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Efficacy of a novel augmentative and alternative communication system in promoting requesting skills in young children with Autism Spectrum Disorder in India: A pilot study

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Abstract

Background & aims: The study assessed the efficacy of a novel, child-friendly, socio-culturally sensitive, icon-based Augmentative and Alternative Communication (AAC) system called Jellow Communicator, in teaching requesting skills to young children with Autism Spectrum Disorder (ASD) in a special school in Mumbai, India. Jellow is a comprehensive AAC system with a lexicon and pictorial library designed using a participatory, user-centric design process. The content of Jellow has been developed bearing in mind the socio-cultural and linguistic diversity of India. Jellow is available in low-tech (flashcards, booklet) and high-tech (Android and iOS app and desktop application) versions.

Methods: The quasi-experimental longitudinal study involved seventeen 3.5–12-year-old children with ASD with communication challenges. Children were taught to use the Jellow AAC system to request for preferred items, as part of their regular speech therapy sessions. Each child received one-on-one training sessions with a licensed speech therapist twice a week over a 3-month duration, with each session lasting around 20–30 min. A systematic training protocol adapted from the original Picture Exchange Communication System (PECS) was developed to train children to use the Jellow system,

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progressing from flashcards to the app version of Jellow. Behavioral training strategies such as modeling, least-to-most prompting, differential reinforcement, and behavior chain interruption were used to facilitate requesting behaviors. The speech therapist assessed children's developmental level across multiple domains at pretest and posttest. We coded 3 videos per child, i.e., one early, one mid, and one late training session each, to assess changes in children's stage of communication, spontaneous requesting abilities, level of attention during training trials, and average time to completion for requesting trials. In addition, caregivers filled out questionnaires to assess training-related changes in children's adaptive functioning levels as well as the psychosocial impact of the Jellow AAC system on children's quality of life.

Results: Children significantly improved their stage of communication, and a majority of children transitioned from flashcards to using the Jellow app to request for preferred items. Children also increased the proportion of spontaneous requests over the course of training. Caregivers reported a positive perceived psychosocial impact of the Jellow AAC system on their child's self-esteem, adaptability, and competence.

Conclusions: The findings from our pilot study support the use of the novel, socio-culturally adapted, Jellow Communicator AAC system for teaching requesting skills to young children with ASD who use multiple communication modalities. Future studies should replicate our findings with a larger group of participants using a randomized controlled trial design. **Implications:** This is the first experimental study to systematically assess the effects of an indigenously-developed comprehensive AAC system adapted to the sociocultural and linguistic landscape of India. Our study results provide support for the use of the cost-effective Jellow Communicator AAC system in facilitating requesting skills in children with ASD who use multiple communication modalities. Clinicians can use low-tech and high-tech versions of Jellow to promote communication skills in children with ASD.

Keywords

Augmentative and alternative communication, autism spectrum disorders, communication and language, requesting skills, culturally-valid AAC intervention

Introduction

Children with Autism Spectrum Disorder (ASD) have difficulties with both receptive communication i.e., understanding communicative bids of others, and expressive communication i.e., speech production during conversations (De Giacomo & Fombonne, 1998; Eigsti et al., 2011; Tager-Flusberg & Calkins, 1990). Around 25–50% of children with ASD either do not develop natural speech or have very limited speech (Prizant, 1996; Tager-Flusberg, et al., 2005). Lack of a functional mode of communication has cascading negative effects on the child's overall development (Martínez-González et al., 2021; Stone & Yoder, 2001; Thiemann-Bourque et al., 2012). For instance, children who are unable to communicate verbally, often engage in maladaptive behaviors to express their needs/feelings (Drager et al., 2010). Impaired communication can also limit the social input received from caregivers and peers, which in turn adversely affects children's further communication and cognitive development (Blackstone et al., 2007; Light, 1997).

Individuals with severe communication challenges who are unable to use speech for routine daily communication are said to have complex communication needs (Raghavendra et al., 2011). For these individuals, unaided or aided Augmentative and Alternative Communication (AAC) systems can serve as a supplement to existing speech or provide an alternative means of communication in case of absent or non-functional speech (Branson & Demchak, 2009; Drager et al., 2010; Ganz, 2015). Unaided systems such as sign language, finger spelling, and use of eye contact or gestures for communication, do not require any supplementary materials/equipment (Lynch, 2016). Aided systems, on the other hand, require some external materials/equipment and may be low-tech (picture cards, communication boards, or tangible objects) or high-tech (speech generating devices, communication apps on tablets/iPADs, and text-to-speech software) (Beukelman & Mirenda, 2013; Ganz et al., 2019; Sennott et al., 2016). Each of these systems has its pros and cons. For instance, unaided systems require good manual dexterity and may not work if social partners are unfamiliar with this communication mode (Bailey et al., 2006). Low-tech aided systems are easy to learn and understand for a broad audience. However, vocabulary may be limited, symbols may be difficult to interpret, creation of materials requires considerable effort, and systems may not be portable with a large vocabulary (Ganz et al., 2014; Light & McNaughton, 2012). Dedicated high-tech AAC systems are flexible and allow customization of spoken output (Light & McNaughton, 2012), but they are very expensive, require considerable training to learn, and may not work under certain settings such as crowded environments (Ganz et al., 2014). The advent of iPADs, tablets, and smart phones has revolutionized the field of AAC (Allen et al., 2016; Shane et al., 2012). In contrast to previously-available, bulky, stand-alone communication devices, (King, et al., 2014; Schepis et al., 1996; Shepherd et al., 2009), digital tablets are portable, cost-effective, provide an accessible, easy-to-use touch screen interface, and are multipurpose, allowing the child to access several software "apps" within a single device to serve their communication and other educational needs (Dixon et al., 2015; Kagohara et al., 2013; Lorah et al., 2013; McNaughton & Light, 2013).

Clinicians frequently start with low-tech AAC systems to provide the child a functional mode of communication and to measure their potential for success with AAC, prior to transitioning to high-tech systems (Alzrayer, 2020; Lynch, 2016). Conversely, other therapeutic frameworks recognize that there are no "prerequisites" for the use of high-tech systems. They recommend the early introduction of complex high-tech systems with capacity for sophisticated language production, to offer children greater opportunities for cognitive and linguistic development (Ganz et al., 2017; Gilroy et al., 2017; Still et al., 2014). Despite their versatility, it is recommended that clinicians conduct a thorough evaluation of pre-linguistic communicative behaviors prior to introduction of high-tech devices (Lynch, 2016). We adopted the former training approach of starting with low-tech aids and progressing in an incremental manner to high-tech AAC systems. This framework is in line with contemporary practices of speech therapists in India. This approach is frequently chosen in low-to-middle income developing countries since low-tech aids are accessible and affordable to a wide variety of people from varying socio-economic backgrounds (Bhatnagar & Silverman, 1999; Muttiah et al., 2022). Moreover, it is easier to educate families with a wide range of literacy levels on the use of low-tech aids as a starting point for the introduction of AAC into their child's life (Dada et al., 2017; Gormley, 2017).

The development of a functional mode of communication is often a protracted process for children with disabilities as they transition from single to multiple flashcards, low- to high-tech systems, or from high-tech systems with fewer symbols to systems with nested, multi-screen, multi-icon displays (Beukelman & Mirenda, 2013; Ganz et al., 2017; King et al., 2020). A review of existing AAC systems suggests significant heterogeneity in types of symbols used, their iconography, and the visual design language used to create symbols (Basson & Alant, 2005; Gevarter et al., 2014; Lloyd et al., 1997). Within high-tech systems, there is variability in the system interface, content organization, and mode of navigation to access content (Alant et al., 2010; Drager et al., 2004; Schlosser et al., 2012; Still et al., 2014). From a cognitive standpoint, as children improve their communication, it is especially challenging for them to transition across systems with differing structures and functionalities (King et al., 2020). A system that can "grow" with the child in terms of content and vocabulary, while retaining its familiar iconography, architecture, and organizational structure may accelerate learning of more complex communication modes.

It is also imperative that the AAC system/symbols be aligned with the socio-cultural sensibilities of the child/family (Blake Huer, 2000; Haupt & Alant, 2002; Nigam, 2006; Soto et al., 1997). For instance, Soto and Yu (2014) propose a sociocultural approach to AAC that recommends provision of the intervention in multiple languages (home and school languages) for bilingual children. They argue that access to multiple languages is crucial for bilingual children, to provide them increased opportunities to participate in interactions with diverse social partners and to preserve and foster linguistic and cultural diversity. Language is an integral part of society, and it influences, and in turn is influenced by, the social, geographic, linguistic, and cultural context that the individual is immersed in (Beukelman & Mirenda, 1998; Blake Huer, 1997; Kuo & Lai, 2006; Lund & Light, 2007). For example, from a cultural standpoint, certain festivals/holidays are highly region-specific, with origins rooted in local cultural, historical, and mythological traditions. From a sociological perspective, for instance, certain societies that are collectivistic may have different linguistic terms to contrast members of extended families from maternal and paternal sides (Morelli et al., 2018; Muttiah et al., 2022). From a linguistic perspective, AAC systems should be available in children's native languages to improve integration into the child's daily routines (An et al., 2017; Genc-Tosun & Kurt, 2017; Mngomezulu et al., 2019; Tönsing & Soto, 2020; Wepener et al., 2021). Overall, language and communication are highly culture-specific (Nigam, 2006; Soto & Yu, 2014; Taylor & Clarke, 1994). Nevertheless, AAC systems have typically been designed based on Western sensibilities and cultural norms; moreover they are often available only in the English language (Costantino & Bonati, 2014; Hetzroni & Harris, 1996; McCord & Soto, 2004). Few other research groups have developed AAC apps in languages such as Brazilian Portuguese and Chinese, with content and symbols appropriately contextualized to the native cultural landscape (An et al., 2017; de Oliveira et al., 2016; Genc-Tosun & Kurt, 2017; Mngomesulu et al., 2019; Wepener et al., 2021). The present study addresses the previously identified gaps in the literature by assessing the efficacy of a novel AAC system, Jellow Communicator, designed bearing in mind the unique sociocultural and linguistic practices native to the Indian context.

To ensure effective adoption of an AAC system, it should be (a) accessible, with an easy-to-learn, intuitive interface, and (b) affordable, thereby facilitating integration into the child's daily routines (beyond speech therapy sessions) and social interactions (Basson & Alant, 2005;

Mandak et al., 2017; Rackensperger, 2012; Sevcik & Romski, 2007). In a developing country like India, the cost of the system is a crucial consideration impacting system adoption (Blake Huer, 2000; Muttiah et al., 2022; Nigam, 2006; Srinivasan et al., 2011). Therefore, we developed an open source, cost-effective, child-friendly, and easy-to-use AAC system available in multiple formats to suit the diverse needs of children with communication difficulties. The AAC system was designed to allow both clinicians and caregivers to easily learn and facilitate its use among children with developmental disabilities. Moreover, in line with the previously outlined sociocultural approach to AAC interventions proposed by Soto and Yu (2014), the Jellow system was made available simultaneously in English and several native Indian languages, with easy language switching features, thereby facilitating adoption by bilingual and multilingual children.

The development of the Jellow communicator AAC system was based on an iterative, user-centric, multi-tiered participatory design process funded initially by Microsoft Design Expo and subsequently through a UNICEF Innovation seed grant. Jellow's first prototype, which was an Adobe Flash-based desktop application used digitized speech for communication. At the time, there was a scarcity of systems designed to suit the unique needs of Indian users. The research team developed an interface with 6 expressive icons that serve as building blocks for communication of basic needs and emotions (see Figure 1). The interface of the first prototype also included a limited number of category icons that were composed of content relevant to a young child's daily routines. The system required the child to click on a combination of expressive and category icons to activate pre-recorded, digitized messages corresponding to the user's selection. Thereafter, the first tier of usability testing was conducted with 7–10-year-old typically developing children (Srinivasan et al., 2017). Based on these study findings, we significantly expanded Jellow's content and functionality, and transitioned from digitized to synthesized speech for the high-tech version of Jellow, by taking advantage of in-built text-to-speech engines within Android/Windows/Apple platforms.

In the next tier of user-centric design supported through a UNICEF Innovation seed grant, we obtained extensive feedback from multiple stakeholder groups including teachers, parents, and therapists across the country through workshops conducted at clinics, hospitals, charitable organizations, schools, and national conferences. This led to further modifications to tailor the system to better suit the needs of target users including—(1) availability in multiple formats (low-tech options and high-tech versions available on multiple platforms), (2) translation of content into multiple Indian languages, (3) expansion of content, (4) improving app accessibility for users with additional visual and mobility challenges through TalkBack and Switch access respectively, and (5) increased customizability within the app to choose grid sizes and vary speech options (speed, pitch, etc.). To tailor the system to be aligned to the socio-cultural sensibilities of the Indian sub-context, the linguistic content in different Indian languages was developed by a team that comprised native speakers of the language, speech therapists, special educators, and physical therapy researchers. Moreover, the basic content was refined in an ongoing manner through feedback from families, children, special educators, and therapists within each region through ongoing workshops and presentations at schools, clinics, conferences, parent support groups, and informational/educational events.

The purpose of this quasi-experimental, longitudinal study was to collect data on the efficacy of the Jellow Communicator AAC system in promoting requesting skills in young children with ASD. The study was conducted in a special school in Mumbai, India and involved the Jellow system being incorporated as part of weekly speech therapy sessions. Our research questions were as follows: (1) How do communication skills of children with ASD who use multiple communication modalities change, following a 3-month training program using the icon-based Jellow communicator AAC system? and (2) How do parent/caregiver perceptions of their child's communication skills, functional independence, well-being, and quality of

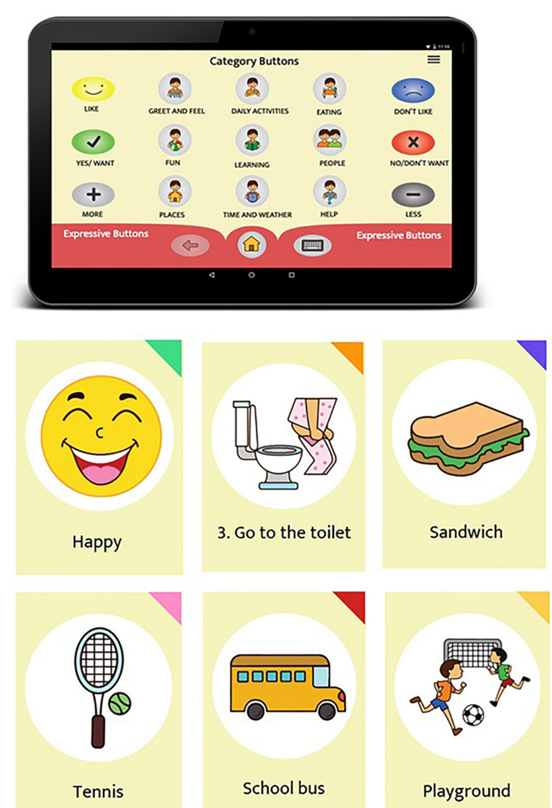

Figure 1. High-tech and Low-tech versions of the Jellow Communicator AAC system including a screenshot of the home screen of the Jellow app and exemplar downloadable Jellow flashcards.

life change, following a 3-month training program using the icon-based Jellow communicator AAC system?

Methods

Description and functionality of the Jellow communication system

The Jellow AAC system is available in multiple formats, i.e., as downloadable and editable flashcards, a printable PDF booklet version, a desktop application, and a downloadable application for the Android and iOS platforms (www.jellow.org). Jellow's display interface is designed to be child-friendly, simple, and intuitive, and allows young children to easily communicate their likes, dislikes, and needs with caregivers and peers. The multiple formats enable users with varying abilities and preferences to choose a format that best suits their needs, and also accommodates for changing needs of users. At the time the study was conducted, the Jellow app was available in multiple local Indian languages, namely, English, Hindi, Marathi, Bengali, and Tamil.

The Jellow app's interface comprises category and expressive icons (Figure 1). The category icons follow a taxonomic system of organization. The category icons on the main screen (Level 1) are organized into nested sub-categories (Levels 2 & 3) across multiple subsequent screens. For example, the "Eating" Level 1 category icon has Level 2 sub-categories of "Breakfast", "Lunch/ Dinner", "Snacks" etc. nested within it, with each of the sub-categories including specific Level 3 options, for e.g., options for "sandwich", "soup", "pasta" etc. within the "Lunch" level 2 sub-category icon. The user is required to double tap a category/sub-category icon to access the nested content within that icon. The 6 expressive icons of "like", "don't like", "yes/want", "no/don't want", "more", and "less" are constant across all the screens of the application. Clicking on an icon (category/expressive) leads to the app speaking out the icon's label aloud. To communicate using the app's pre-programmed sentences, the user must first click on a category/sub-category icon followed by an expressive icon. For instance, if the user clicks on the "eating" icon followed by the "yes/want" button, the app says aloud, "I want to eat". The 6 expressive icons therefore when combined with clicks on category/sub-category icons can produce 6 types of pre-programmed sentences: "I like…", "I want…", "I want more…", "I don't like…", "I don't want…", "I want less..". The pre-programmed sentences are appropriately grammatically formulated based on the category/sub-category icon chosen (e.g., "I want water", "I want to go to the park", etc.). Although the app presently allows user-defined customization of content, at the time the study was conducted, we only used the pre-made picture cards with standard icons and the basic version of the app with preprogrammed content.

Study design and participants

17 children with ASD (14M, 3F; all Asian ethnicity) between 3.5 and 12 years (Mean(SE): 6.54(0.61)) were recruited through convenience sampling. In terms of languages spoken at home, 8 children spoke Marathi, 7 children spoke Hindi, 1 child spoke Bengali, and 1 child spoke Telugu. The medium of instruction for children at school was a mix of English, Hindi, and Marathi languages. None of the children had any previous exposure to low-tech or high-tech AAC systems. Eleven out of 17 children were completely non-verbal and 6 used single words or short phrases to communicate. The overall expressive vocabulary of children who used single words or phrases to communicate ranged between 5 and 30 words. Inclusion criteria included 3.5–12-year-old children with a diagnosis of ASD, who were unable to use natural speech as their primary mode of day-to-day functional communication, and who were familiar with either Hindi, Marathi, or English languages. Medical diagnosis of ASD was confirmed using the Modified Checklist for Autism in Toddlers (Robins et al., 2001), the Indian Scale for Autism (ISAA, 2009), and a physician/psychiatrist/clinical psychologist/pediatric neurologist-provided clinical diagnosis of ASD using DSM-V criteria (American Psychiatric Association, 2013). Children with co-morbid epilepsy/genetic syndromes or moderate to profound intellectual disability leading to an inability to understand and follow 1-step verbal instructions such as "click this" or "give me the picture card" were excluded.

The study was conducted as a collaboration between the IDC School of Design at the Indian Institute of Technology Bombay (IIT Bombay) and the departments of Speech & Language Therapy and Psychiatry at Topiwala National Medical College and Topiwala National Medical College and BYL Nair Charitable Hospital, both of which are located in Mumbai, India. The software development of Jellow was undertaken at IIT Bombay, a premier Indian engineering institute. The BYL Nair Charitable Hospital is a government-owned hospital, affiliated to a prominent medical school, and the study was conducted in a special school for children with ASD within the premises of Nair hospital. The study was approved by the Institutional Review Board/Ethics Committees at IIT Bombay and Nair Hospital. The study was conducted with students enrolled in the academic year 2017–2018. Pretests were conducted in August-September 2017 and posttests were conducted in April 2018. Note that there were school closures and additional student absences associated with a couple of major Indian festivals during the months of November and December. Therefore, training was provided consistently on a weekly basis over the months of January, February, and March 2018 for all children (# of sessions/ child—Mean(SE): 22.24(0.78), Range: 19–30 sessions). Children participated in the study following written parental permission. Parental permission forms were available in

English and also translated into Hindi and Marathi languages. Although we had an IRB-approved assent form (simplified and written at a 1st grade reading level) available in English, Hindi, and Marathi languages, given the comprehension level of children participating in our study, child assent was obtained using the following procedures. Researchers and the child's parents explained study procedures briefly to the child using pictures (Jellow flashcards, showing the Jellow app on the iPAD) and asked the child if they would like to play with Jellow. Children could respond verbally or use gestures (head nod, thumbs-up, or thumbs-down). For children who did not have any natural speech, we also observed their body language for any signs of dissent including if a child ran away or pushed the card/tablet away. We also obtained child assent at the beginning of every session using similar procedures. Children's self-initiated attempts to explore the app or the flashcards or intentional looking towards Jellow materials were taken as indicating interest in and willingness to engage in the session.

Testing protocol and measures

Baseline assessments of children's developmental level including communication levels were conducted using parent- and clinician-rated questionnaires, i.e., the Vineland Adaptive Behavior Scales, 2nd edition (VABS-2, Sparrow et al., 2005) and the Communication DEALL-Developmental Checklist (CDDC, Karanth, 2011). Tables 1A and 1B report on individual participant data on the VABS-2 and the CDDC at baseline. Both measures were repeated at posttest. At posttest, we also asked parents to fill out the Psychosocial Impact of Assistive Devices (PIADS, Day et al., 2002).

The VABS-2 is a valid and reliable parent-rated questionnaire that assesses an individual's (from birth-90 years) adaptive functioning and includes domains of socialization, communication, motor skills, daily living skills, and problem behaviors (Sparrow et al., 2005). The VABS-2 was scored by caregivers in an interview format with the researchers. We report on standard scores of the VABS-2 across multiple domains including the adaptive behavior composite. The CDDC is a 288-item, criterion referenced, reliable checklist to assess developmental skills in 8 domains (gross motor skills, fine motor skills, activities of daily living, receptive language, expressive language, cognitive skills, social skills, and emotional skills) (Karanth, 2011). The checklist provides an estimate of the child's developmental age based on their abilities in different domains. A licensed speech therapist scored the CDDC at pretest and posttest.

The PIADS (Day et al., 2002) is a reliable and sensitive 26-item questionnaire that assesses the effects of assistive devices on the individual's functional independence, well-being, and quality of life. Each item is scored on a 7-point Likert scale ranging from −3 (decreases) to +3 (increases), with a rating of 0 indicating no perceived impact of the assistive device. Therefore, positive scores indicate positive effects and negative scores indicate adverse effects of assistive devices on the individual's function. The 3 sub-scales of the PIADS assess competence (12 items), adaptability (6 items), and self-esteem (8 items). The competence subscale assesses efficacy and is sensitive to the impact of assistive systems on performance and productivity. The adaptability subscale assesses willingness to try out different things and take risks. The self-esteem subscale is sensitive to effects of assistive devices on self-confidence and emotional well-being. Research with the PIADS has shown high overall agreement between user self-report and caregiver reports (Jutai et al., 2000). We asked caregivers to complete the questionnaire as a proxy for child responses.

We also video-recorded all training sessions for later scoring. At the end of every training session, the speech therapist recorded her observations using a data logging form. Parents were also asked to log the daily time spent using the system at home throughout the study.

Intervention protocol

The intervention was provided to children as part of regular, weekly, school-based speech therapy sessions. Prior to study initiation, a training workshop was conducted for caregivers and teachers to provide information on Jellow and to facilitate its use outside speech therapy sessions at school and at home. At the workshop, the Jellow AAC app was installed on participant's devices; for families that did not own a device, low-tech flashcards with Jellow icons were provided to promote use of Jellow at home.

Weekly one-on-one speech therapy sessions were conducted by a licensed female speech therapist (2nd author) with the child and their caregiver. Caregivers were included in the sessions so that they could learn strategies to facilitate Jellow's use for communication at home. Sessions were conducted in a designated speech therapy room in the school. Training was provided 2 times/week for 20–30 min/session. The training focused on teaching children requesting skills. Specifically, the therapist prompted children to request for preferred items i.e., snacks and toys/games using the Jellow system. Prior to initiation of training, the therapist conducted a preference assessment and used additional caregiver input to identify preferred items for each child. The therapist used behavioral instructional techniques including behavior chain interruption, modeling, least-to-most prompting, incidental training, expectant delay, differential reinforcement, and verbal expansion to train requesting skills (Clarke & Williams, 2020; Ganz et al., 2019; Schepis et al., 1998; Sigafoos et al., 2013). Taking into consideration the languages that children were exposed to at home/school, nine children received Jellow AAC training in Hindi and 8 children received training in Marathi.

Table 1A. Individual data on developmental level of participants across multiple domains measured at baseline using the CDDC checklist

Child # (Gender)	Age at pretest (years)	Gross motor (mos.)	Fine motor (mos.)	Activities of Daily Living (mos.)	Receptive Language (mos.)	Expressive Language (mos.)	Cognitive Skill (mos.)	Social Skill (mos.)	Emotional Skill (mos.)
1 (M)	11.75	66–72	66–72	66–72	30–36	12–18	30–36	12–18	18–24
2 (F)	8.83	60–54	36–42	36–42	12–18	12–18	12–18	6 12	12–18
3 (M)	7.17	54–60	48–54	42–48	18–24	12–18	24–30	12–18	30–36
4 (M)	3.83	54–60	48–54	42–48	24–30	24–30	30–36	30–36	24–30
5 (M)	7.42	60–66	54–60	54–60	24–30	12–18	24–30	12–18	18–24
6 (M)	6.33	66–72	54–60	54–60	18–24	12–18	30–36	12–18	18–24
7 (M)	11.08	48–54	42–48	30–36	12–18	6 12	18–24	12–18	24–30
8 (M)	6.83	54–60	54–60	54–60	24–30	18–24	30–36	30–36	30–36
9 (M)	4.00	30–24	24–18	24–18	12–18	6–12	12–18	12–18	12–18
10 (M)	4.50	54–60	54–60	54–60	24–18	12–18	30–36	12–18	18–24
11 (F)	3.78	36–42	24–30	24–30	18–24	12–18	24–30	12–18	18–24
12 (M)	4.83	60–66	42–48	54–60	30–36	30–36	30–36	18–24	18–24
13 (M)	9.42	66–72	54–60	54–60	24–30	12–18	24–30	12–18	18–24
14 (M)	4.33	54–60	54–60	54–60	24–30	12–18	30–36	36–42	30–36
15 (F)	6.33	30–36	30–36	30–36	12–18	12–18	12–18	12–18	24–30
16 (M)	6.50	54–60	48–54	36–42	30–36	24–30	30–36	18–24	18–24
17 (M)	4.25	48–54	42–48	42–48	12–18	12–18	24–30	18–24	18–24

Table 1B. Individual data on adaptive functioning of participants measured at baseline using the VABS-2 questionnaire.

Child # (Gender)	Comm. Standard Score	Comm. % Rank	DL Standard Score	DL % Rank	Social Standard Score	Social % Rank	ABC Standard Score	ABC % Rank	Mal V scale Score	Mal Descriptive Level
1 (M)	50	<0.1	66	1	42	<0.1	53	0.1	20	Elevated
2 (F)	45	<0.1	57	0.2	50	<0.1	51	<0.1	20	Elevated
3 (M)	53	0.1	54	0.1	53	0.1	54	0.1	20	Elevated
4 (M)	72	3	73	4	65	1	67	1	17	Average
5 (M)	56	0.2	57	0.2	55	0.1	57	0.2	16	Average
6 (M)	49	<0.1	62	1	51	<0.1	54	0.1	19	Elevated
7 (M)	36	<0.1	40	<0.1	38	<0.1	36	<0.1	21	Clinically significant
8 (M)	47	<0.1	62	1	53	0.1	54	0.1	17	Average
9 (M)	42	<0.1	53	0.1	48	<0.1	46	<0.1	19	Elevated
10 (M)	34	<0.1	66	1	57	0.2	54	0.1	16	Average
11 (F)	31	<0.1	62	1	59	0.3	51	<0.1	15	Average
12 (M)	44	<0.1	66	1	57	0.2	58	0.3	16	Average
13 (M)	53	0.1	63	1	48	<0.1	56	0.2	17	Average
14 (M)	65	1	77	6	63	1	67	1	12	Average
15 (F)	31	<0.1	43	<0.1	48	<0.1	42	<0.1	18	Elevated
16 (M)	52	0.1	55	0.1	51	<0.1	52	0.1	18	Elevated
17 (M)	31	<0.1	60	0.4	57	0.2	50	<0.1	17	Average

Note: Standard scores have a normative mean of 100 and a normative standard deviation of 15.
Comm.: Communication; DL: Daily Living, Social: Socialization; Mal: Maladaptive Behavior; ABC: Adaptive Behavior Composite; % Rank: Percentile rank
Percentile rank indicates % of individuals in the individual's normative age group who scored the same or lower than the individual.

During the training session, the therapist incorporated at least 5 requesting trials each for snacks and play items, except if a child was non-compliant (frequent running away, physical tantrums, or aggressive behaviors towards self or others) or having a bad day (as reported by the child's caregiver or teacher). The therapist used visual picture schedules to acquaint children with the session structure and activities. Each session started with greetings, followed by 1–2 games/activities, snack time, and then farewells. The therapist chose games/activities based on the child's overall speech therapy-related goals for the academic year. Exemplar activities involved puzzles, board games, story-telling, picture recognition, word association, object categorization, etc. All activities were designed to provide multiple opportunities to use the Jellow system for the purpose of requesting, making choices, and indicating yes/no. The therapist started by using Jellow flashcards with children. As the child improved requesting skills using flashcards, the therapist transitioned to teaching the child to use the Jellow app to request.

A requesting trial consisted of the therapist initially showing the child their preferred item and letting them engage with the item for around 30 s. Thereafter, the item was gently taken out of the child's reach and the card for the item (if the child was at the flashcard stage) or the tablet with the app screen containing the item's icon (if the child was at the app stage) was placed in front of the child. The therapist elicited the request and asked the child, "What do you want?" The caregiver was taught to model requesting behaviors for the child (Sennott et al., 2016). The therapist and caregiver then encouraged the child to use the Jellow system to request for their preferred item using verbal, gestural, and physical cues as required. We used the least-to-most prompting system i.e., therapists used gestural cues (e.g., pointing at the card or the icon or using a gesture for "give me" the card) followed by verbal cues (e.g., "give teacher the card" or "click on this button", etc.), and repeat demonstrations/modeling to encourage child to use the Jellow system to request. If the child still did not request, then gentle hand-on-hand assistance (i.e., caregiver or therapist manually helped the child hand over the card to the therapist or manually guided their hand to click on the icon within the app) was provided and the behavior was immediately rewarded with the preferred item to reinforce/strengthen the desired behavior.

The training was divided into progressive phases/stages developed by adapting the original protocol for the Picture Exchange Communication System (PECS; Bondy & Frost, 2003) that comprises 6 phases (see Table 2). Stages I and II involved the use of flashcards for requesting and Stages III-VII involved the child using the Jellow Communicator AAC app for the purpose of communication. As Table 2 indicates, progression across stages required children to be able to find and select the appropriate flashcard or icon for the preferred item among other distractors. Moreover, training was designed to advance children from the use of single words to using sentences generated through the app to request for preferred items. Progression through stages was based on the child fulfilling the criterion of 80% success (8 out of 10 trials) in requesting at their current stage.

Coding methodology

A detailed coding system was developed to assess training-related changes in children's requesting skills using video data from training sessions. The third and fourth authors rated one "early", "mid", and "late" training session for every child to assess changes in children's requesting skills using the Jellow system. Typically, we chose the first, last, and a session at the exact mid-point of training to represent the early, middle, and late parts of the training. Exceptions were made if the chosen session did not have enough number of trials due to child non-compliance, illness, etc. For each child, we ensured that the 3 sessions chosen had roughly equal number of trials to allow a fair comparison across training weeks. Prior to coding the entire dataset, coders established inter- and intra-rater reliability of over 90% using a subset comprising 20% of the data. Specifically, the correlations between ratings provided by both raters across variables coded were as follows: (a) stage of communication: 0.98, (b) nature of request: 0.92, and (c) attention: 0.96. All disagreements between coders were resolved through consensus coding with the first author.

Each trial within a session was coded for the stage of communication, nature and type of request, and child's level of attention (see Table 2). We coded for whether the child spontaneously initiated the request or had to be prompted by the therapist or caregiver to request the preferred item. For coding child attention, coders observed children's gaze and focus during the task by observing their body language (direction in which face, arms, and body were oriented, e.g., whether the child was looking in the direction of the flashcards/tablet, whether the child was actively interacting with the AAC system or the preferred item that the therapist used to encourage requesting). We also documented the time taken by the child to request an item starting from the time the therapist provided a requesting bid (see Table 2).

Outcome measures and statistical analyses

The dependent variables for the study include the stage of communication, nature of request, level of attention, and time to completion measured across all trials during an early, mid, and late training session each for every child. Given the study's pilot nature, we report on both group data trends as well as individual data to determine the number of children that followed the group trends. Typically, within a session, children engaged in trials spanning mostly 1 or 2 sequential communication stages and very rarely (3 out of 17 children) engaged in trials spanning 3 stages of communication. Therefore, we compared the most frequently used stage of communication within a session across early, mid, and late training sessions. If the child used a specific stage of communication for ≥55% of session trials, it was considered to be the most frequent stage of communication for that session. We also report data on the proportion of trials (out of total trials within a session) at specific stages of the communication hierarchy (see Table 2) across early, mid, and late training sessions

Table 2. Coding scheme used for scoring videos of early, mid, and late training sessions

Category	Definition	Coding Scheme
Stage of Communication	Child's mode of communication (flashcard/app) during the trial.	1: Single Flashcard used. 2: Multiple flashcards used – 2A: Two Flashcards used (1 with preferred item and 1 with distractor item) 2B: Three Flashcards used (1 with preferred item and 2 with distractor items) 3: App introduced—Child can tap on single icon without added navigational demands. 4: App used—Child can communicate in sentences using app (by pressing category followed by expressive icons) without added navigational demands. 5: App navigational demands added— 5A: Single level navigational demand added—Child can navigate from Level 1 to Level 2 OR Level 2 to Level 3 screens of the app and then click on a single icon for requesting preferred item. 5B: Dual level navigational demands added—Child can navigate from Level 1 all the way to Level 3 to find preferred item and clicks on the single icon to request for it. 6: Sentence-based communication with navigation—Child can navigate through the app to find preferred icon and can communicate in sentences using the app. 7: Child able to independently launch the app and request for preferred item across all screen levels using sentences. ** Note: Progression through stages was based on the child fulfilling the criterion of 80% success (8 out of 10 trials) in requesting at their current stage.
Nature of Request	To evaluate if the request was spontaneously initiated by the child or if it was made in response to the therapist/ caregiver's bid.	0 (No Response): The child did not request for preferred item. 1 (Responsive): The child requested for the item following the therapist's or caregiver's bid/questions/prompting. 2 (Spontaneous): The child requested for the item spontaneously without therapist or caregiver bidding/ questions/prompting.
Attention	To assess the child's level of attention during the requesting trial.	0 (Inattentive): The child was inattentive during the trial. 1 (Attentive with cueing): The child was attentive but needed prompting and cues from therapist/caregiver to stay on task during the trial. 2 (Attentive without cueing): The child was engaged and attentive throughout the trial without significant additional cueing/prompting from the therapist/ caregiver.
Time to Completion	The amount of time in seconds it took the child to request for the preferred item.	The time was measured from the instant the preferred item was presented in front of the child and the therapist asked the child, "what do you want?" to the time the child either gave the flashcard to the therapist or clicked on the app icons to communicate their verbal message to the therapist/caregiver. Note that if the child did not provide any response to the trial, the time to completion was scored as NA.

for children. For the nature of request, we compared the proportion of "spontaneous", "responsive", and "no response" trials across early, mid, and late training sessions. Similarly, for the level of attention, we compared the proportion of trials that children were "attentive without cueing", "attentive with cueing", and "completely inattentive even with cueing" across all 3 sessions. We also calculated the average time to completion across all the trials within each session.

All data were assessed for assumptions of parametric statistics. We used repeated measures analyses of variance (ANOVA) to evaluate changes in assessed outcome measures. The ANOVA for the most frequent stage of communication had session (early, mid, late) as the within-subjects factor. The ANOVA for nature of request had session and request type (spontaneous, responsive, no response) as the within-subjects factors. For level of attention, the ANOVA included session and attention type (attentive without cueing, attentive with cueing, inattentive) as within-subjects factors. The ANOVA for average time to completion had session as the single within-subjects factor. For analyzing questionnaire data, we used dependent *t* tests to assess training-related changes from pretest to posttest. For the PIADS, all 3 subscale means were compared to an alternate hypothesis of no effect (0) using dependent *t* tests.

In case of violations of the Mauchly's test of sphericity for the ANOVAs, Greenhouse Geisser corrections were applied. If there was a significant main effect and an interaction involving the same factor, post-hoc *t*-tests were conducted to evaluate the significant interactions only. Significance was set at $p \leq 0.05$ and statistical trends are reported at $p \leq 0.1$. Effect sizes (ES) are reported using partial eta-squared (η_p^2) and standardized mean difference (SMD) values (using Hedge's g) (Hedges, 1981). We also report confidence intervals (CI) of the SMD values (Huedo-Medina & Johnson, 2011).

We had missing data from only 1 caregiver for the PIADS questionnaire. We were able to obtain data from all study participants for all other video-and questionnaire-based assessments.

Results

Parent-and clinician-rated questionnaires

Children did not show significant training-related improvements in standard scores on the communication sub-domain of the VABS-2 questionnaire (Mean(SE)—Pretest: 46.53(2.86), Posttest: 45.65(3.47)). On the clinician-rated CDDC checklist, 11 out of 17 children showed improvements in receptive communication and only 1 child showed improvements in expressive communication from pretest to posttest.

On the PIADS, caregivers reported a significant positive perceived psychosocial impact of Jellow on their child when tested against a no change null hypothesis. Specifically, they reported a large positive effect on their child's self-esteem (Mean(SE): 0.28(0.07), $p = 0.001$, SMD: 0.95, CI(SMD): 0.29–1.60) and adaptability (Mean(SE): 0.24(0.07), $p = 0.004$, SMD: 0.81, CI(SMD): 0.19–1.44), and a medium-sized effect on competence (Mean(SE): 0.14(0.05), $p = 0.02$, SMD: 0.66, CI(SMD): 0.07–1.26). In terms of individual data, out of the 16 caregivers who filled out the PIADS, 15 reported improvements in child self-esteem, 11 indicated improvements in adaptability, and 9 indicated improvements in child competence following introduction of the Jellow system.

Stage of communication

The ANOVA indicated a significant main effect of session (F (2, 32) = 26.40, $p < 0.001$, $\eta_p^2 = 0.62$). Post-hoc analysis suggested that children showed improvements of medium-to-large ES in their most frequently used stage of communication across all three sessions, i.e., from early to mid, mid to late, and from early to late sessions (Mean(SE)—Early: 1.12(0.12), Mid: 1.94(0.23), Late: 2.59(0.19), p values <0.01, SMD range: 0.65–1.58, CI(SMD) range: 0.08–4.05). Individual data suggest that 16 out of 17 children showed improvements in the most frequently used stage of communication from an early to a later (mid or late or both) session. Figure 2 shows individual data in the form of bar graphs for all children in the study. In each bar graph, the proportion of trials at different stages of communication are depicted for each of the three training sessions coded. For example, child 14 started with around 92% of trials at stage 1 and 8% trials of stage 2A in the early session, progressed to around 70% at stage 2B and 30% trials at stage 1 in the mid-session, and finally used stage 3 as the only mode of communication for 100% of trials in the late session. Overall, these findings suggest that a majority of the children progressed to more sophisticated modes of communication across training weeks.

Nature of request

The ANOVA indicated a main effect of request type (F (2, 32) = 98.69, $p < 0.001$, $\eta_p^2 = 0.86$) and a request type × session interaction (F (4, 64) = 5.40, $p = 0.001$, $\eta_p^2 = 0.25$). Post-hoc analysis of the interaction suggested that across all sessions, children engaged in significantly greater proportion of responsive followed by spontaneous trials with the least proportion of no response trials (Mean(SE)—Responsive: 74.09(3.10), Spontaneous: 17.09(2.67), No Response: 8.82(2.22), p values < 0.05, SMD range: 0.72–4.86, CI(SMD) range: 0.13–6.84). In terms of training-related changes (see Figure 3), there were significant increases of medium-to-large sizes in spontaneous requesting from early to the mid and early to late training sessions (Mean(SE)—Early: 7.63(2.99), Mid: 17.25(4.35), Late: 26.39(5.30), p values < 0.05, SMD range: 0.74–1.45; CI(SMD) range: 0.15–2.21), with a similar trend of increase from mid to late

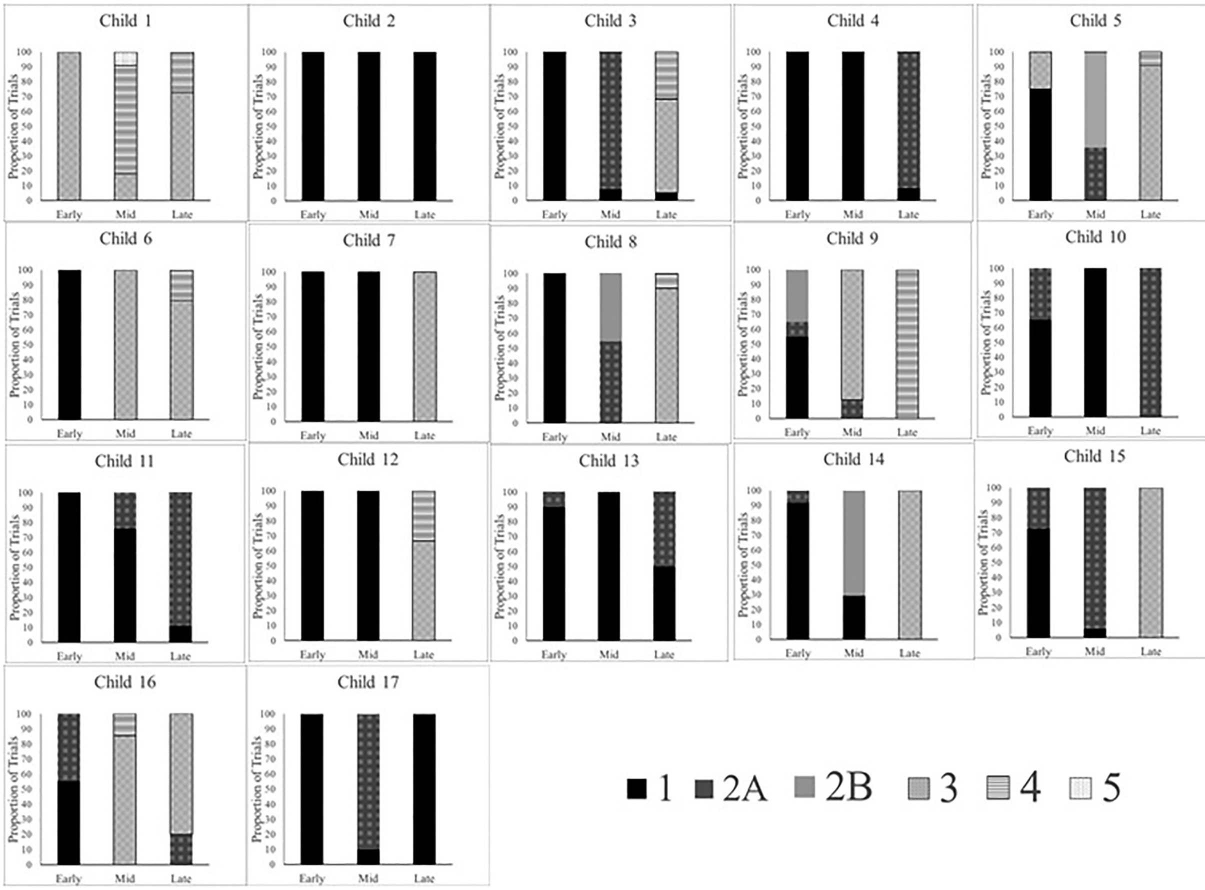

Figure 2. Individual data on stage of communication across training sessions.

sessions ($p = 0.08$, SMD: 0.49, CI(SMD: −0.06–1.03). There were concurrent statistically significant decreases of large sizes across training sessions in the proportion of responsive requests especially from early to late and mid to late sessions (Mean(SE)—Early: 84.30(5.34), Mid: 77.54(4.23), Late: 60.44(4.98), p values < 0.01, SMD range: 0.93–1.03, CI(SMD) range: 0.30–1.68). There were no significant changes in the proportion of no response trials across sessions (see Figure 3). Our data suggest that across weeks, children reduced the need for trainer prompting to request for preferred items and instead improved their spontaneous requesting skills using the Jellow system.

Specifically, 12 out of 17 children increased the proportion of spontaneous requesting with a concomitant decrease in responsive or no response trials. Among the remaining 5 children, 3 increased the proportion of responsive requesting trials. These 3 children were either more severely involved, had behavioral issues, required greater support, or were at the younger end of the age range. In fact all 3 children remained at either stage 1 or 2A of communication throughout the training duration. Two other children were at ceiling levels (100% trials) for responsive requests in early and mid-sessions but showed some reduction in responsive requests with a concurrent increase in no response trials in the late session. It is likely that the late training session chosen might not have been appropriately reflective of their capabilities, due to higher levels of non-compliance during this session. However, both children showed an increase in the stage of communication from the early and mid to late training sessions and in fact were at Stage 3 (app stage) during the late session. Alternatively, the transition from picture cards to the app that occurred at or around the last session coded for these children may have accounted for some of the trends observed.

Attention during trials

The ANOVA indicated a significant main effect for attention type (F (2, 32) = 19.42, $p < 0.001$, $\eta_p^2 = 0.55$) and a trend for an attention type × session interaction (F (4, 64) = 2.12, $p = 0.08$, $\eta_p^2 = 0.12$). Post-hoc analysis for the significant main effect suggested that across training sessions, children engaged in the greatest proportion of trials where they were attentive with cueing, followed by trials not requiring cueing, with a relatively low proportion of trials falling in the inattentive category (Mean(SE): Attentive with cueing: 65.08(4.38), Attentive without cueing: 26.88(4.10), Inattentive: 8.04(1.42), p values < 0.001, SMD range: 0.06–3.01, CI(SMD) range:

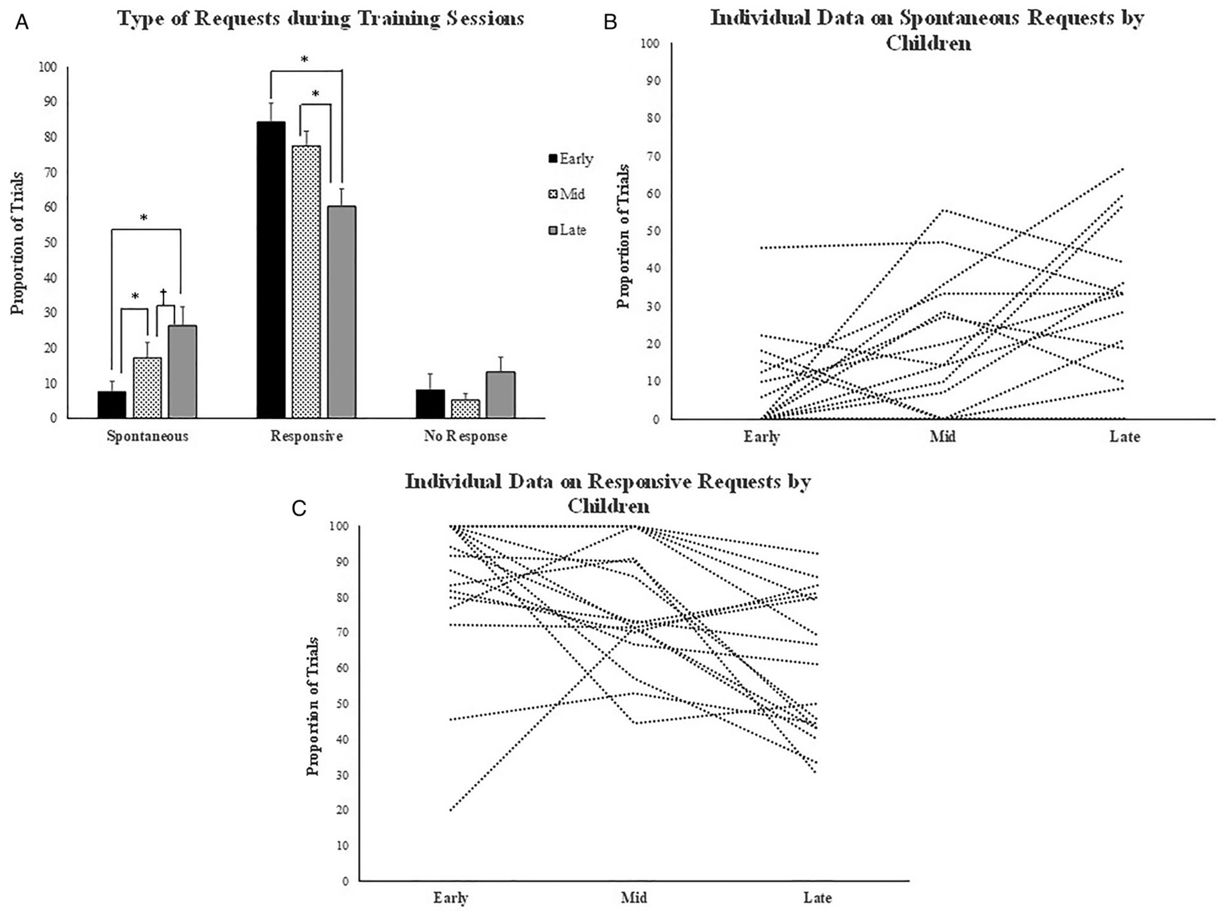

Figure 3. (A) Group data on training-related changes in type of requests children engaged in during training sessions. (B) Individual data on training-related changes in spontaneous requesting. (C) Individual data on training-related changes in responsive requesting.

0.40–4.30). Although the attention type × session interaction was only a statistical trend, further exploratory analyses suggested that children showed a pattern for reduction in proportion of trials requiring cueing to maintain attention, with a concurrent increase in trials where children were attentive without additional cueing from early to late sessions (see Figure 4; Mean(SE): Attentive with cueing—Early: 72.81(6.92), Late: 59.20(8.45), $p = 0.04$, SMD: 0.45, CI(SMD): –0.99–0.08; Attentive without cueing—Early: 20.42(6.68), Late: 32.90(7.74), $p = 0.06$, SMD: 0.43, CI(SMD): –0.10–0.97). Overall, there is some preliminary evidence that across sessions children improved their ability to maintain attention on task while making requests, without extra prompting from the trainer.

Eleven out of 17 children reduced proportion of cued and/or inattentive trials and increased proportion of uncued trials from an early to a late session. Among the remaining 6 children, 4 children required cueing to remain on task for a majority of the trials across all three sessions. Two other children showed an increase in the need for cueing from an early to a late session with an increase in the proportion of inattentive trials.

Average time to completion

There were no significant training-related changes in the average time taken to request for preferred items across sessions (Mean(SE)—Early: 9.39(0.99), Mid: 9.97(0.98), Late: 12.39(1.71), SMD range: 0.14–0.70, CI(SMD) range: −0.38–1.13). We found that that a majority of children actually increased the time taken to complete trials in the late compared to the early session, although this trend was not significant at the group level. Further analysis suggested that these children also showed an increase in the stage of communication across training sessions.

Discussion

Background of study and summary of findings

Our longitudinal study assessed the efficacy of a novel AAC system, Jellow Communicator, in promoting requesting skills in 17 young children with ASD. The Jellow AAC system is one of the first of its kind developed to cater to the unique socio-cultural sensibilities of the Indian diaspora. A majority of the commercially available AAC systems have been developed from an Anglo-European perspective (Muttiah et al., 2022; Nigam, 2006; Srinivasan et al., 2011). It is paramount that AAC systems be designed bearing in mind the local socio-cultural, linguistic, and geographic context (Blake Huer, 2000; Huer & Saenz, 2002; Nigam, 2006; Parette & Huer, 2002; Soto & Yu, 2014). For instance, a mixed methods study conducted in Southern India to evaluate trends in communication interventions suggested that speech language pathologists, special educators, and behavior therapists acknowledge that existing West-centric systems would need to be significantly modified to suit local needs; in fact, stakeholders highlighted the need for collaborations between health care professionals and local research institutes to develop *affordable* and *appropriate* culture- and child-specific communication systems to cater to the cultural and linguistic diversity in India (Srinivasan et al., 2011). Moreover, popular lexicons such as the Picture Communication System (PCS) may not be appropriate for a culturally and linguistically diverse population of Asian Indians (Nigam, 2006). Specifically, certain items in the PCS lexicon were not important for Asian Indians, whereas other items of importance for the group were missing in West-centered lexicons. The author suggested building and validating a socio-culturally appropriate lexicon as the first step in providing a culturally-valid AAC intervention (Nigam, 2006).

We used an iterative and participatory user-centric design process to develop the pictorial symbols and textual content for Jellow (Boster & McCarthy, 2018; Lubas et al., 2014; Srinivasan et al., 2017). The only other systems that have been specifically designed for the Indian population include the Avaz app and the AutVisComm communication system (Sampath et al., 2013; Sankardas & Rajanahally, 2017). Out of these systems, the Avaz app is currently commercially available in India. The open-source Jellow system has several advantages over other indigenous systems including availability in multiple formats, accessibility to users with diverse abilities, constant expansion of system content based on user input, and finally being available free-of-cost, thereby, enabling access even for the most economically disadvantaged families. Moreover, we first developed Jellow's high-tech version in local languages for the Android platform prior to initiating efforts directed towards the iOS platform. In contrast to the Western market that is dominated by Apple products (including phones and iPADs; Kagohara et al., 2013), 95% of the Indian market is dominated by Android products that are more affordable than their iOS counterparts (Statcounter GlobalStats, 2021). Similar to our efforts, other researchers have also developed AAC apps in native languages such as Brazilian Portuguese and Chinese, with content and symbols chosen to suit the cultural practices of the region (An et al., 2017; de Oliveira et al., 2016).

Our study has several strengths including the inclusion of children with ASD who lack natural speech, implementation of a longitudinal design, and delivery of the intervention in a public special school that caters predominantly to families belonging to lower socioeconomic strata. Moreover, compared to previous studies, we had a larger sample size of 17 subjects (Ganz et al., 2017; Muharib & Alzrayer, 2018; Still et al., 2014). Following the longitudinal intervention using the Jellow system, a majority of the children improved their stage of communication, spontaneous requesting skills, attention during trials, and receptive communication skills. Caregivers also indicated a positive impact of Jellow on their child's self-esteem, adaptability, and competence. Below, we further discuss our key findings in relation to existing literature in the field and implications of our work.

Improvements in requesting skills following intervention using Jellow AAC system

Sixteen of the 17 children in our study showed improved requesting skills following a relatively short AAC intervention. For young children with complex communication needs, provision of a functional mode of communication can have far-reaching positive effects on children's communication development, expressive and receptive language skills, behavioral issues, cognitive development, literacy, and overall social participation (Collette et al., 2019; Drager et al., 2010; Franco et al., 2009; Schepis et al., 1998; Thunberg et al., 2009). Although we did not conduct follow-up testing, parent reports of improved quality of life and clinician-based assessment of improved receptive communication skills following the intervention lend support to the effects of the AAC intervention on children's overall well-being and social participation.

We developed a hybrid training program (incorporating both the low-tech flashcard and high-tech app versions of Jellow) based on the PECS protocol, that involved children transitioning from the low-tech to high-tech versions of Jellow as part of the training program. With training, 11 children transitioned from flashcards to using the app to request preferred items. Similar improvements in independent requesting skills were reported by Wendt and colleagues who used a modified PECS training protocol to teach requesting skills to 3 young adults using an iPAD-based SPEAKall!® AAC application (Wendt et al., 2019). While Wendt et al., implemented their modified PECS training solely on the iPAD, we used a hybrid training protocol that integrated low-tech and high-tech AAC modes. Nevertheless, similar to our study, Wendt and colleagues also reported considerable variation in magnitude of individual improvements that they attributed to baseline differences in cognitive skills among participants (Wendt

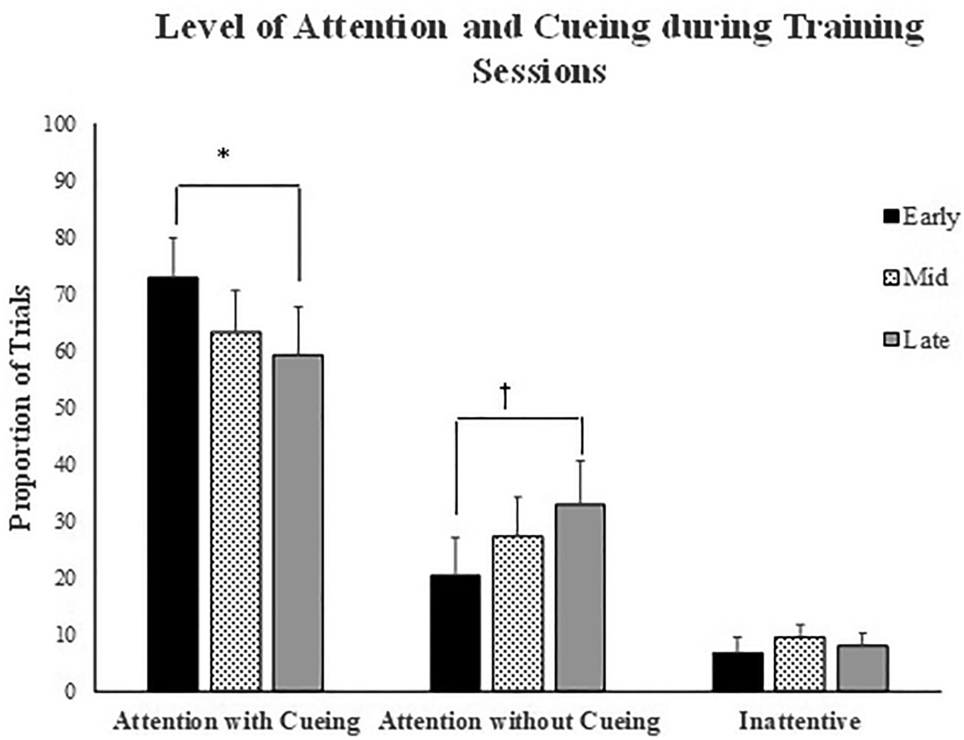

Figure 4. Children's level of attention during test trials within training sessions.

et al., 2019). Other research has also indicated significant variability among participants in their response to picture-based versus high tech AAC systems (Agius & Vance, 2016; Bock et al., 2005; Boesch et al., 2013; Gilroy et al., 2018; Lorah et al., 2013; Van der Meer et al., 2012). For instance, a study comparing request training using picture exchange and an iPAD-based system in 5 children with ASD suggested that on the whole, the high-tech system led to more independent responses in children. However, 3 of the individual children met mastery criterion for requesting more quickly using the iPAD, whereas the remaining 2 participants showed better results with picture exchange (Lorah et al., 2013). On the other hand, in a larger randomized-controlled trial comparing effects of a 4-month training using either PECS or a high-tech AAC system in 35 children with ASD, it was found that both approaches led to improvements in rates of prompted and unprompted requesting as well as social responding (Gilroy et al., 2018). Ultimately, communication skill acquisition using low-tech and high-tech systems may be associated with individual child preferences for AAC modalities (Lorah et al., 2013; Van der Meer et al., 2012).

Although we did not conduct an individualized preference assessment for low-tech versus high-tech AAC modalities, in a developing country like India, we think that in addition to culturally-sensitive high-tech AAC apps, it is equally important to provide families access to low-tech aids that are more affordable and that families may regard as being "easier to use" given their existing comfort level with technology (Muttiah et al., 2022). This is also beneficial from the perspective of clinicians who may be initially more comfortable facilitating mastery of low-tech aids using well-established instructional protocols (Gilroy et al., 2017). Provision of low-tech aids also helps overcome technology-related issues/barriers such as low battery, muted volume, difficulty navigating between multiple applications on the device, etc. Therefore, we designed Jellow as a single comprehensive system of AAC solutions available as a continuum of low-tech and high-tech options that use a common design language, thereby enabling ease and flexibility of transition across available formats as child and family needs change. Along the same lines, it has been suggested that despite ongoing research on high-tech systems as a replacement for low-tech AAC aids, a better alternative would be to incorporate elements of low-tech approaches into the training protocol for high-tech aids (Allen et al., 2016; Gilroy et al., 2017).

Improvements in requesting skills following training using Jellow are in line with previous systematic reviews and meta analyses that generally reported positive effects of high-tech AAC systems in promoting social communication skills including requesting in individuals with ASD (Ganz et al., 2017; Gilroy et al., 2017; Muharib & Alzrayer, 2018; Still et al., 2014). For instance, King et al. (2014) trained three 3–5-year-old children with ASD to use the Proloquo2Go™ app on the iPAD® to request preferred items using a modified PECS Phase I-IV protocol. All 3 children improved their requesting skills; however, similar to our study, children were not able to complete all phases of the study due to lack of time (King et al., 2014). It has been suggested that completion of all phases of the adapted PECS protocol may be beyond the scope of a single study (An et al., 2017; King et al., 2014; Sulzer-Azaroff et al., 2009). In another study, Lorah and colleagues also used the Proloquo2Go™ application within a classroom setting to teach 3 preschool-aged children with ASD to discriminate between picture symbols and request for a preferred item. Children were able to maintain acquired skills even after completion of training (Lorah, 2018). Although we did not assess maintenance of gains, ours is the first study to indicate that a novel, socio-culturally valid AAC system designed for the Indian population can be used effectively to teach children to request for preferred food and toys.

We found that children increased the proportion of spontaneous requests over the course of the training, with 12 out of 17 children following the group trends. This is specifically salient since children with ASD exhibit greater deficits in spontaneous compared to responsive communication (Tager-Flusberg et al., 2005; Vismara & Rogers, 2010). Specifically, children have difficulties in spontaneous initiation of speech, lack spontaneity in social interactions, and often rely on prompts to elicit communication (Brinton & Fujiki, 2009; Carr & Kologinsky, 1983; Chiang, 2009; Duffy & Healy, 2011; Stone et al., 1997). In our study, although children had high levels of responsive/prompted requesting to begin with, they increased spontaneous requesting using flashcards and the Jellow app as training progressed. The use of evidence-based behavioral training strategies may have helped enhance children's understanding of cause-effect and consequently led to increase in spontaneous requesting for preferred items.

Despite improvements in requesting skills following training, we did not find any statistically significant decreases in the time to complete test trials (although individual data suggest that 6 out of 17 children showed reduction in time taken to request for preferred items). It is likely that as children progressed to higher stages of communication that required them to discriminate among multiple pictorial symbols or navigate through the app to request preferred items, the associated higher levels of cognitive demand may have led to children requiring greater time to make the request. Given the severity of communication impairments in study participants, the 3-month study duration may simply have not have been long enough to teach all children independent requesting skills. Several studies have acknowledged this variability in individual responses to training across children with ASD (Alzrayer, 2020; King et al., 2014; Schlosser & Wendt, 2008; Wendt et al., 2019). Although our original intention was to continue training through the entire school year, delays in getting approvals from the hospital IRB and school authorities led to a limited duration of training that may have impacted our results.

In a recent systematic review, Sievers and colleagues argued that individual variability in outcomes associated with AAC interventions need to be assessed in-depth to best identify children most likely to benefit from specific types of AAC interventions (Sievers et al., 2018). The review therefore aimed to identify baseline child characteristics that serve as predictors (factors associated with improvements in outcomes irrespective of the type of AAC intervention), moderators (factors predictive of child's response to specific type of AAC intervention), or mediators (factors that explain child's response to a specific AAC intervention) of response to AAC interventions. They found that child cognition, age, severity of ASD symptoms, as well as receptive and expressive language levels at baseline predicted response to AAC interventions (Sievers et al., 2018). All children in our study were categorized as having "low" levels of adaptive functioning on the VABS-2 and fell below 0.5 percentile rank on the adaptive behavior composite. Specifically, all children fell below the 6th percentile rank for communication, daily living, and socialization skill domains. Given the severity of their impairment, it is not surprising that children did not show improvements in all outcome measures within the limited study duration. Moreover, as mentioned above, 6 of the 17 children remained at the flashcard stage. These children fell at or below 0.3 percentile rank in terms of all individual domains on the VABS as well as on the adaptive behavior composite. In future studies, we will systematically assess the association between baseline child characteristics and their responses to AAC interventions.

Another major factor that may have influenced our findings is the lack of carryover of training beyond speech therapy sessions into the child's naturalistic routines at home and at school. Knowledge of AAC, perceptions towards AAC, and amount of adult input/instruction at home have been identified as mediators for outcomes associated with AAC interventions (Sievers et al., 2018). There is strong evidence that caregiver training to implement AAC instruction can lead to improved requesting skills in children with ASD (Hong et al., 2016; Sigafoos et al., 2004; Suberman & Cividini-Motta, 2020). Although we provided regular caregiver training during the study and involved them in weekly training sessions, caregivers reported difficulty in continuing AAC instructional activities at home. Caregivers often continued habitual practices of fulfilling their child's needs preemptively without waiting for the child to initiate a request using the AAC system, thereby limiting opportunities for children to practice requesting skills. These findings are in line with other research that has reported on challenges with adoption of AAC systems within home settings by culturally and linguistically diverse families (Kulkarni & Parmar, 2017; McCord & Soto, 2004).

As mentioned previously, included families predominantly belonged to lower socioeconomic strata; caregivers had several responsibilities related to home chores and family care. For a majority of the children, the mother was the only person involved in therapy sessions and there was limited carryover of AAC instructional strategies at home by other family members. Our study suggests that within the context of a developing country like India, there is a need for greater emphasis on overall family education to ensure caregiver buy-in and to encourage consistent caregiver-delivered AAC instruction at home for best possible outcomes (Kent-Walsh et al., 2010; Srinivasan et al., 2011). Difficulties in involving families in AAC interventions may partly also be explained by cultural differences, literacy and beliefs towards AAC, and perceptions towards healthcare (McCord & Soto, 2004; Parette & Huer, 2002; Kulkarni & Parmar, 2017). For instance, compared to Euro-American families, Asian cultures may be more hesitant to adopt AAC intervention due to fears of adverse impact on speech production and social stigma associated with using external aids, they may prefer professionals to assume responsibility of training and using AAC with their child, and families may get discouraged in the absence of signs of immediate success with training (Blake Huer, 2000; Haupt & Alant, 2002; Parette & Huer, 2002; Schlosser & Lloyd, 2003; Schlosser & Wendt, 2008). Overall, we recommend that greater efforts be directed in the future towards involving families in all steps of the AAC decision-making and intervention delivery process.

Psychosocial impact of the Jellow AAC system on children with ASD

We used the PIADS to assess the direct impact of Jellow on children's quality of life and indirectly to assess the usability of Jellow. Caregivers perceived a positive effect of introduction of the Jellow AAC system on their child's quality of life. The greatest impact of the intervention was perceived on self-esteem, followed by adaptability, and then competence levels. The PIADS is able to reliably predict abandonment and retention of an assistive device (Day et al., 2002; Jutai & Day, 2002). Other studies have used the scale to assess the impact of assistive technologies such as eye tracking-based communication devices and standers in individuals with disabilities (Caligari et al., 2013; Garry et al., 2016; Nordström et al., 2014). Although the use of a parent proxy for child ratings is not accurately reflective of children's opinions, there is some evidence that parents of children with health conditions often tend to underestimate their child's quality of life (Huang et al., 2009). Therefore, it is encouraging to see an overall parent-reported positive impact of Jellow on their children with ASD.

Limitations and future directions

Our findings are limited by a quasi-experimental study design, relatively small sample size, limited training duration, and a lack of follow-up assessments to evaluate generalization and maintenance of learned skills outside training sessions. Our training was restricted to one-on-one speech therapy sessions with the child with limited carryover into the child's naturalistic routines at home and during the rest of the school day. We also coded only 3 representative sessions per child as being indicative of their performance at early, mid-point, and late parts of the training. Although our sample included families from socioeconomically disadvantaged backgrounds, our findings cannot be directly generalized to the wider Indian population from rural and other urban areas. In rural areas, families frequently lack access to smart phones or internet connectivity which may preclude use of high-tech AAC systems. At the time the study was conducted, the Jellow system had limited customizability and was available in only a select number of Indian languages. For instance, the app had only 3- or 9-icon grid display options to choose from. Similarly, the app did not have a "lock screen" functionality that was reported by the speech therapist to be a limitation, as children frequently navigated between screens instead of focusing on a single screen. We recommend more research to replicate our findings using a randomized controlled trial design with more homogenous samples, to systematically assess the efficacy of the latest customizable version of the Jellow communicator AAC system with children with ASD. Moreover, there is a need to identify and better understand child- and environment-related factors that may influence the child's response to the Jellow AAC intervention.

Clinical implications and conclusions

Our study suggests that the novel, child-friendly, Jellow Communicator AAC system, specifically designed bearing in mind the socio-cultural landscape in India is effective in teaching requesting skills to children with ASD who use multiple communication modalities. The Jellow AAC system provides a culturally-validated lexicon and pictorial library that has been developed through an iterative, user-centric design process. The study demonstrates that following a 3-month longitudinal AAC intervention, children can learn to use low-tech and high- tech versions of the Jellow system to request for preferred items. Moreover, once children learned cause-effect associations, they increased levels of unprompted, spontaneous requesting for preferred items using Jellow. The study provides clinicians a systematic and incremental hybrid training program adapted from the original PECS protocol to teach children requesting skills by incorporating low-tech and high-tech versions of the Jellow system. Although the present work needs replication and expansion to other social communication skills beyond requesting, our pilot data provide support for the use of a novel, cost-effective, child friendly AAC system, Jellow Communicator, to teach requesting skills to children with ASD.

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Ethical statement

All procedures performed with human subjects as part of this research were approved by the Ethics Committee at the Indian Institute of Technology Bombay and the Ethics Committee for Academic Research Projects (ECARP), Topiwala National Medical College and BYL Nair Charitable Hospital. All procedures were in compliance with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Declaration of Conflicting Interests

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