and after intervention program. In addition, we compared the differences in social communication behaviors of children with ASD between the robot-based and human-based intervention groups.

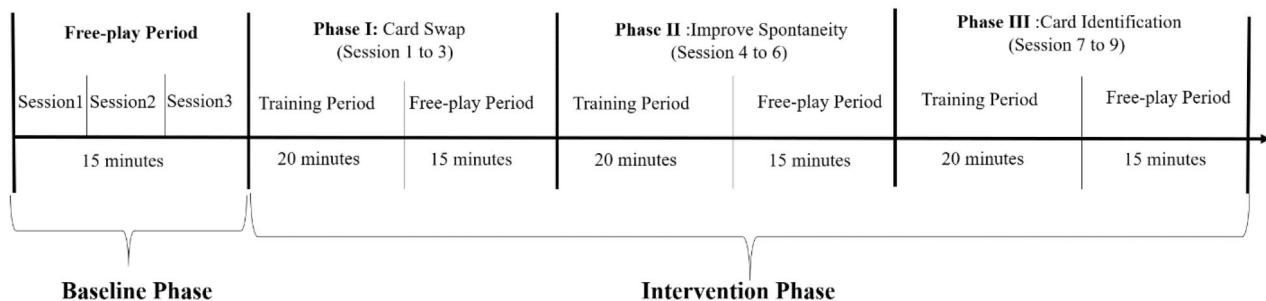
All interventions were conducted in treatment rooms at a Child Health Hospital equipped with a robot and a camera. Children's social communicative behaviors were observed and videotaped during the baseline phase session and the nine intervention sessions (three for the respective phase). Verbal and nonverbal communication behaviors were coded based on the videos to answer the research questions. The verbal communication behaviors were presented as words or sentences that describe the tasks, whereas the nonverbal communication behaviors comprised the use of facial expressions and gestures to communicate with others (such as using fingers, nodding, and shaking the head).

The Wizard of Oz (WOZ) model was used to explore the interaction between the robot and the participants. The WOZ technique involves simulating the functionality of a system or interface for the user, typically in research or usability testing scenarios, while keeping the manipulations of the system in the background ([Sequeira et al. 2016](#)). In the WOZ method, an experimenter assumes the role of the system while manipulating the interactions with the user to give an impression of a fully functional system ([Sequeira et al. 2016](#)). The participants were unaware that a human expert controlled the system instead of a computer program ([Sequeira et al. 2016](#)). In this study, a therapist acted as the expert hidden from the participants' view in a separate location. The therapist observed the participants' behaviors and responses and then controlled the robot.

### Procedures

The participants with ASD were assigned into the robot-based intervention group or the human-based intervention group. The procedures in the two intervention groups were conducted for two months according to the first three phases of the PECS ([Cummings, Carr, and LeBlanc 2012](#)). During the procedures for the two intervention conditions, children with ASD received training in verbal and nonverbal communication interactions consistent with the first three phases of the PECS ([Frost and Bondy 2002](#)).

All the procedures included a baseline phase and an intervention phase, adhering to the protocol outlined in the PECS training manual ([Frost and Bondy 2002](#)). The baseline phase included three sessions. Each session lasted 15 min and corresponded to a free-play period. During the 15 min' free-play period in each baseline session, unobtrusive observations were conducted to assess the communication behaviors of the participants before the intervention. The intervention phase included nine sessions. Each session included a training period lasting approximately 20 min and a free-play period lasting 15 min. The training periods covered Phase I to Phase III as outlined in the PECS training manual. Researchers evaluated the individual reinforcers that could stimulate the communication behaviors of the participants ([Frost and Bondy 2002](#)). These reinforcers were used during the training periods to induce the communication behaviors of each child. In the 15-minute free-play period following each training period, children's communication behaviors were assessed ([Figure 1](#)).



**Figure 1.** The procedure for baseline and intervention session.

Children with ASD interacted with a robot therapist or a human therapist in a therapy room. Throughout each respective phase, a research assistant was positioned behind the participants in the two intervention groups to assist and ensure their safety. The research assistant did not administer the intervention.

### **Free-play**

The communication behaviors of the participants were observed and assessed during the baseline and the intervention sessions through free play. Children with ASD and their caregivers engaged in play activities in a room equipped with various toys. The children were free to move around the room, choose their preferred activities and toys, and play with their caregivers. The communication behaviors of children with ASD during free-play observation during the baseline and intervention sessions were recorded through videotaping. The verbal and nonverbal communicative behaviors of the participants were recorded using a wide-angle camera. Subsequently, the verbal and non-verbal communicative behaviors recorded during the baseline session and each post-intervention free-play task were coded and analyzed based on the videotapes.

### **Procedures for Phase I of the PECS**

Phase I primarily comprised physical exchange training as indicated in the protocol outlined in the PECS training manual (Frost and Bondy 2002). Participants were instructed to request their preferred reinforcers from the therapist seated directly beside them by exchanging a picture card. Depending in the intervention group, the therapist was either a robot in the robot-based intervention group or a human therapist in the human-based intervention group. Initially, the participant received assistance from the robot or human therapist to pass the picture card to their preferred reinforcer. Subsequently, the robot or human therapist corrected any errors in the child's movements and offered verbal and nonverbal cues. For instance, after the child handed

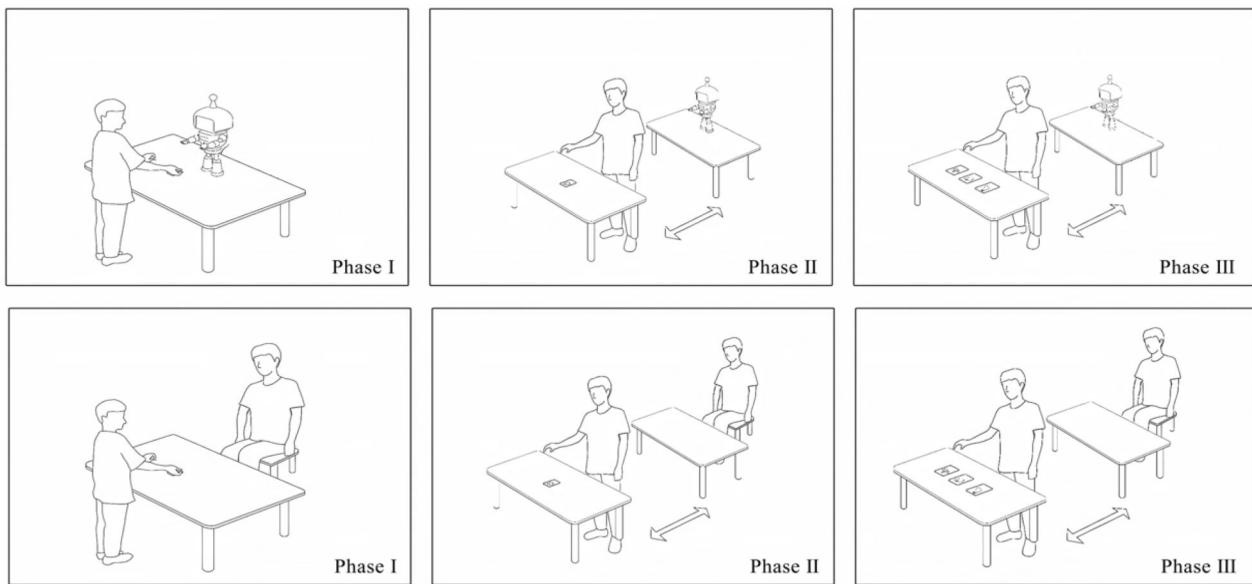
the picture card to the robot or the human therapist, the therapist responded with a verbal statement (e.g. 'Oh! You want letters!') and provided the preferred item to the participant. When the child demonstrated accurate communication behaviors, the robot or human therapist responded with a verbal praise (e.g. 'Great, you have done a good job!') and positive nonverbal gestures (e.g. clapping hands). In instances where the child exhibited incorrect behaviors, the robot or human therapist responded with verbal statements (e.g. 'Please try again') and nonverbal cues (e.g. shaking their head).

### **Procedures for Phase II of the PECS**

Upon successful completion of Phase I, the children progressed to Phase II. In this phase, the participant was instructed to traverse different distances within the room to request a reinforcer from either the robot (in the robot-based intervention group) or human therapist (in the human-based intervention group). A thorough assessment of the children's abilities and the need to balance challenge with achievability was conducted based on methods described in previous studies (Carr and Felce 2007; Ganz et al. 2012). A 2-meter distance was used in the present study to ensure the task presented an appropriate level of challenge to the participating children. The participants would pick a card and present it to the robot or the human therapist for reinforcement. After the card presentation, the therapist praised the child (e.g. You have done a great job!). As the success rate increased, the child was required to extend their reach to hand the card to the therapist. Consequently, the participating child walked a distance of 2 meters before handing the card to either the robot or the human therapist.

### **Procedures for Phase III of the PECS**

Phase III involved increasing the children's ability to differentiate between different picture cards. The number of cards provided to the children was determined by their age. For instance, a child might begin with two cards: one featuring a reinforcement object and the other displaying a significantly different object. Subsequently, the



**Figure 2.** The three phases of interventions used in the robot-based and human-based intervention groups.

participant was prompted to select the correct card and hand it to the therapist. If the child selected the correct card and handed it to the robot or human therapist, the therapist immediately provided verbal responses (such as You have done a great job!) and offered physical praises (e.g. clapping hands) while providing the child with the corresponding reinforcer. In the event of the child selecting the wrong card, the robot or human therapist offered verbal and physical cues to guide the child to choose another card, and the reinforcer was not provided (Figure 2).

#### **Evaluation and coding of children's communicative behaviors**

During the baseline and intervention sessions, all interactions between children and caregivers during the free-play observations were recorded using a wide-angle camera. Three free-play periods in baseline phase as well as the nine free-play periods following the training periods in intervention phase were video-recorded (Figure 1). So, twelve 15-minute video clips for each child were available. As a result, we obtained 96 video clips for the 8 children were included in the study. The 96 video clips were then transcribed by research assistants who were native Mandarin Chinese speakers. Subsequently, two research assistants coded the transcripts. Initially, two coders independently coded the communicative performances in 10 transcripts. Single measures of interclass correlation coefficients were adopted to assess interrater reliability, yielding an ICC of 0.989 ( $p < 0.001$ ). The two coders resolved any discrepancies through

discussion to reach a consensus. Subsequently, each coder independently coded half of the remaining cases (43 transcripts for each coder). The transcripts included analysis of breaths, pauses, and speech dysfluencies such as self-interruptions, corrections, and repetitions. Speech streams were divided into utterances, with each utterance corresponding to a clause. Utterances that included more than one clause joined by a conjunction (e.g. 'and then' (然后) or 'but' (但是) were split into two separate utterances (Hou and So 2017). The number of verbal and non-verbal behaviors exhibited by each child during the free-play task in both the baseline session and each subsequent post-intervention session was recorded. The numbers of verbal and non-verbal behaviors exhibited by each child during the baseline and post-intervention sessions were compared. In addition, the numbers of verbal and non-verbal behaviors exhibited by the children were compared between the robot-based and human-based intervention group.

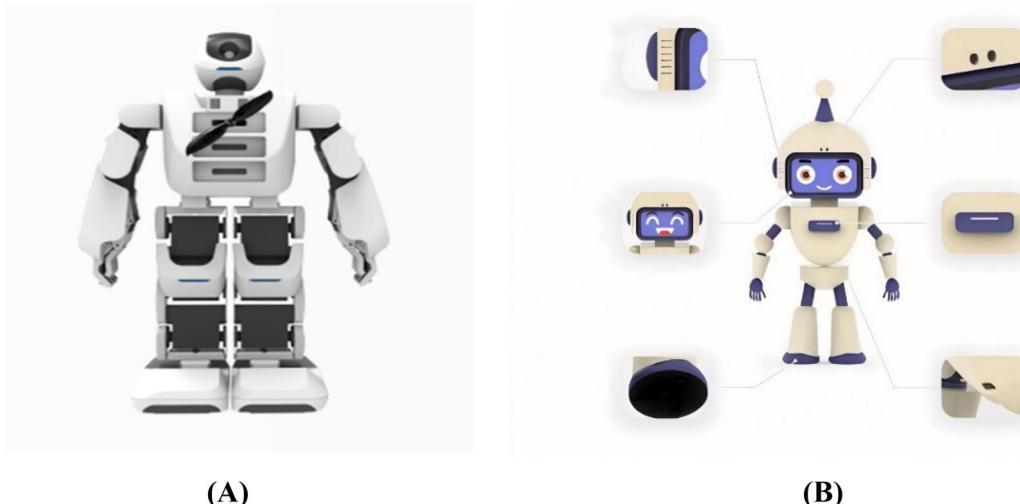
#### **Robot therapist used in the robot-based intervention**

Aelos Pro robot was used as the robot therapist for the robot-based intervention group (LeJu Robot Company, China). The limbs, torso, and head of the Aelos Pro robot collectively have 17 movable joints. Each joint has an independent steering gear capable of achieving a turning angle of nearly 180 degrees. These joints can be adjusted individually and coordinated to work together seamlessly. The corresponding remote-control handle can be customized to suit

different scenarios and execute a wide range of actions (Figure 3(A)). Aelos Pro robot is capable of grasping and moving while carrying out tasks such as receiving picture cards and delivering reinforcements. In addition, the robot has the ability to perform face recognition to identify children with ASD who are positioned in front of it. The robot facilitates natural language interactions based on children's movements, encouraging verbal and nonverbal such as giving a thumb up sign or clapping) interactions in children with ASD, thereby enhancing their motivation.

Additionally, the robot's arm can select gifts for the child to incentivize their performance.

Aelos Pro was redesigned to enhance its appearance and make the interactive function more feasible and favorable. Adjustments were made on the layout and the interactive function of the robot (e.g. the color, materials, sound effect, quality of tone, action feedback, and verbal feedback) based on the feedback provided by 2 therapists, 2 doctors and 6 children with ASD to make it more applicable and feasible for children with ASD (Figure 3(B)).



**Figure 3.** The layout of the Robot Aelos Pro (A) and the redesigned appearance of the robot therapist used in this study (B).

**Table 1.** Robot-based intervention group.

|                         | Case 1  | Case 2  | Case 3   | Case 4  |
|-------------------------|---|---|--|---|
| Age                     | 3 Years old   | 5 Years old   | 2 Years old  | 3 Years old   |
| Gender                  | Male  | Male  | Female   | Male  |
| Nonverbal communication | He rarely expresses thoughts and wishes. He usually expresses intentions through behaviors. He exhibits behaviors such as screaming and crying when he feels uncomfortable. | He does not communicate with others. He has limited nonverbal communication behaviors such as eye gaze. | She does not communicate with others. She rarely has nonverbal communication behaviors and expresses few emotions. | He does not communicate with others. He has limited nonverbal communication behaviors such as eye gaze. |
| Verbal communication    | His verbal expression is poor and unclear. He only uses vague words. There are few oral communication behaviors used in his daily life.                                     | He has very limited verbal communication behaviors, with only slurred speech.                           | She has very limited verbal communication behaviors, with only slurred speech.                                     | He only uses onomatopoeia and does not produce sentences.   |

**Table 2.** Human-based intervention group.

|                         | Case 5  | Case 6  | Case 7   | Case 8  |
|-------------------------|---|---|--|---|
| Age                     | 2 Years old   | 2 Years old   | 5 Years old  | 3 Years old   |
| Gender                  | Male  | Male  | Male   | Female  |
| Nonverbal communication | He conducts nonverbal communication behaviors, such as pushing to express needs, but conducts less proactive communication behaviors. | He can understand most commands and has some communicative behaviors but conducts no nonverbal communication behaviors. | He conducts few nonverbal communication behaviors. | She is able to use nonverbal communication behaviors to express ideas and feelings. |
| Verbal communication    | He has few verbal communications and produces only simple words.  | He has few or no verbal communication behaviors.  | He has few or no verbal communication behaviors.   | She has few verbal communications and produces only simple words.                   |

**Table 3.** Verbal behavior of the robot therapist.

| Verbal pattern     | Content (examples)   |
|--------------------|--|
| Welcome words      | Hello! I'm XX (Name).<br>Let us play a game together!<br>I will play with you!       |
| Introductory words | Oh! You want (e.g. blocks).<br>You like (e.g. blocks).<br>Here you go (e.g. blocks). |
| Encouragement      | You did an awesome job!<br>You tried to do it! Great!<br>You did a great job!        |
| Cueing             | Try again please!<br>Please reconsider.<br>No hurry; take your time.                 |

**Table 4.** Nonverbal behavior of the robot therapist.

| Non-verbal pattern   | Content (examples)                           |
|----------------------|--|
| Welcome              | Waving hand<br>Touching chest                |
| Introductory actions | Holding out a hand<br>Grabbing<br>Applauding |
| Compliments          | Lifting up hands and cheering                |
| Cueing               | Shaking head<br>Clapping head                |

The robot therapist was equipped with various verbal and nonverbal behaviors to facilitate interaction with children with ASD during the PECS. The verbal behaviors provided by the robot therapist are presented in [Table 3](#). The nonverbal behaviors provided by the robot therapist included feedback that accompanied the verbal cues, such as raising the hand, opening the palm, receiving a card, clapping, patting the head, and nodding (see details in [Table 4](#) and [Figure 4](#)).

### **Human therapist in the human-based intervention group**

A pediatrician from Shenzhen Maternity & Child Healthcare Hospital participated in the human-based intervention group worked as a human therapist. The therapist had over 6 years of experience in treating ASD and was proficient in several protocols, such as the PECS and Early Start Denver Model. The therapist played a specific role in the three phases of the PECS in the human-based intervention group, which was identical to the robot-based intervention.

### **Data analysis**

Data analysis comprised visual examination and was conducted using quasistatistical techniques ([Manolov et al. 2016](#)). The frequency of communication behaviors (both verbal and nonverbal behavior) across the conditions were compared. C statistic was used in the preliminary analysis of the data. This method involves time series

analysis to detect any systematic deviations from random variation present in the dataset ([Tryon 1982](#)). For instance, in the sequence 1-2-1-1-2-1-1-2 there is no indication of significant deviation from randomness, so the C statistic would be deemed not statistically significant. Conversely, the sequence 1-2-3-4-5-6-7-8 exhibits a deviation from random fluctuation, so the C statistic would be considered statistically significant.

The ratio of a C statistic to its standard error was denoted as a z-statistic ( $Z = C/SE$ ). The statistical significance of C was assessed using a one-tailed z-statistic with a critical z value of 1.64 at  $p = 0.05$ . The basic formula for the C statistic is presented below, where the X array represents each data point in the series and M represents the mean of the X values.

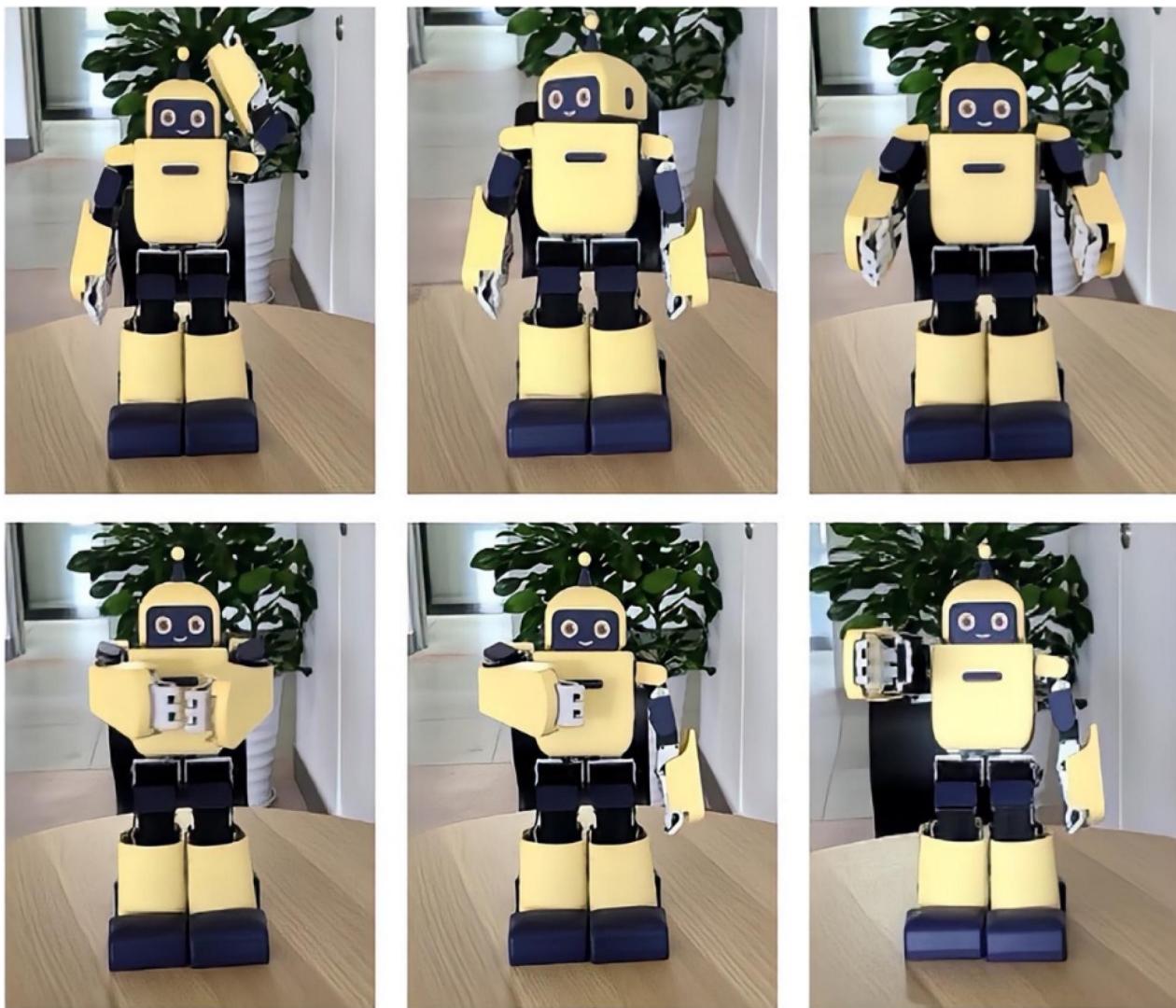
$$C = 1 - \frac{\sum_{i=1}^{n-1} (X_i - X_{i+1})^2}{2 \sum_{i=1}^n (X_i - M_x)^2} \quad SE_C = \sqrt{\frac{n-2}{(n-1)(n+1)}}$$

In this study, the intervention effect was deemed present when no trend was observed during the baseline session, whereas a significant increasing trend was observed across all the 12 data points in the series, comprising the baseline and intervention sessions.

## **Results**

### ***The communication behavior of children with ASD in the robot-based intervention group before and after intervention***

The frequencies of verbal and non-verbal behaviors of each child during the baseline and intervention sessions in the robot-based intervention group are presented in [Figure 5](#) (the left part). An increasing trend in the mean frequency of communication behaviors was observed for the robot-based intervention group during the intervention session compared to baseline session ([Figure 5](#)). The mean frequency of verbal behaviors increased from 5 during the baseline session to 9 during the intervention session), whereas the mean frequency of non-verbal behaviors increased from 8 during the baseline session to 14.33 during the intervention session in Case 1. In case 2, the mean frequency of verbal behaviors increased from 2.33 during the baseline session to 3.22 during the intervention session, whereas the mean frequency of non-verbal behaviors increased from 9 during the baseline session to 10.78 during the intervention session. In Case 3, the mean frequency of verbal behaviors showed a slight increase from 3 during the baseline session to 3.44 in the intervention session, whereas the mean frequency of non-verbal behaviors



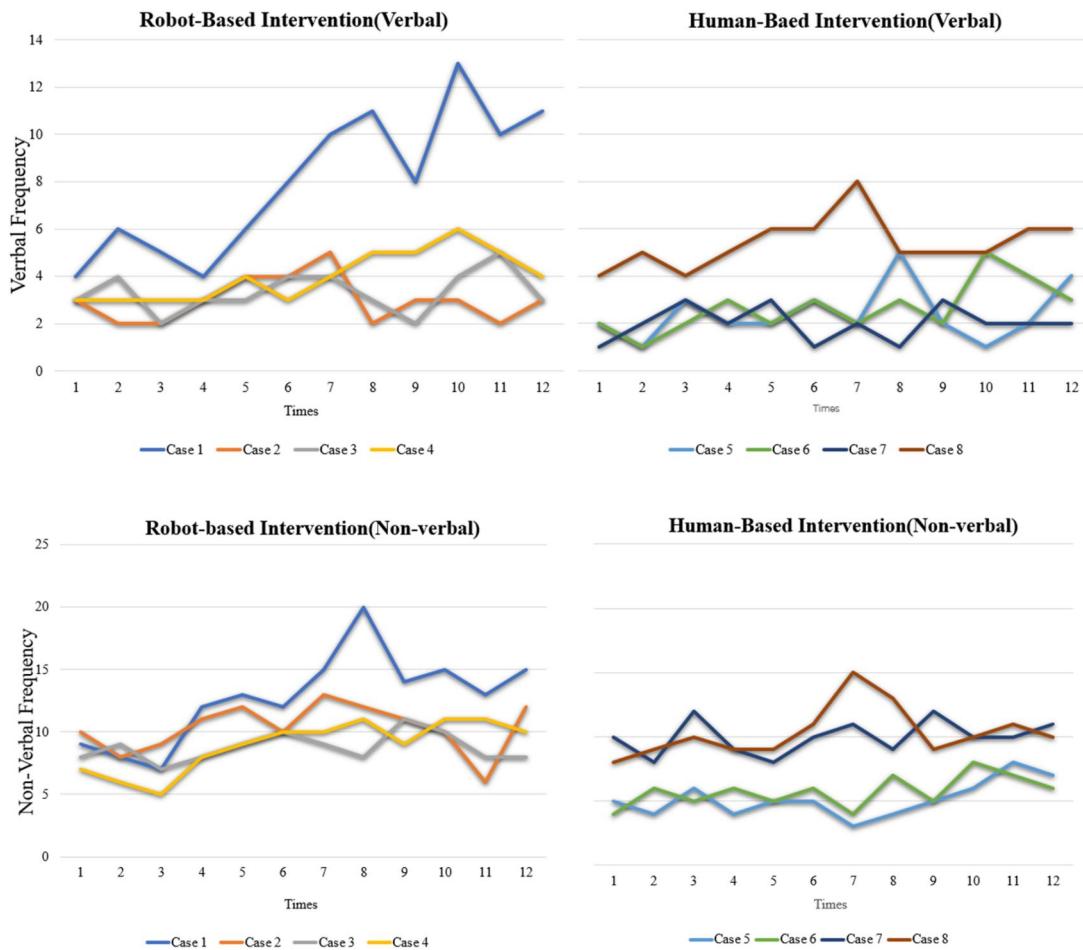
**Figure 4.** Examples of gestures produced by the robot therapist. From the upper left corner and proceeding from left to right, the following gestures were used: wave hand, shake head, open arms, clap hands, pat chest, and raise hand to grab.

increased from 8 in the baseline session to 9 during the intervention session. In Case 4, the mean frequency of verbal behaviors increased from 3 during the baseline session to 4.33 during the intervention session, whereas the mean non-verbal behaviors increased from 6 during the baseline session to 9.89 during the intervention session. Two children (Case 1 and Case 4) exhibited a significant increase in both verbal and nonverbal communication behaviors (Tables 5 and 6).

#### ***The communication behavior of children with ASD in the human-based intervention group before and after intervention***

The frequency of verbal and non-verbal behaviors of the participants during baseline and intervention session in human-based condition are presented in

**Figure 5** (the right part). The mean frequency of verbal behaviors increased during the PECS intervention in the human-based intervention group, whereas no clear trend was observed in the mean frequency of non-verbal behaviors (Figure 5). The mean frequency of verbal behaviors in participants increased after the intervention. However, only one child exhibited a significant increase in the mean frequency of nonverbal behaviors. The mean frequency of verbal behaviors slightly increased from 2 (baseline session) to 2.56 (intervention session), whereas the mean frequency of non-verbal behaviors in Case 5 exhibited a slight increase from 5 (baseline session) to 5.22 (intervention session). In Case 6, the mean frequency of verbal behaviors increased from 1.67 (baseline session) to 3 (intervention session), whereas the mean frequency of non-verbal behaviors slightly increased from 5 (baseline session) to 5.22 (intervention session). In Case 7,



**Figure 5.** Verbal and non-verbal behaviors 12 data points across baseline and intervention session in robot-based and human-based intervention groups.

**Table 5.** Comparison of verbal communication behaviors between intervention and baseline session in the robot-based and human-based intervention groups.

| Case         | Robot-based intervention |             |             |             | Human-based intervention |             |             |             |
|--------------|--------------------------|-------------|-------------|-------------|--------------------------|-------------|-------------|-------------|
|              | 1<br>M (SD)              | 2<br>M (SD) | 3<br>M (SD) | 4<br>M (SD) | 5<br>M (SD)              | 6<br>M (SD) | 7<br>M (SD) | 8<br>M (SD) |
| Baseline     | 5.00 (0.67)              | 2.33 (0.22) | 3.00 (0.67) | 3.00 (0)    | 2.00 (0.67)              | 1.67 (0.22) | 2.00 (0.67) | 4.33 (0.22) |
| Intervention | 9.00 (6.88)              | 3.22 (0.84) | 3.44 (0.69) | 4.33 (0.89) | 2.56 (1.36)              | 3.00 (0.89) | 5.78 (0.44) | 5.78 (0.84) |
| C            | 0.65                     | 0.20        | -0.05       | 0.71        | -0.29                    | 0.24        | -0.25       | 0.28        |
| Z            | 2.47**                   | 0.75        | -0.19       | 2.68**      | -1.09                    | 0.92        | -0.95       | 1.08        |

Note. \*\* $p < 0.01$ ; the significance of Z value represents a significant changing trend during the series including baseline and intervention session.

**Table 6.** Comparison of nonverbal communication behaviors between intervention and baseline session in the robot-based and human-based intervention groups.

| Case         | Robot-based intervention |              |             |             | Human-based intervention |             |              |              |
|--------------|--------------------------|--------------|-------------|-------------|--------------------------|-------------|--------------|--------------|
|              | 1<br>M (SD)              | 2<br>M (SD)  | 3<br>M (SD) | 4<br>M (SD) | 5<br>M (SD)              | 6<br>M (SD) | 7<br>M (SD)  | 8<br>M (SD)  |
| Baseline     | 8.00 (0.67)              | 9.00 (0.67)  | 8.00 (0.67) | 6.00 (0.67) | 5.00 (0.67)              | 5.00 (0.67) | 10.00 (2.67) | 9.00 (0.67)  |
| Intervention | 14.33 (5.33)             | 10.78 (3.73) | 9.00 (1.11) | 9.89 (0.99) | 5.22 (2.17)              | 5.22 (2.17) | 10.00 (1.33) | 10.78 (3.73) |
| C            | 0.60                     | 0.02         | 0.12        | 0.74        | 0.40                     | -0.11       | -0.39        | 0.46         |
| Z            | 2.27**                   | 0.08         | 0.47        | 2.79**      | 1.51                     | -0.42       | -1.49        | 1.73*        |

Note. \* $p < 0.05$ ; \*\* $p < 0.01$ ; the significance of Z value represents a significant changing trend during all the series including baseline and intervention session.

the mean frequency of verbal behaviors increased from 2 (baseline session) to 5.78, whereas the mean frequency of non-verbal behaviors showed no change

with a mean frequency of 10 for both baseline session and intervention session. In Case 8, the mean frequency of verbal behaviors increased from 4.33

(baseline session) to 5.78 (intervention session), whereas the mean frequency of non-verbal behaviors increased from 9 (baseline session) to 10.78 (intervention session). The mean frequency of nonverbal behaviors in Case 8 exhibited a significant increase after the human-based intervention (Tables 5 and 6).

### ***Comparison between robot-based intervention and human-based intervention on communication behaviors***

Analysis of the communication behaviors in both the robot-based and the human-based intervention groups revealed that a higher number of children with ASD in the robot-based intervention group exhibited enhanced verbal and nonverbal communication behaviors. Two participants in the robot-based intervention group showed a significant improvement in verbal communication behaviors after the intervention. Conversely, no significant improvement in verbal communication behavior was observed in the human-based intervention group (see Table 5 for details). Two participants in the robot-based intervention group exhibited a significant improvement in nonverbal communication behaviors after the intervention, whereas only one child in the human-based intervention group showed significant improvement in nonverbal communication (see Table 6 for details). In summary, a larger proportion of children in the robot-based intervention group demonstrated significant improvements in social communication skills for both the verbal and nonverbal behaviors compared to participants in the human-based intervention group.

## **Discussion**

In this study, the results indicated that robot-based PECS intervention can potentially enhance social communication skills in children with ASD. In fact, significant improvements in social communication skills were observed in two of the children exposed to the robot-based intervention and none of the children exposed to the human-based intervention.

Previous studies indicate that children with ASD display greater interest in social robots, and the social communication behaviors increased during interactions with robots than interaction with humans (Cabibihan et al. 2013; Sartorato, Przybylowski, and Sarko 2017). Kim et al. (2013) reported that children with ASD engage in more verbal communication when interacting with social robots than with human

adults. Children with ASD also exhibit rapid and frequent response to robots compared to therapists (Dickstein-Fischer et al. 2018; Tapus et al. 2012; Yousif, Kazem, and Chaichan 2019). Besides, they demonstrate a reduced need for cues to initiate communication during interactions with robots (Vanderborght et al. 2012). The current results demonstrated that the robot-based intervention is effective in enhancing both verbal and nonverbal communication skills in children with ASD, which is consistent with previous findings.

One potential explanation could be that children with ASD find it easier to understand and interact with robots compared to with human. Previous studies showed that children with ASD exhibit insensitivity to the actions of human beings (Lee and Carter 2012). Therefore, they may have difficulties in orienting to social stimuli provided by human therapists (Chevallier et al. 2012), and encounter challenges in understanding the social clues (Klin and Jones 2006; Selever, Roth, and Gillis 2013). Differently, operation of robots is based on predictable and legitimate systems, providing a highly structured learning environment that helps children to focus on relevant stimuli (Klinkert 2021; Kumazaki et al. 2022). Therefore, children with ASD may not feel the need to navigate complex social-emotional expectations when interacting with social robots (Cano et al. 2021). This potentially reduces the social anxiety level and enhances their communication behaviors (Mitchell, Parsons, and Leonard 2007). In this sense, children with ASD in this study potentially experienced less pressure when considering the social-emotional expectations while interacting with robots than with human therapists during the interventions. As a result, they were able to concentrate on the intervention tasks, leading to greater improvement in social communication skills.

Another plausible explanation is that the user-friendly nature of social robots might simplify the social communication behaviors for children with ASD. Previous research indicate that social robots are less complex than humans (Cabibihan et al. 2013; Dautenhahn 2003). The ability to effectively replicate an identical action across interactions is crucial for enhancing the social communication skills of children with ASD (Cabibihan et al. 2013; Ricks and Colton 2010). In this study, the streamlined training process for social communication provided by robot may be straightforward than that with human therapists.

Children with ASD may find it easier to follow instructions from a robot given their simplicity and predictability compared to a human therapist. Therefore, robots functioned as both playmates and trainers for the children, ensuring that the children were relaxed during interactions (Dautenhahn 2003). The seamless interaction with robots may further assist children with ASD in effectively repeating the successful social communication skills across different scenarios.

Recent studies have confirmed the effectiveness of the PECS in enhancing speech skills (Alzrayer 2020; Wood and Standen 2021). Lerna et al. (2012) reported that the PECS significantly improves social communication skills among children with ASD. Our results further indicated that the PECS intervention based on the robotic system also effectively improved verbal and nonverbal communication behaviors in young children with ASD. In addition, children with ASD may exhibit better engagement with robot-based interventions compared to human-based interventions, leading to more effective execution of the PECS technique. These findings represent a significant advancement in highlighting the effectiveness of robot-based PECS interventions in improving social communication abilities of young children with ASD. In future clinical or educational contexts, integrating robots with the PECS can be a valuable approach to enhance the communication skills of young children with ASD.

## Limitations and future research

The study has some limitations. Firstly, the use of single-case design to test the changing trends of participants during intervention, resulted in a small sample size. The behavioral characteristics of children with ASD are several and diverse. Therefore, use of larger group sizes could enhance the generalizability of the findings and demonstrate the effectiveness of robot-based PECS intervention in improving social communication skills across different subtypes of autistic children.

Secondly, interactions with robots may have both short- and long-term implications. A study investigating the daily interactions of normally developing children with a social robot revealed that a decrease in engagement with the robot in the second week (Kanda et al. 2004). Therefore, the therapeutic efficacy of a social robot may only be validated based on the effects observed over a two-month period. Future research should aim to investigate the long-term effect

of robot-based PECS intervention through follow-up studies.

Thirdly, we assessed the effectiveness of PECS intervention on improving the communication behaviors using only one type of robot that we developed in this study. However, different format and human-machine interactive systems of robots may also influence the intervention outcomes. Future research should explore the integration of PECS intervention into various robotic systems to verify its reliability and diversity.

## Ethical approval

All procedures in studies involving human participants were in accordance with the ethical standards of the Department of Child Psychiatry and Rehabilitation, Affiliated Shenzhen Maternity & Child Healthcare Hospital, Southern Medical University institutional review board (Number: SFYLS[2022]007). Informed consent was obtained from all participants included in this study

## Disclosure statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Data availability statement

The data and transcripts used in this study are available from the corresponding author upon reasonable request.

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