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POMA: A tangible user interface to improve social and cognitive skills of Sri Lankan children with ASD

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A R T I C L E I N F O

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A B S T R A C T

A Tangible User Interface (TUI) can bridge real-world physical objects with the digital world, which has much potential for children with ASD. However, at present, most TUIs have been developed for children in affluent countries. Such solutions may not be applicable for children with ASD in low resource countries like Sri Lanka. Therefore, we have designed a tablet-based, and cost-effective TUI called POMA (Picture to Object Mapping Activities) for supporting social and cognitive skills of Sri Lankan children with ASD. This paper presents the evaluation of POMA with 20 children with ASD (moderate: 6; mild: 14) and five special education teachers. Results show that both groups of children were able to play POMA accurately. However, children with moderate ASD required more time and help from the special education teachers to play POMA compared to children with mild ASD. This study identified several lessons for designing TUI, such as the importance of including audio prompts when the system is in idle state, using appropriate helper cues, using multiple types of reinforcements, easy-to-handle nature of the tangibles and the properties of them. Finally, we provide guidelines to overcome the issues for designing low-cost TUIs for children with ASD.

1. Introduction

Tangible User Interface (TUI) has demonstrated its potential in supporting children for their learning activities in the past ten years. Numerous studies have shown that TUI-based tools can be used in educational activities such as geometry training (Bonnard et al., 2012), colour matching (Kubicki et al., 2015), science activities (Shaer et al., 2014), computer programming (Horn et al., 2012) for typically developing (TD) children as physical objects interacting with virtual environments can cater playful learning environment (Shaer et al., 2014). According to Piaget developmental theory, manipulation of concrete physical objects can improve thinking and spatial skills for young children (Wadsworth, 1996). In addition to such skills, the work on TUI has suggested that TUIs might be suitable for engaging children and collaborative learning for children (Marshall, 2007). Prior research has shown that tangible interactions with technological platforms (i.e., tabletop technologies) offer a variety of possibilities and opportunities to design educational activities for children (Zuckerman et al., 2005). A number of design-focused projects have researched on TUIs to improve social and cognitive skills for young TD children (Schneider et al., 2011) as well as for children with social cognitive impairment such as Autism Spectrum Disorder (ASD) (Alessandrini et al., 2016; W. Farr et al., 2010b; Villafuerte et al., 2012). Hence, it is clear that TUI-based applications are well suited for children, especially when they are designed to facilitate their early childhood development, where physical object manipulation is a critical component.

Although TUI-based interventions can be beneficial for children, most of the TUI-based applications are designed for affluent English-speaking resourceful countries. Furthermore, most TUI-based applications designed for children are based on high-cost technological platforms such as tabletop devices (Anastasiou et al., 2016; Jurdi et al., 2018; Villar et al., 2018). Therefore, this study investigates the applicability and suitability of a low-cost TUI called POMA, designed to support children with ASD in low resource countries like Sri Lanka. POMA is an economical, culturally applicable TUI-intervention for Sri Lankan children with ASD, which can be used to get the children engaged in regular learning activities along with social interactions. The key contributions of the paper are the following aspects:

1) evidence showing that children with ASD could play a low-cost, culturally adaptable TUI-based educational game called POMA.
2) identification of the structure of the tangible toys that would prevent children from placing the toys correctly on the iPad screen.
3) distinguishing the suitability of POMA for different groups of children with ASD in low-resource regions.
4) a set of design implications to develop low-cost TUIs for children with ASD.

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2. Related work

2.1. Technological platforms to improve social and cognitive skills of children with ASD

ASD is a developmental disorder that can appear from a very early stage of childhood, and it is associated with cognitive impairment in attention, social communication, along with restrictive and repetitive interests and behaviours. Due to such impairments, children with ASD demonstrate problems in social engagement, impatient in turn-taking and waiting (CDC, 2016) that could potentially affect their day-to-day activities and their quality of life (Heyvaert et al., 2014). Therefore, it is imperative to diagnose children with ASD and direct them to proper intervention programs from a very early stage to support such skills (i.e., social interactions and turn-taking). Similar to social interaction and turn-taking skills, another most essential skills children with ASD need to develop is academic skills, which can be improved using technological interventions. Therefore, two of the significant things that users want from technology are the development of social and academic skills (Putnam and Chong, 2008).

Technological interventions often include tangible toys (i.e. cause and effect toys), visual support (flash cards) to represent both concrete and abstract real-world concepts (Asher, 2017). For instance, occupational and special education teachers use cognitive therapies like object discrimination with pretend-play toys (i.e., plastic toy fruits and vegetables) to empower very young (ages 4–6) children with ASD (Wimpory et al., 2007). Similarly, some special education teachers and general education teachers used Montessori teaching methods and Montessori toys (Montessori, 2013), to improve sensor-motor training and spatial abilities via physical objects (toys) that are relatable and natural for children. Further, such Montessori teaching methods highlight the importance of learning through exploration, physical play, repetition and simplicity, not only for TD children but also for children with ASD (Bartak and Rutter, 1973; Gustafsson, 2018). For instance, in teaching children to understand the basic geometric shapes, teachers use flashcards containing the picture of the shape to match the correct physical object that represents the geometric shape in the flash card. The strengths of hands-on interaction with physical objects are that they can help understand the representations of relations within and between objects (e.g. shapes) (Verdine et al., 2014). Such skills are essential for early childhood development for both TD children as well as children with ASD. These significant factors such as learning through physical play, repetition and visual support can be considered when designing technologies and tools targeting young children.

Prior research has shown that technological platforms such as televisions, computers, tablets and robots can enhance social and cognitive skills of children with ASD (Caro et al., 2017; Chien et al., 2015; Dillon and Underwood, 2011). For instance, video modelling using platforms such as televisions have shown that children with ASD can improve their social initiation (Nikopoulos and Keenan, 2004), social engagement (Bellini et al., 2007), social communication (Sansosti and Powell-Smith, 2008) skills of children with ASD. Furthermore, computer software programs and tablet applications can also be used to improve collaborative (Boyd et al., 2015), requesting (King et al., 2014), turn-taking (Kim and Clarke, 2015) skills and play dialogues (Murdock et al., 2013) of children with ASD.

When compared to traditional intervention programs, technology interventions can offer many advantages. The main advantage of using technology over traditional intervention programs is that technology can provide consistency and predictability, immediate feedback while establishing clear routines and expectations that satisfy the needs of children with ASD (Bernard-Opitz et al., 1999; Moore and Calvert, 2000; Panyan, 1984; Silver and Oakes, 2001). Additionally, technological interventions such as computer-based interventions can provide a wide array of resources (visual images, variations of learning environments, audio clips related to academic contents) that can be tedious in the traditional learning environment (Bosseler and Massaro, 2003). Additionally, most of the technological interventions can provide colourful graphical contents with animations and sounds effect (Massaro and Bosseler, 2006; Moore and Calvert, 2000; Whalen et al., 2010) as sensory reinforcements to make children more interested and attentive in the learning process while decreasing distractions. Therefore, it is fair to predict that technology-based interventions would be advantageous for some children with ASD and their therapists than traditional intervention programs.

2.2. TUIs for children with ASD

Although there have been many technological tools designed to support children (Boucenna et al., 2014; Hutchby and Moran-Ellis, 2013), most of these technological interventions support 2-dimensional learning with visual and auditory support such as touch-based technologies (iPad, tablets and tabletop applications) (Muharib et al., 2018; Whitehouse et al., 2017), computer-based technologies (computer software) (Fletcher-Watson, 2014), virtual reality (computer software) (Didehbani et al., 2016) etc. Such technologies and tools can be beneficial for children, especially children with ASD as these tools promote visual learning with immediate feedback. However, these tools lack the benefit of 3D learning and the use of real-world objects that support more effective or more natural learning (Sluis et al., 2004). TUI-based technologies can effectively be used to avoid such limitations, as it embeds digital technology into graspable forms blending the best of both digital and tangible worlds. Prior research has shown that TUI-based technologies can be used to facilitate a wide array of learning topics from basic puzzles (Xie et al., 2008) to carpentry (Cuendet et al., 2015) for children. TUI is particularly beneficial for children with ASD as it supports tactile and sensory stimulation with digital feedback and effects, which are important factors for children with ASD as it can facilitate the sensory needs of children with ASD (Joosten and Bundy, 2010). Therefore, TUI is used to improve social interaction (W. J. Farr, 2011; Villafuerte et al., 2012) and cognitive skills (Alessandrini et al., 2014; Escobedo et al., 2014; Sitdhisanguan et al., 2012) skills of young children with ASD. Most of these aforementioned TUI-based tools are designed using tabletop devices as an input device and as a visual feedback display for the children, which enable children to engage in natural and direct interactions (Marco et al., 2013). In addition to tabletop-based TUIs, researchers have built smart toys such as Polipo (Tam et al., 2017) that offers various multisensory stimuli aimed at promoting fine-motor skills of children with ASD. Similarly, researchers have designed tangible educational interfaces (i.e., “ReduCat”) for therapists to engage with children with ASD in educational activities via social stories (Alessandrini et al., 2016).

These studies suggest that TUI-based technologies can be effectively used to support 3D learning for children with ASD. However, to the best of our knowledge, there is no study that focuses on developing affordable TUIs to support the learning of children with ASD in low-resource regions.

2.3. Technology designs for children with ASD in developing and low-resource countries

Even though there is a positive impact on the use of technology for children with ASD, there is only a few research on technological interventions for children with ASD in the developing world (Nuria and Begonya, 2014; Sharma et al., 2016). Recently, researchers from Mexico built multimodal interfaces for children with autism to support sensory impairments. For example, ‘SensoryPaint’ (Ringland et al., 2014) is a tool that allows painting on a display using tangible objects and whole-body interactions for supporting sensory integration therapies. Another exergame called ‘Hunting Relics’ (Cibrian et al., 2016) was developed for school children to motivate them to exercise together. Hunting Relics runs on an interactive floor and uses a Kinect sensor to track the location of the user and projector to demonstrate it. Similar to 'SensoryPaint' another large-scale multisensory system called 'BendableSound' (Cibrian et al., 2017) was designed to provide music therapy to children with severe autism. BendableSound also used a Kinect sensor and projector similar to Hunting Relics so that children with autism could make music by tapping and touching on top of the fabric. All these systems have been evaluated successfully and were perceived to be easy for children. However, these systems might not be fully utilised in low-resource regions because of the use of sophisticated technologies and the lack of technical knowledge amongst the therapists working in remote locations like Sri Lanka.

Sri Lanka has the highest known autism prevalence (1.07% or one in 93) in South Asia (Hossain et al., 2017; Perera, 2008); however, to our knowledge, there has been no technological interventions designed to support children with ASD in Sri Lanka. Winter (2000) has highlighted that due to limited research and literature on the latest technology and current educational innovation in developing countries, developing countries trailing behind developed countries (Winter, 2000). In the recent past, there have been a few pieces of researches that focused on designing technology interventions (such as digital media) to support children with ASD in the developing regions such as Ecuador, Africa, Indonesia, Bangladesh and India (Galán-Mena et al., 2016; Hassan et al., 2011; Mensah and Hayfron-Acquah, 2018; Pradibta and Wijaya, 2017; Sharma et al., 2018; Vellanki et al., 2016). However, all these studies were limited to digital technology, which focused on 2-dimensional learning. All the prior studies (Escobedo et al., 2014; W. J. Farr, 2011; Sitdhisanguan et al., 2012; Tam et al., 2017; Villafuerte et al., 2012), related to TUI for children with ASD are limited to developed regions like the United States, the United Kingdom and Australia using expensive technologies such as tabletop devices. However, such technologies might not be useful for children in low-resource countries. Due to the low-resources and the lack of materials in local languages, there has been a digital divide in low resource countries like India, Sri Lanka (Singh, 2010).

The above studies demonstrate that existing applications developed for the western countries might not be suitable for low-resource countries due to their high cost and interface elements may not be culturally appropriate. Therefore, the body of work suggests that there is a need to develop affordable technology to support children with ASD in developing countries. To address this gap, we have designed and developed a TUI-based intervention called POMA (Picture to Object Mapping Activity) to support children with ASD in Sri Lanka. POMA (Picture to Object Mapping Activity System) is a TUI-based educational game running on iPad that promotes Picture to Object Mapping Activities via placing tangible objects on top of the iPad surface. POMA consists of several activities with both single-player and multi-player modes to incorporate playful social interactions via turn-taking for children with ASD. Tangible interaction is achieved in this game by using a set of low-cost pretend-play toys (i.e., iPPy toys). During the play, children are required to keep the relevant iPPy toys on the iPad screen for digital-tangible interactions. The total cost for one set of iPPy toys (i.e., animal-shaped toys with ten animal type iPPy toys) is around 2.75 USD. POMA was primarily designed targeting children with ASD (age 3–6 years) to support practitioners (teachers and therapists) at Sri Lankan autism therapy centres; therefore, both practitioners and children are the main stakeholders of POMA.

2.4. Study purpose and research questions

POMA was co-designed and evaluated with Sri Lankan special education teachers; however, POMA's usability was not validated by children with ASD. The main objective of the current study was to investigate how children with ASD would use POMA with their special education teachers and identify potential limitations and improvements of POMA to cater to the needs of the children. POMA was meant to be played collaboratively, and it is essential to understand if children with ASD could learn to play POMA without asking for help from the therapists. We assumed that if children were able to learn POMA, they would need less help over the time to play the different levels of POMA and eventually it would ensure the usability of POMA. Furthermore, it was expected that children would need relatively less time to finish each level of POMA as compared to previous levels, and that would indicate the learnability of POMA. Since POMA was designed to support the turn-taking skills of children with ASD, it was assumed that the number of turn-takings and social interactions would be increased while children play and move to different levels of POMA. While interacting with POMA, it was expected that children would be able to place the toys correctly, however; due to the severity of ASD and motor skills, some children might identify the iPPy toys and place them differently on the iPad screen. Therefore, it would be essential to find out if the current design of POMA would need to be changed to support a wider group of children with ASD. Based on our above assumptions, the following research questions were formed.

Q1 To what extent can children with ASD play POMA without asking for help?

Q2 Can children with ASD play the levels of POMA efficiently?

Q3 How do children with ASD use tangible components (i.e., iPPy toys) of POMA?

Q4 How do children with ASD react to software reinforcements prompted by POMA?

Q5 To what extent does POMA promote turn-taking and social interactions in children with ASD?

Throughout the above questions, we were also interested in if there were any differences in children with ASD while playing POMA. Though the focus of our current study is the evaluation of POMA with children with ASD, we provide a brief background about the design process of POMA, its design rationales and key features.

3. POMA: a low-cost TUI for children with ASD

3.1. The design process of POMA and rationale for designing it

An informant-led design and co-design approach were followed to develop POMA, including sixty participants; 32 parents of children with ASD, 18 practitioners who work closely with children with ASD. We established contact with local therapy centres in Colombo, Sri Lank and observed therapy sessions. Similar to existing studies (e.g., (Frauenberger et al., 2019)), we also conducted focus groups with parents and practitioners in Sri Lanka. During the interviews with practitioners and parents, we identified several barriers to involving Sri Lankan Children with ASD in the design process. Parents were not favourable to allow their children in the co-design study and lack of practitioners and their time commitment to support the children during the co-design process. Therefore, we designed POMA with the practitioners (i.e., participation via proxies as described in (Frauenberger et al., 2012)) and decided to involve children with ASD once we develop a matured prototype of POMA.

The design and the development process of POMA was broken down to four phases including; 1) informant-led design, 2) co-designing and wireframing, 3) development and formative evaluation with practitioners, and 4) usability testing (see Fig.1 and (Soysa et al., 2018) for the detailed design process of POMA). Via focus group and interview sessions with 32 parents of children with ASD and 18 practitioners, we found the key characteristics required in a technological intervention designed for children with ASD. These characteristics include a) support for social interaction to avoid social isolation, b) timers to avoid screen addiction, c) support for digital and physical play to enable 3-dimensional learning, d) customisation, e) support for Sri Lankan cultural context. After finalising the key requirements, we conducted a brainstorming session with Sri Lankan practitioners (n = 18). During the session, practitioners analysed seven existing social skill-based tablet applications to investigate their suitability for children with ASD (age 3–10 years) in Sri Lanka. The details of the selection process of seven table application can be found here (Soysa and Al Mahmud, 2018a). Throughout the brainstorming sessions, practitioners emphasised that tablet applications could be a powerful tool for children with ASD who might have fewer well-developed motor skills. However, they were concerned that tablet applications could also promote social isolation for children with ASD as most such applications have only child to tablet interactions. Therefore, they suggested designing tablet applications that would enable multi-user interactions simultaneously via collaborative activities and role changing. Through this approach, children would be forced to connect with their peers when using tablet applications. Another important aspect both therapists and teachers expressed was interacting with physical objects. They believed that interacting with touchscreens would not be enough for healthy brain development. Also, they were keen to introduce play-based learning where children get to interact with physical toys that provide the same educational concepts in a playful manner to support sensory integration, brain development, and special interest.

Even though social interactions were targeted in the proposed tablet application, another key aspect all the special education teachers and educational therapist highlighted was embedding current educational content (i.e. picture matching, colour matching, shape matching) currently practised in Sri Lankan therapy centres in the tablet application. Based on the above considerations, practitioners came up with the idea that incorporated picture-to-object mapping activities called POMA that allowed multiple activities that could incorporate many educational concepts. They designed POMA to allow two players to play simultaneously by dividing the tablet screen into two sections. Based on the activity type (i.e., shapes, fruits, and vegetables), POMA shows different images on both parts of the screen along with their respective name written in the Sinhalese language.

Later, paper-prototypes were designed according to practitioner requirements considering the therapeutic goals, cultural context and resources. In addition to learning collaboration, practitioners also highlighted that using familiarised physical objects can especially benefit children with ASD to develop sensory integration deficits and to support their special interests. Practitioners provided physical toys (everyday-used physical toys used in Sri Lankan therapy centres) to design the tangible component of POMA. Finally, fine-tuning sessions were conducted with practitioners to refine (i.e., select suitable reinforcements and feedback mechanism) POMA. Once the initial designs were finalised, wireframes were designed for the software component of POMA, and these wireframes were further evaluated with three practitioners (see Fig. 2).

We built the first working prototype of POMA based on the software-wireframes and the toys provided by practitioners. The software component (i.e., an iPad application) was developed under the iOS platform using Objective C and Swift programming languages. To design the interactive toys, we used plastic pretend-play toys that were provided by the Sri Lankan practitioners. We used small pieces of (2.5 cm X 2.5 cm X 2.5 cm) conductive foam to create unique touchpoint patterns on the bottom layer of the toys. These touchpoint patterns are identified from the x, y coordinate position of each touchpoint and the distance between each touchpoint (see Fig. 1). We were able to build 30 iPPy toys from one conductive foam (Size 225(L) x 150(W) x 6(H) mm). These touchpoint patterns were sewed using conductive threads on Acryl Felt sheets. Pattern-sewed acryl sheet pieces were then pasted on the bottom of each physical toy. To close the circuit, conductive threads were pasted around each toy using UHU plastic glue. Finally, the developed prototype was validated with the practitioners, and improved iteratively before we conducted the usability study with 20 Sri Lankan children with ASD, which is the key focus of the current study.

3.2. Features of POMA

The architecture of POMA has two main parts, namely software component, and tangible component. The software component is an interactive iPad application that has four activities and six levels. The four activities are related to the identification of 1) shapes, 2) fruits, 3) vegetables, and 4) animals. The levels start from beginner to more advanced levels from single-user modes to multi-user modes (see Table 1, Fig. 4). When children play POMA, they get to select the child preferred background colour, child's level and the activity of their choice (see Fig. 3). Table 1 lists the main activities and levels that are supported by POMA.

The tangible component consists of a set of interactive pretend-play toys (iPPy toys) that can communicate with multi-touch surfaces (see Fig 5). To give a variety of interactive pretend play toys (iPPy toys) for children, in consultation with the Sri Lankan therapists, we selected four different categories of play toys that are commonly used by children with ASD in Sri Lanka, namely, animals (chicken, elephant, cat, sheep, horse, goat, cow, dog, tiger and lion), shapes (round, square, star and triangle), fruits (orange, papaya, strawberry, melon, banana, apple, pineapple and grapes) and vegetables (mushroom, cabbage, tomatoes, pumpkin, chilli, eggplant, bitter melon and carrot).

4. Evaluation methodology

A mixed-method evaluation was conducted with both qualitative and quantitative data. The quantitative data for this study was captured from video recording and coding the behaviours of the children while qualitative data was collected via conducting a focus group session with the special education teachers who took part in the study with the children.

4.1. Participants

The children were recruited from a local autism centre in Colombo, Sri Lanka, after the study was explained to their parents and a written parental consent for their participation was collected prior to the participation from their parents.

After obtaining the approval from the ethical review board of our university, we recruited twenty children with ASD from a Sri Lankan autism centre. The children were recruited to this study by distributing leaflets in a local autism centre in Colombo, Sri Lanka and talking to their parents and practitioners. The children with ASD were recruited, if they had (a) medical diagnosis of autism according to practitioner's reports, (b) autism diagnosed under mild and moderate level, (c) verbal communication without the use of an augmentative and alternative communication device as verified by the parents, (d) age group of 3–6 years, (e) hearing and vision within normal (6/6 vision, hearing ranging 0–20 dB) limits (aided or unaided) based on parents' report, (f) motor and physical abilities to manipulate a tablet device. Practitioners categorized the children based on the children's medical records, mild level ASD for level 1 diagnosis of DSM-V criteria, moderate level ASD for level 2 diagnosis of DSM-V criteria of ASD. See Table 2 for demographic characteristics of the recruited children. Before recruiting the children, we got written consent from parents/caregivers of the children.

We also recruited five special education teachers to conduct the study with the children. Special education teachers were recruited for this study if they had 1) five years experience working with children with ASD, 2) experience handling technology for children with ASD in Sri Lanka, 3) professional qualifications to teach children with ASD, 4) minimum of 3 months of experience working with the recruited children. The special education teachers were recruited from the Sumaga Autism centre, and they worked closely with the recruited children.

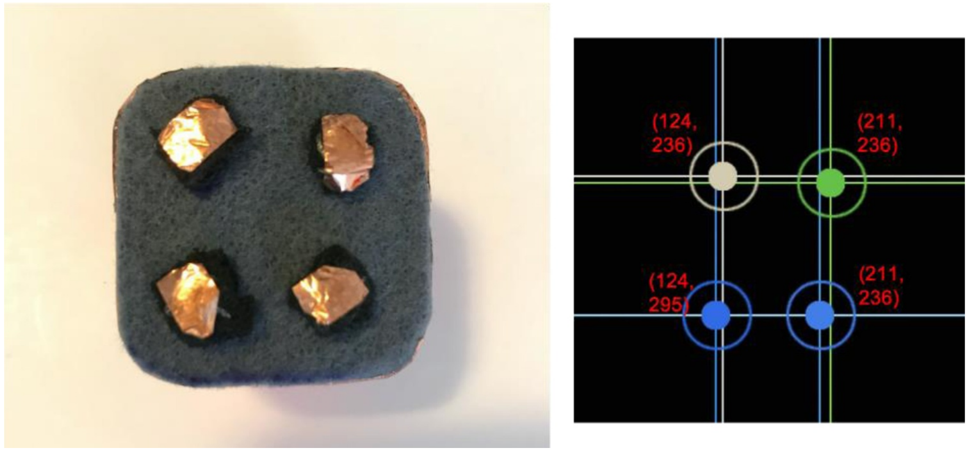

Fig. 1. Multi-touch point pattern recognition in iPPy toys.

4.2. Materials and settings

POMA was installed in an iPad Pro-device (12.9 inches) with 30 iPPy toys including; four types of shapes (round, star, triangle and square), eight types of fruits (orange, papaya, strawberry, melon, banana, apple, pineapple and grapes), eight types of vegetables (mushroom, cabbage, tomatoes, pumpkin, chilli, eggplant, bitter melon and carrot) and ten types of animals (chicken, elephant, cat, sheep, horse, goat, cow, dog, tiger and lion). Using these materials, we facilitated tangible user interfaces for recruited children with ASD. The study was carried out at a classroom in Sumaga Autism Centre, Sri Lanka. This autism centre caters therapies for children with ASD in different ethnicities.

4.3. Procedure

Before conducting the study, we described the functionalities of POMA software application and iPPy toys to each practitioner, then gave them time to explore the system. Once the special education teachers were familiar with the system, they started the sessions with the respective recruited children with ASD. In each session, a child with ASD was paired with a special education teacher who was familiar to the child (i.e., participated in therapy sessions at the centre). The evaluation sessions with the children were planned for one hour per each individual child; however, if special education teachers felt the need to stop the session, or if a child showed the need to stop the session, the session was terminated immediately.

At the beginning of each session, special education teachers first locked the iPad to the POMA application, using the guided access feature of the iPad. This was done to prevent children from accessing other applications (such as YouTube) on the iPad during the sessions. Secondly, special education teachers introduced the iPPy toys to each child, starting with the iPPy shape-toys. Depending on the child's preference, special education teachers switched the iPPy shape-toys to the other toy categories, namely the iPPy animal-toys, the iPPy vegetable toys or the iPPy fruit toys. After introducing the toys to the children individually, special education teachers started playing the iPad application with children from the basic level (Level 1). Special education

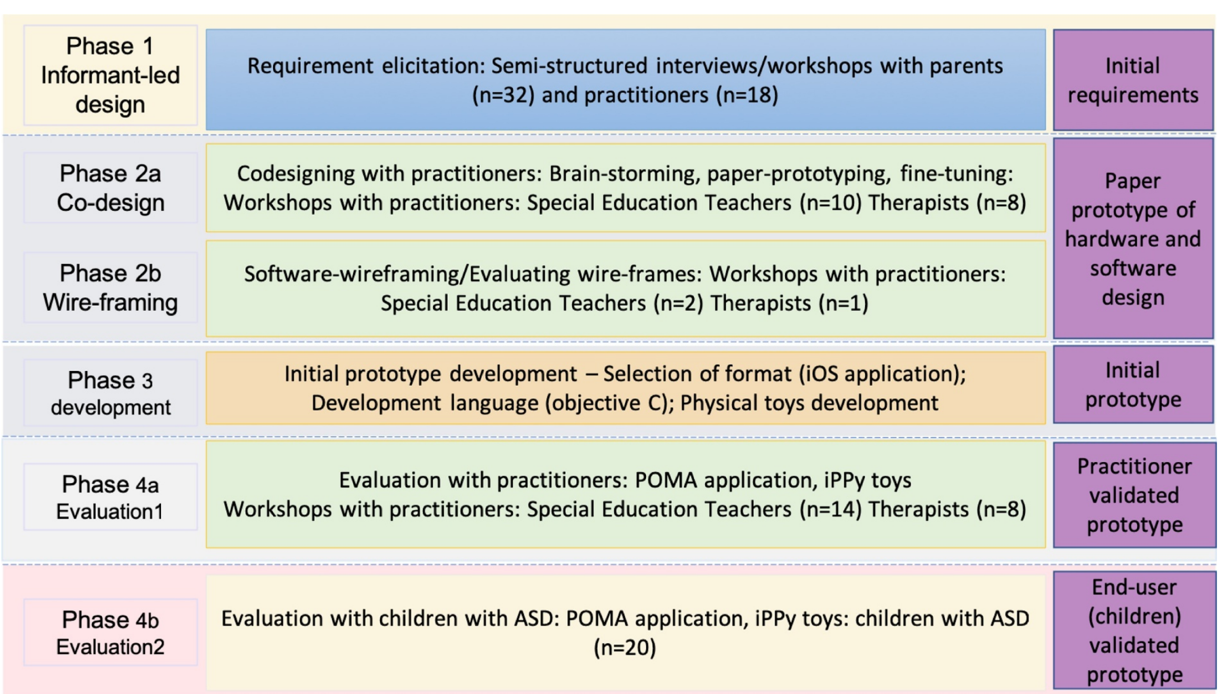

Fig. 2. The design process of POMA.

Table 1
Activities and levels supported by the POMA iPad application.

Feature	Description	Design rationale
Activities	Shapes, fruits, vegetables and animal identification activities.	Based on the traditional learning activities at Sri Lankan therapy centres.
Levels (Level 1- 2: Single player mode, Level 3–6 Multiplayer mode)	Level 1: players need to match the correct physical toy with the identical image of it shown in the iPad. Level 2: players need to match the correct physical toy with the identical image of it shown in the iPad. Level 3: turn-taking beginner level with two players. Share a single toy while playing the game. Level 4: turn-taking level for advanced children with two players. Share multiple toys while playing the game. Level 5: generalisation level, with turn-taking activities (with multiple toys) using unfamiliar images. Level 6: collaborative level with two players. Both players need to work collaboratively to win in the game.	Level 1- Level 2: For children to get familiarized with TUI and using digital and physical toys (based on practitioner requirements). Level 3 – Level 4: Practice turn-taking and sharing toys. Level 5: To test the generalizability of the learnt concepts. Level 6: Practice co-operative and collaborative play.
Reinforcements and cues	Audio and visual reinforcements are given to the children at the end of each game. Score based reinforcement – each child's score is also displayed at the bottom of the screen as a reinforcement. When the child is not placing the correct toy in level 1 and 2, help cues will be displayed on the screen in the form of images.	Based on practitioner requirement and traditional reinforcement techniques where children were given multiple reinforcements after a learning activity (i.e., food, play with a toy, music).
Colour picker	Each child gets to pick their preferred colour, based on the selected colours, iPad screen is divided into two sections. The background colour of each section represents each child's space to play.	Based on practitioner requirement where practitioners believed that different children prefer different colours, hence it is important to change colours based on an individual child.
Administrative functionalities	Add new children to POMA, monitor the progress of the children and the ability to customise images and play duration.	Practitioners requested to control the application duration, ability to change the educational content as well as monitor progress of an individual child.

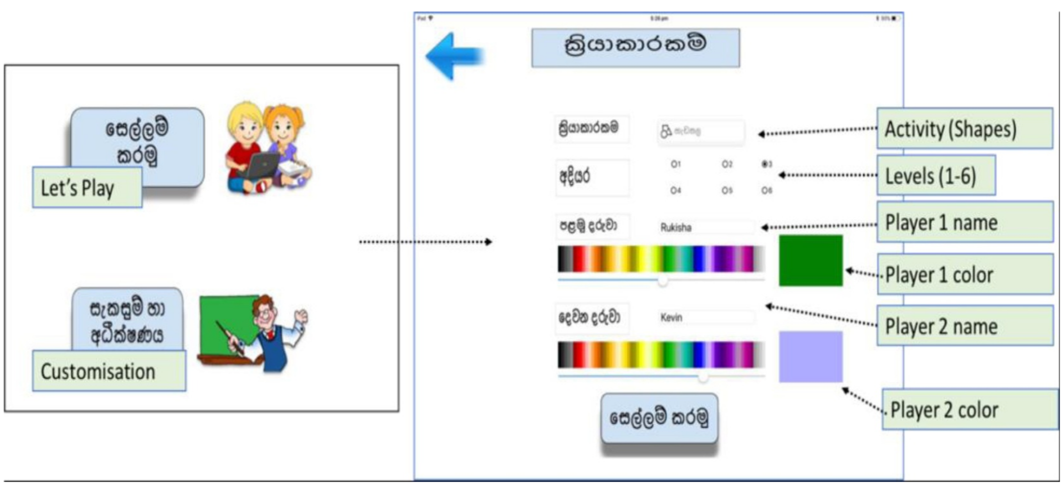

Fig. 3. Activity (i.e., animals, shapes, fruits and veggies) and level selection of POMA.

teachers were free to choose the activities that best responded to the child's need and lead the session.

If a child performed well at a given level (i.e., if a child places the correct toys at least 60% of the time), he/she would be promoted to the next level by the practitioner. If a child did not perform well, the child would be asked to repeat the level until he/she performed well. Before repeating a level or going to another level, special education teachers asked each child if they wanted to continue playing with POMA or if they wished to stop playing with the POMA application. Furthermore, at the end of each activity, children were given 2–7 minutes' break (depending on the child's requirement), before moving onto the next activity. For activities with two players, special education teachers played the role of the child's peer and played alongside the children. If practitioners were comfortable two children playing together in two-player modes, practitioners selected two suitable children to play multiplayer modes of POMA. On average, with 2 min duration per each level, it takes 48 min to complete all six levels and all four activities. However, based on each child's capabilities practitioners had the option to change the duration per each level or repeat the levels. After a maximum duration of one hour, children were asked to stop playing with POMA by the special education teachers to avoid any screen addictions, as children with ASD are more prone to screen addiction (Soysa and Al Mahmud, 2018; Westby, 2018).

Based on the initial findings of the evaluation sessions with children with ASD, a focus group session was conducted with the special education teachers who participated in the study. This focus group session was conducted to supplement the findings of the observational data, to discuss the usability issues children faced during the sessions and potential improvements to POMA, to mitigate such issues. Following topic questions were discussed during the focus group session, including 1) how can we improve the learnability of POMA ?, 2) how to improve the tangible component of POMA?, 3) what features are lacking in POMA software component?, 4) what can we do to improve the usability of POMA? The focus group session was audio-recorded and lasted for 50 min.

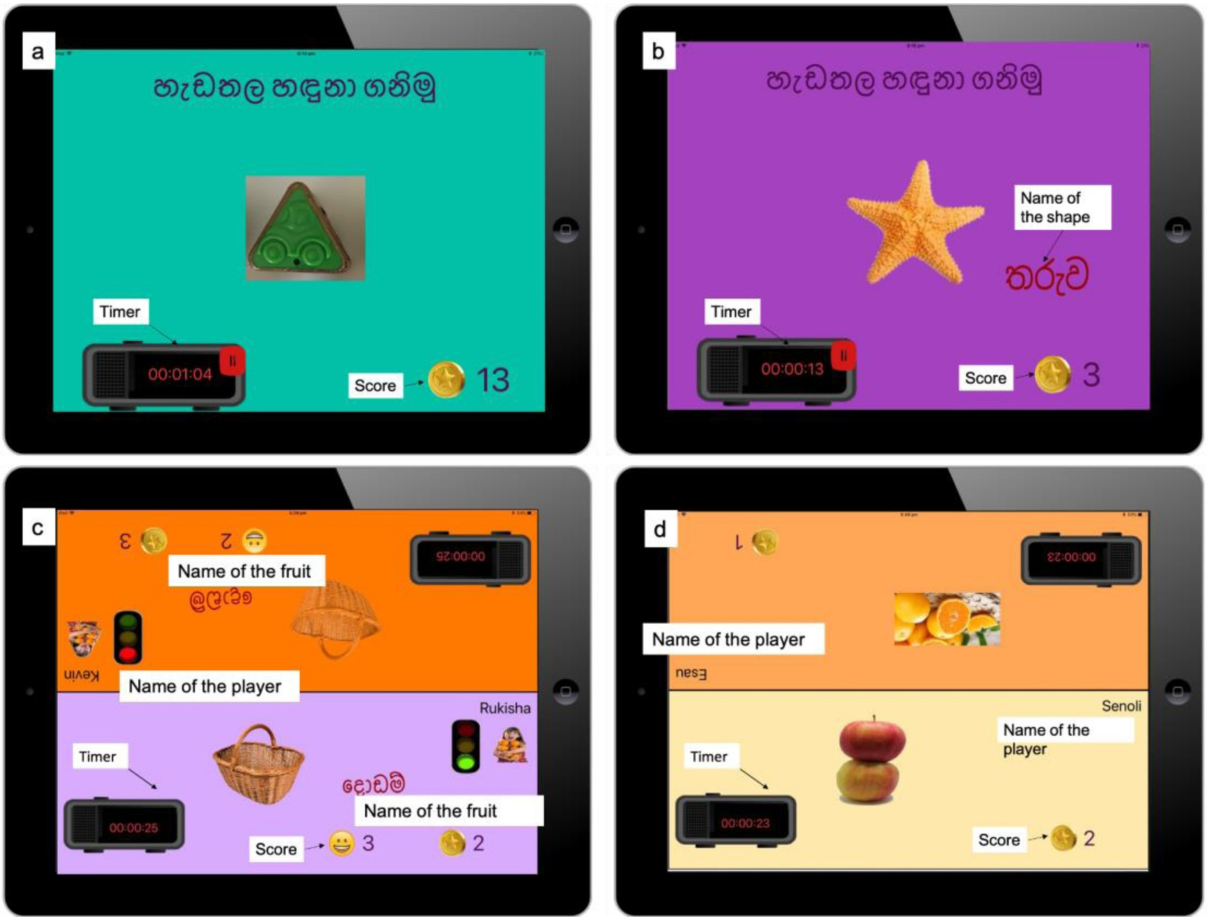

Fig. 4. Levels of POMA, a) level 1: shape identification activities, b) level 2: shape identification activities, c) level 3: fruits identification basic turn-taking activities, d) level 4: fruits identification turn-taking activities.

Fig. 5. iPPy toys designed to support POMA application.

4.4. Data collection and analysis

To capture and analyse the usability of POMA, observational data that consisted of all the events occurring in the game for each user was stored in the POMA software application. We collected data from three sources. First, we collected data from the system log of POMA (i.e., time taken to play each level, correct/incorrect responses and the number of levels completed). Secondly, we video-recorded the children playing with POMA to collect data on how children played POMA (i.e., help required to play POMA, how children use tangibles and reactions to reinforcements). The video recordings lasted for 9 h and 40 min for all the sessions. Finally, we conducted focus group sessions with practitioners who took part in this study, to supplement the findings of the system log and video recordings, to discuss the usability issues children faced during the sessions and potential improvements to POMA, to

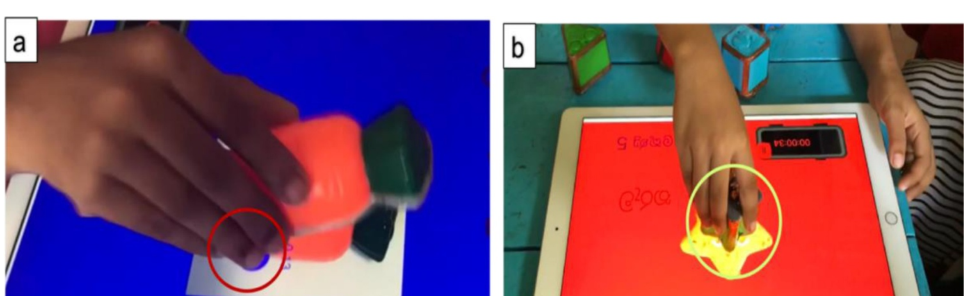

Fig. 6. Incorrect iPPy toy placement, a) fingers touching (FT) the iPad while child is placing the carrot-shaped toy, b) child is placing the star-shaped toy upside down (UD).

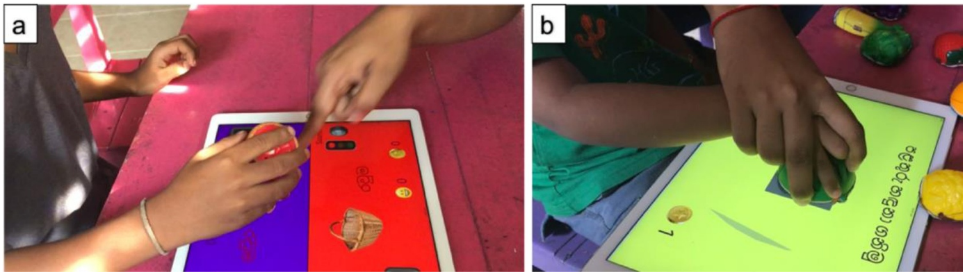

Fig. 7. Children getting help from the special education teachers, a) special education teacher directing the child via pointing, b) special education teacher guiding via holding hands.

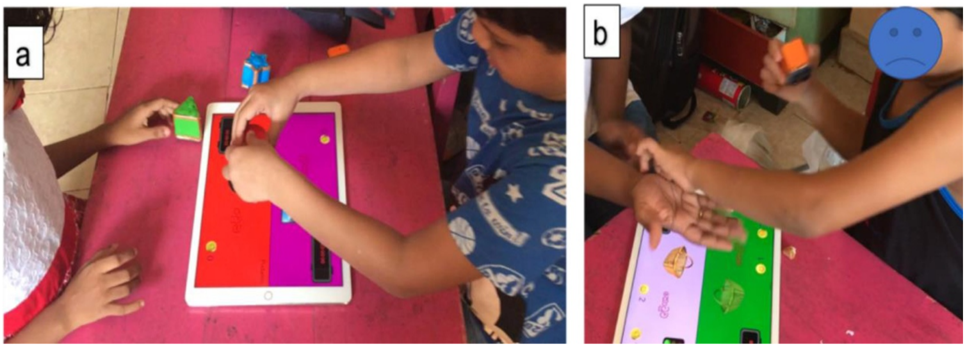

Fig. 8. Children hesitating to turn-take, a) child placing the objects on the other player's screen instead of sharing the toys, b) child hesitating to share the physical object with the partner.

mitigate such issues. The focus group session was audio-recorded and lasted for 50 min. Table 3 represents the types of data collected to answer each evaluation question.

During the data analysis stage, the video recordings were coded according to each of the indicators described in Table 4 using the DEVAN (Detailed Video Analysis) method, developed by Vermeeren et al. (Vermeeren et al., 2002). Two coders coded 20% of the videos. Inter-rater reliability on the coding scheme was assessed by a second trained coder analysing video data of four out of 20 children (20% of the data). Inter-rater reliability yielded a kappa of 0.79, which is known as substantial agreement. Hence, the second author coded the remaining videos.

The data derived from the system log (i.e., POMA software application) were categorised into numerical formats for further analysis. These video coded data and system log data were then analysed using inferential statistical methods. A series of one-way analysis of variances (ANOVA) was conducted to explore the differences between children with mild ASD and moderate ASD, with respect to each dependant variable (i.e., play duration). ANOVA tests were conducted using SPSS software. Prior to conducting ANOVA, the assumption of normality was evaluated. Due to the uneven sample sizes across participants, (we had 14 participants with mild autism and 7 participants with moderate autism) statistics were adjusted in ANOVA and were reported for unequal variances and unequal sample sizes. “Levene's Test of Equality of Error Variances” (Levene, 1961) was conducted while comparing the variances of dependent variables (average play duration between children with mild and moderate ASD, average help required for children with mild and moderate ASD) in ANOVA. For the dependent variables that had Levene's statistics significant, Welch adjusted statistics were calculated and reported (De Winter, 2013).

In addition to the observational data (i.e., video recordings of children playing with POMA, system log data), we analysed the qualitative data (audio recordings of the focus group data) using thematic data analysis (Braun and Clarke, 2013). The audio recordings were first translated into the English language, transcribed and analysed thematically. The second author is a native Sinhala speaker and proficient in English. Once the themes were finalised, we summarised the findings and translated them in Sinhala and gave to the special education teachers to comment on the accuracy of the findings. All the participants verified the accuracy of the results, and no disagreements were observed.

5. Evaluation results

In general, all children were able to play up to level 2 of POMA for a minimum of 8 min to maximum 43 min, and it confirmed that children were able to learn to play POMA. Furthermore, all children were able to try out a minimum of two activities (i.e., fruits/shapes); however, these activities were based on the child's preference. For instance, if a child had a particular interest towards animals, he/she was given animal-related activities first, similarly, if a child had a particular interest on shapes, he/she was given shape-related activities. Based on the results, five children were able to try out all four activities, 11 children were able to try out three activities, and four children were able to try out at

Table 2
Demographic characteristics of the recruited children ($N = 20$).

Age range	**4–5.5 (*M = 4.6, SD = 0.48*)**
Severity*	Level 1 (Mild): 14 (8 Male, 6 Female); Level 2 (Moderate): 6 (6 Male)
Verbal abilities*	Verbal: 14; low-willingness/passive: 5; nonverbal: 1
Behaviour*	20% having behaviour issues (engaging in self-stimulatory behaviour such as rocking, hopping and hand-flicking, aggressive and tantrum behaviours).

* Demographic data regarding children with ASD were provided by the therapists.

Table 3
Evaluation objectives and their indicators.

Evaluation Questions	Indicator
Q1 To what extent can children with ASD play POMA without asking for help?	Overall help was required for children with ASD to play POMA? In which levels did they need more help?
Q2 Can children with ASD play the levels of POMA efficiently?	Average time children with ASD spent on different levels. Average number of trials children played POMA (different levels).
Q3 How do children with ASD use tangible components (i.e., iPPy toys) of POMA?	Rates of toy placing per time throughout the game (Shapes, Animals, Fruits, Vegetables). • Number of times the child placed the tangible toys correctly. • Number of times the child identified the tangible toys incorrectly. • Number of times the child identified the tangible toys correctly but placed the toys upside down. • Number of times the child identified the tangible toys correctly, but the child's fingertips touched the iPad screen while placing the toys.
Q4 How do children with ASD react to software reinforcements prompted by POMA?	Most frequent reaction to the reinforcement (smiling, laughing, clapping).
Q5 To what extent does POMA promote social interactions in children with ASD?	Number of social interactions made during the playtime. • Average number of vocal initiations per activity? • Average number of toys shared willingly with practitioner/peers and cooperatively played with others. • Average number of times children hesitated to share the physical objects or tried not to cooperate with the other player. • Average number of communications via gesture per each child for different levels.

least two activities (see Fig. 9). Practitioners also reported that they had to complete playing with POMA for six children before one hour due to distress, distractions or addiction-related concerns. Remaining 14 children ended their session after they started playing with POMA for one hour. This playtime includes playing with POMA as well as breaks taken in between playing with POMA. All children played POMA with their special education teachers as peers. Two children were able to play POMA with a child peer as both children had played with their teachers first and they were found suitable to play POMA within the time limit (i.e., 1 h) based on teacher's judgement.

5.1. To what extent children with ASD play POMA without asking for help?

On average 83.63% (mild: $M=$ 87.72%, SD = 6.303; moderate: $M=$ 70.37%, SD = 8.366) of the time children with ASD were able to play POMA without any help from teachers. It was also found that there was a significant difference of help required at the $P<0.05$ level for the two groups [$F\,(1,\,18)$ = 31.307, p = 0.01. Furthermore, an analysis of variance revealed that the help required at level 1 and level 2 was significant, $F\,(1,\,18)$ = 10.692, p = 0.002, $F\,(1,\,18)$ = 7.567, p= 0.046 respectively. However, no statistical significance between the two groups of children for level 3 was observed.

Additionally, it was observed that in the initial levels (level 1 and 2), both groups of children with ASD required more help from the special education teachers to complete the early levels and required less help in working with the more advanced levels which might be because children got familiar with POMA. For instance, to play level one, overall 22.32% (mild: $M=$ 17.95%, SD = 11.57; moderate: $M=$ 34.17%, SD =7.49) of the time the children required help. However, to play level two they required less help, overall 16.85% (mild: $M=$ 14.32%, SD =10.61; moderate: $M=$ 28.03%, SD =14.71). When comparing the statistical significance of the help required between the levels of POMA, a post hoc comparison using the Games-Howell test indicated that the average help required for level 1 ($M=$ 22.32%, SD = 13) and level 2 ($M=$ 16.85%, SD = 13.7) was significantly higher than level 3 ($M=$ 22.32%, SD = 13) and level 4 ($M=$ 22.32%, SD = 13). Children generally required less help for level 3, even though this level introduced turn-taking activities for the children using a single iPPy toy. Interestingly, only one child with moderate ASD was able to play level 4, and on average he required more help when playing level 4, compared to when he was playing level 3, which had turn-taking activities with many toys. However, children with mild ASD required the same amount of help as level 3 (see Fig. 10). Furthermore, the video recordings showed that none of the children with moderate ASD was able to play level 5, which was the generalisation level for each activity. However, five children with mild ASD were able to play the level 5 with additional help ($M=$ 12.42%, SD = 16.9) from the special education teachers (see Fig. 10).

During the focus group sessions, special education teachers noticed that children with moderate ASD required additional help when there were multiple toys to engage with. Furthermore, they also observed that both children with mild ASD and children with moderate ASD

Table 4
Video codes and their descriptions.

Codes	Description
Toy placements 1. UD-placement 2. FT-placement	To capture the degree of physical toy selection and incorrect placement following behaviour were coded (see Fig. 6); 1 UD-Placement: Some children tended to place the physical toys upside down, which the system recognised as an incorrect selection. 2 FT-Placement: When placing the toys on the screen, the fingertips of some of the children touched the iPad screen; and the system recognized this action as an incorrect selection, as the capacitive touch pattern got distorted.
Playing POMA without any help	How much help is given to each child on each level by coding practitioner help (see Fig. 7).
Turn-taking	Turn-taking in using physical toys with their partner, waiting for his/her turn while playing, giving their partner the space to play the application when it is not his/her turn (see Fig. 8).
Response to reinforcement	Children's responses to reinforcements by analysing facial expressions after each reinforcement. We coded children's reactions to reinforcements under two categories, namely 1) reactions to immediate vocal reinforcements (i.e., vocal reinforcements: “Good job!!”), 2) reaction to multi-sensory reinforcements (sensory animations with clapping sounds).
Vocal initiations	Vocal initiations were also coded during the level 3,4 and 5 to understand how much vocal initiations were promoted by POMA. We coded number of verbal exchanges by each child when playing with their partner. For vocal initiations, we only counted new verbal interactions (i.e., when the child first started talking or started talking again after an adult or their peers speak).

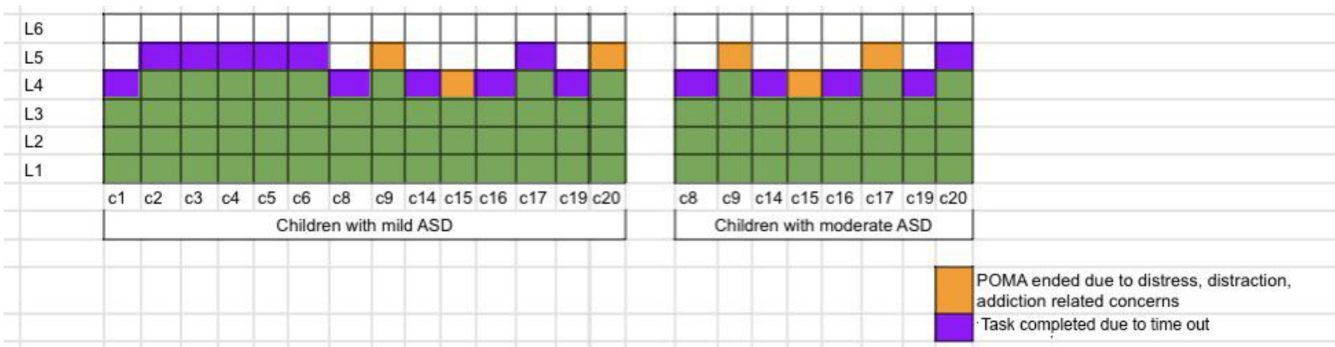

Fig. 9. The number of POMA levels completed by each child.

tended to get distracted from time to time in keeping the toys aligned with the task in hand, especially getting distracted working with the animal toys.

> "I think sometimes when children see animal toys, they tend to play with them by themselves without focusing on the iPad screen." – Special education teacher 2.

5.2. Can children with ASD play the levels of POMA efficiently?

From the system log files and video streams, we found out that all the recruited children were able to play POMA up to the second level of POMA. However, as the levels increased, the number of children play advanced levels of POMA decreased, and none of the children was able to play the level six of POMA. Table 5 further illustrates the number of children who completed the levels of POMA along with their autism severity.

From the children who completed the levels, we analysed the time taken to complete each level of POMA. Generally, children with ASD spent 28.9 min on average (Minimum = 8 min; Maximum = 43 min) using POMA and were able to complete four levels on average (Minimum = 2 min: Maximum = 5 min). Additionally, children with mild ASD spent more time (M= 32.85 min, SD = 7.19) completing more levels (M= 4, SD = 0.51), while children with moderate autism spent less time (M= 17.33 min, SD = 7.86) and completed fewer levels (M= 3, SD = 0.63). There was a significant difference on the overall time spent at the $p<0.05$ level for two groups of children [F $(1,18)$ = 18.571, p= 0.003].

The one-way analysis of variance (ANOVA) test was applied between the five levels of POMA to compare the average time spent to complete each level (p < 0.5, [F (4, 72) = 24.557, p= 0.000]). Post hoc comparisons using the "Games-Howell" test indicated that there was a significant difference in the average time spent to complete each level. Regarding the average time taken in terms of completing a level, Fig. 11 shows that even though level 1 is the most basic level, children with ASD took more time to complete level 1 as compared to the time it took to complete the other levels.

While analysing the practitioner focus group data, special education teachers reported that children with ASD took distinct time durations to complete different levels of POMA, depending on their individual capabilities.

> "Some children tend to get distracted by the toys, and they spend their time lining up the toys or staring at the toys without playing. So, for children like that, it takes more time to complete." – Special Education Teacher 3.

5.3. How do children with ASD use tangible components (i.e., iPPy toys) of POMA?

To explore how children use the iPPy toys, we analysed whether children could place the iPPy toys on top of the iPad effectively. To calculate the effectiveness of the iPPy toy placement, three independent variables were analysed namely, 1) the average percentage of time each

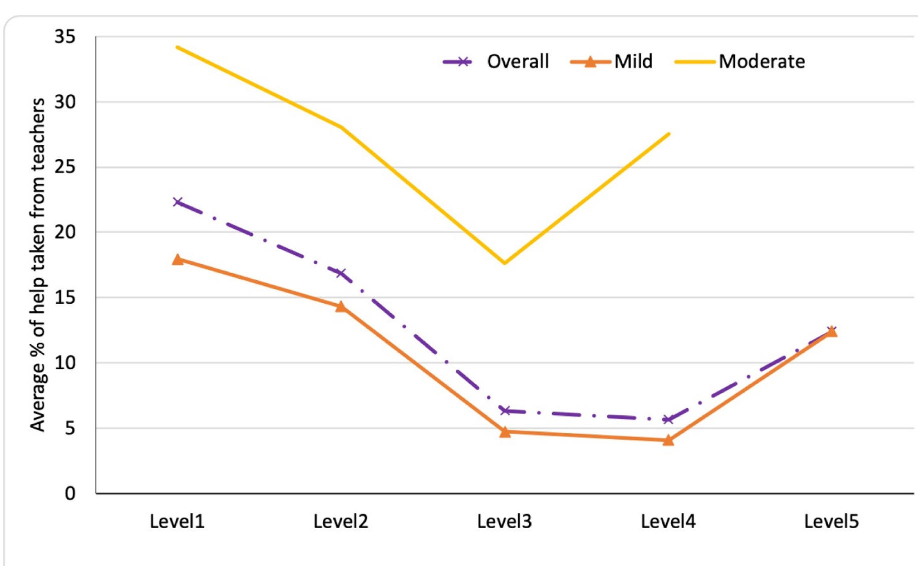

Fig. 10. Average percentage of help required from the special education teachers to play POMA.

Table 5
Number of children completed the levels of POMA.

Levels of POMA	Children with mild ASD	Children with moderate ASD	Comments
Level 1	14	6	All children were able to complete level 1 at least with one activity.
Level 2	14	6	All children were able to complete the levels at least with one activity.
Level 3	14	2	Four children with moderate ASD were not able to complete level 3, and practitioners stopped playing POMA to avoid any addictions, distress or distractions.
Level 4	14	1	Five children with moderate ASD were not able to complete level 4 and stopped playing POMA to avoid any addictions, distress or distractions.
Level 5	8	–	Six children with moderate ASD and two children with mild ASD were not able to complete level 4 and stopped playing POMA due to avoid any addictions, distress or distractions and time limitations.
Level 6	–	–	None of the children were able to attempt level 6 of POMA, due to time limitations, addictions, distress or distractions.

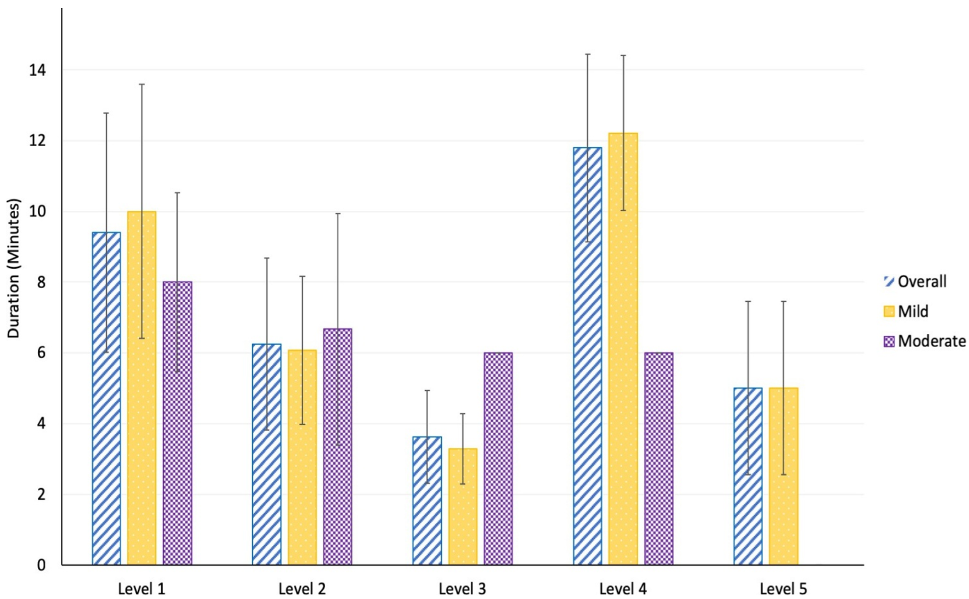

Fig. 11. Average time taken to learn each level of POMA.

child placed the toys correctly after identifying the toy correctly, 2) the average percentage of time each child identified the toys incorrectly and placed the toys correctly on the iPad, 3) the average percentage of time each child identified the object correctly, but placed the object incorrectly on the iPad screen. For these variables, the percentages (%) of correct and incorrect toy identifications were analysed according to the category of the iPPy toys.

On average, 71.77% (Mild: $M = 75.85\%$, $SD = 10.11$; Moderate: $M = 62.24$, $SD = 11.34$) of the time on average, children were able to identify the correct iPPy toys and place them on the iPad correctly while playing POMA. Further, 19.82% of the time (Mild $M = 17.91\%$, $SD = 7.4$; Moderate $M = 24.25\%$, $SD = 13.2$) children were not able to identify the correct iPPy toys to place on the iPad. The one-way analysis of variance (ANOVA) showed that the incorrect toy identification did not significantly differ between the two groups.

Additionally, the study found out that even though 8.47% (Mild: $M = 6.38\%$, $SD = 5.2$; Moderate: $M = 13.32\%$, $SD = 5.6$) of the times on average, children were able identify the correct toys to be placed; they were still not able to place them on the iPad screen properly. Furthermore, differences in incorrect object placement were not significant between children with mild ASD and children with moderate ASD, [$F\,(1,18) = 7.0$, $p = 0.31$]. Interestingly, it was found that there were instances where although children were able to identify iPPy toys correctly, they were not able to place them successfully on the iPad screen. Video recordings showed that children were not able to place the toys correctly on the iPad screen for two main reasons, a) fingers touching (FT) the iPad screen – FT placements and b) upside down (UD) placement – UD placements. Seeking to better understand which toys were more prone to FT and UD placement, we further analysed the incorrect object placement against different types of iPPy toys (i.e., shapes, fruits, vegetables and animals).

While analysing the types of iPPy toys for incorrect object placements, it was identified that the shape type iPPy toys were more prone to UD placement. From the incorrect object placements, 18.69% of the times the shape type iPPy toys were placed upside down by children with ASD. In contrast to UD placement, FT placements were more common for the vegetable type iPPy toys. Furthermore, it was also observed that children were more likely to place objects with FT compared to UD placement.

During the focus group session, special education teachers pointed out that keeping the iPPy toys correctly on the iPad screen might have helped children with ASD improve their fine-motor skills. However, special education teachers also explained that due to ASD children's deficits in fine-motor movements, they would require more practice in placing the toys correctly on the iPad screen. However, some special education teachers declared that the design of the iPPy toys might lead to FT placement in some instances. For example, flat surface toys may increase FT placements and the symmetric nature of the shape type toys may lead to UT-placements.

> *"I think it is hard for children with ASD to keep these flat surface toys (*i.e., *carrot, eggplant) on the iPad screen without touching the screen." – Special education teacher 1.*

Although special education teachers generally reported that FT placements were common for flat surface toys, some of the special education teachers suggested that putting the toys on the touch surface without an FT placement could be seen as an opportunity in improving the fine-motor skills of children with ASD. Another special education teacher suggested how POMA software design could be improved to avoid UD placement.

> "Well, I also noticed children sometimes get confused about how to place the toys. For this star, the shapes look the same even if you turn it upside down, so children get confused, so if we can show them how to place it from the iPad itself can be good." – Special education teacher 4.

Concerning the animal toys object placement, most special education teachers (n = 3; 60%) claimed that some of the children with ASD confused the dog-shaped toy with a horse. Hence, they also advised us to change the dog shape toy to a smaller dog shape toy as an improvement.

5.4. How do children with ASD react to software reinforcements prompted by POMA?

During the video coding process, four types of reactions were identified, including; clapping, smiling/laughing, flapping and staring at the reinforcement for more than 15 s. These reactions were also categorised under two reinforcement types, 1) immediate reinforcements, and 2) multi-sensory reinforcements at the end of the game (see Table 4).

Video recordings showed that children were engaged and enjoyed playing POMA. Furthermore, it was observed that more than half of (n = 12; 60%) the children with ASD reacted to immediate reinforcements via laughing and smiling. Some children reacted to immediate reinforcements via flapping and clapping (see Table 6). However, the video recordings further illustrated that most children were more focused on playing the activities rather than responding to immediate vocal reinforcements during the playtime.

In contrast to immediate reinforcement, all the children with ASD were more attracted to multi-sensory reinforcements such as animated balloons with clapping sounds that were provided at the end of the game (see Table 6). Therefore, we analysed the average percentage of children with ASD staring at the screen for more than 15 s on multi-sensory feedback at the end of each level of POMA. Additionally, we found out that children with moderate ASD always reacted to sensory reinforcements. However, children with mild ASD decreased their attention to sensory reinforcements over time. For instance, in level 1, 78.04 per cent of the time children with mild ASD were focused on sensory reinforcements. However, when they moved on to more advanced levels, the children were less focused (21.42%) on the reinforcements.

Special education teachers also reported that they believed sensory reinforcements were a vital feature to have in POMA. Furthermore, they confirmed that most children with moderate ASD enjoyed the sensory reinforcements. However, they also explained why some of the children with mild ASD were not paying much attention to sensory reinforcements.

Table 6
Children's reactions to software reinforcements.

Reactions to immediate audio reinforcements	Reactions to multisensory (video and audio) at the end of each level of POMA
Smiling/laughing (n = 12)	Staring at the screen (n = 20)
Clapping (n = 1)	Smiling/laughing (n = 8)
Flapping (n = 2)	Clapping (n = 3)
	Flapping (n = 1)

Note. n represents the number of children.

> "I think it is because you put the same multi-sensory reinforcements over and over. Sometimes children get bored seeing the same thing. Especially for high functioning children with ASD." – Special education teacher 2.

5.5. To what extent does POMA promote social interactions in children with ASD?

To explore the promotion of social interaction by POMA, two independent variables were selected, namely, 1) percentage of children collaboratively played POMA in multi-player settings, 2) the number of vocal initiation when playing POMA in multi-player settings and 3) the number of times children communicated via gesture while playing the levels of POMA.

POMA promotes sharing physical objects from level 3 to level 6, where children were asked to share iPPy toys amongst each other while taking turns to place these toys. In general, children were able to share iPPy toys 88.72% of the times. Furthermore, they improved their willingness to share when they got promoted to more advanced levels. Since most (n = 4; 66.66%) children with moderate ASD were not able to play level 3, we could not calculate the percentage of collaborative turn-taking for all the participants. However, from analysing the behaviour of children who were able to complete level 4, it was observed that children with moderate ASD were more reluctant to share the iPPy toys with their partner when compared to children with mild ASD (see Fig. 12).

Even though it was expected that children would have more vocal initiation while playing POMA, video recordings showed very few vocal initiations happening during POMA playtime. Only 11 children communicated verbally while playing POMA. Although children with ASD had limited verbal communication with their partner, special education teachers claimed that the children kept on making requests for the toys using hand gestures.

> "When I was playing with 'Child-A' he mostly communicated with me via pointing and hand gestures to request for the toys. But I am glad he communicated with me because he usually does not communicate or socially engage." – Special education teacher – 5.

Furthermore, video recordings indicated that children kept on repeating the audio feedback/reinforcements given by the iPad when his/her partner was doing well (i.e., "Well done", "You got it").

Although children had limited verbal interaction, the video recording shows that all the children with mild ASD communicate with the therapists via gesture during group activities of POMA (Level 3, 4 and 5). Hence, we video coded the children requesting for toys using gesture (see Fig. 13) and calculated the average number of communications for each level via gesture during group activities (Fig. 14).

In general, the data analysis showed that more children (n = 16) were able to communicate with the therapist via gesture when compared to verbal requests (n = 11). However, the study also observed that children with mild ASD had more communication via gesture for each level compared to moderate level children with ASD.

6. Discussion and implications

The main objective of this paper is to understand how children with ASD use POMA with their special education teachers and to identify potential improvements to POMA to support the needs of Sri Lankan children with ASD.

6.1. Learnability of POMA and iPPy toys

In our study, we observed that children with ASD required more time on level one compared to other levels, especially for children with moderate ASD. The reasons for this might be the unfamiliarity of POMA

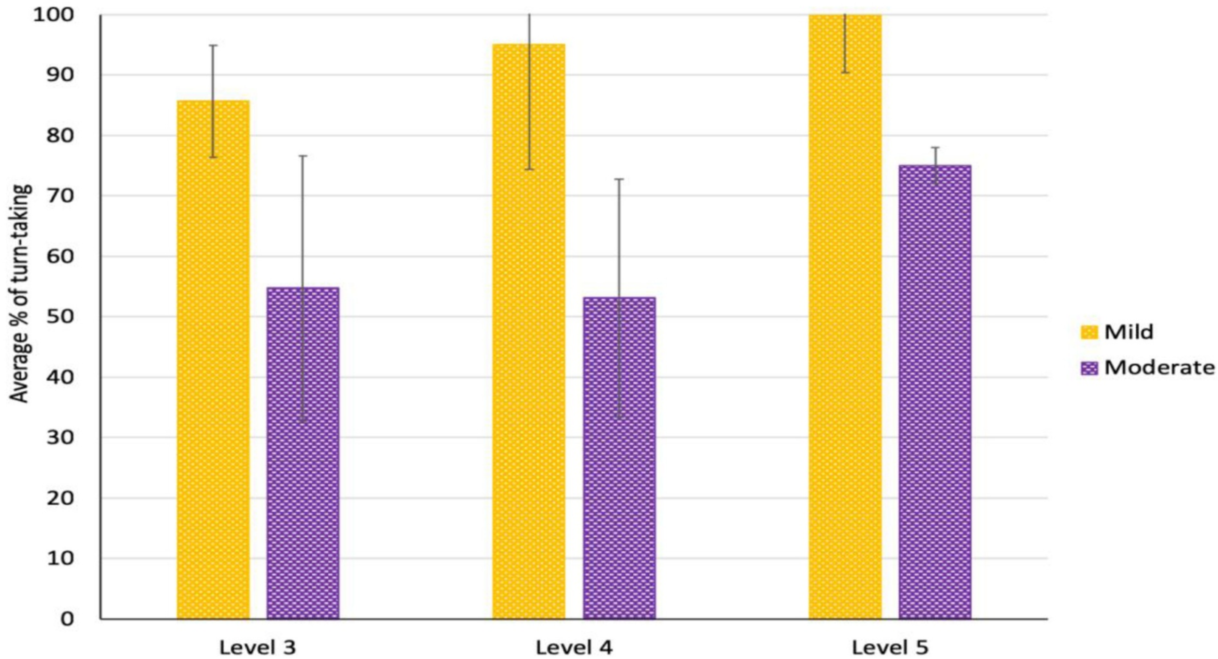

Fig. 12. Average percentage (%) of turn-taking during different levels of POMA.

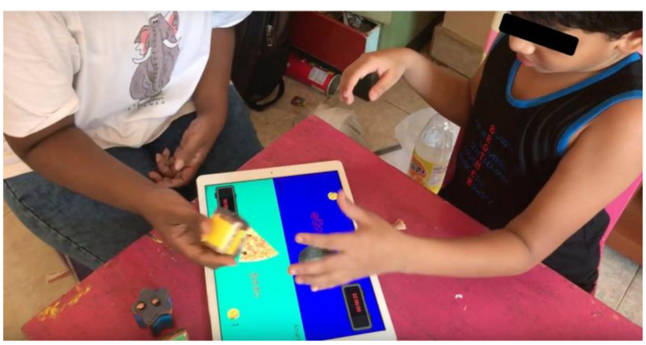

Fig. 13. Children communicating via gesture.

to the children. We further observed that both groups of children required less time from special education teachers to complete the levels as they increased their levels; this might be because the levels of POMA were easy to learn due to with smooth transitions. However, we also found out that children with moderate ASD took more time as they got distracted by aligning the toys and just looking at the toys.

We observed that both groups of children required help from the special education teachers during the initial levels of POMA, and this might be because of the unfamiliarity of using TUI. Similar to the findings of our study, another TUI-based technological intervention (i.e., Polipo) study also showed that children with ASD required practitioner help to complete tasks especially when they move on to more advanced tasks (Tam et al., 2017). However, unlike prior studies (Tam et al., 2017), in our study, we observed that the required help decreased when children moved into the advanced levels of POMA. Compared to children with mild ASD, children with moderate ASD required more help from the special education teachers to sustain attention during POMA play sessions. To reduce the amount of help required from special education teachers to sustain the focus and attention, special education teachers proposed to have audio-visual feedback from POMA when it is in an idle state without interacting with the POMA.

In this study, we found out that the majority of children with ASD were able to identify the correct iPPy toys and place them correctly on the iPad screen. We observed both children with mild and moderate ASD were able to identify shapes, animals, veggies and fruits correctly more than 65% of the time. Prior studies show that children with ASD may not always react to tangible objects appropriately when using TUI-intervention (Tam et al., 2017). Similar to Tam et al. study, we also observed that some of the times children with ASD, especially children with moderate ASD, were not able to place the tangible toys on the iPad screen. For instance, 19.82% of the time, children were not able to identify the correct iPPy toys to place on the iPad due to FT (Finger Touching) and UD (Upside Down) placements. We further observed that FT placements often happened for flat-surface toys (i.e., carrot, eggplant, chilli shaped toys) and UD placement occurred for shape-type toys (round, star, square, triangle). Therefore, the design of POMA needs to be modified to better support children with ASD, especially children with moderate ASD. For instance, add non-conductive layer around the flat-surface toys may limit children placing their fingertips on the iPad screen when placing the toys. Most children with ASD have fine-motor skill deficits (Provost et al., 2007). Hence, when designing flat-surface tangibles children with ASD with touchpoint patterns matching technology, it is critical to incorporate non-conductive layers around the toys to avoid FT placements. Similar to FT placements, to avoid UD placements, we can provide better cues on POMA software application to demonstrate how to keep the toys on the iPad screen. For instance, prior studies have shown that moving visuals, such as animations can improve the engagement of children with ASD (Yee, 2012). Therefore, to enhance the child-engagement and to provide additional guidance on keeping the tangibles on the iPad screen, we propose to provide additional cues (i.e., helper cues in an animated GIF format) when designing TUI with passive tangible toys.

6.2. Avoid providing the same sensory reinforcements

Concerning reinforcements, we found out that children with ASD, especially children with moderate ASD, paid much attention and focused on sensory reinforcements. Sensory reinforcements are crucial elements when designing technology-based interventions for children with ASD (Moore and Calvert, 2000). Similar to the design guidelines provided by prior researchers (Sitdhisanguan et al., 2012; Van Rijn and Stappers, 2008), we have added multi-sensory feedback throughout the

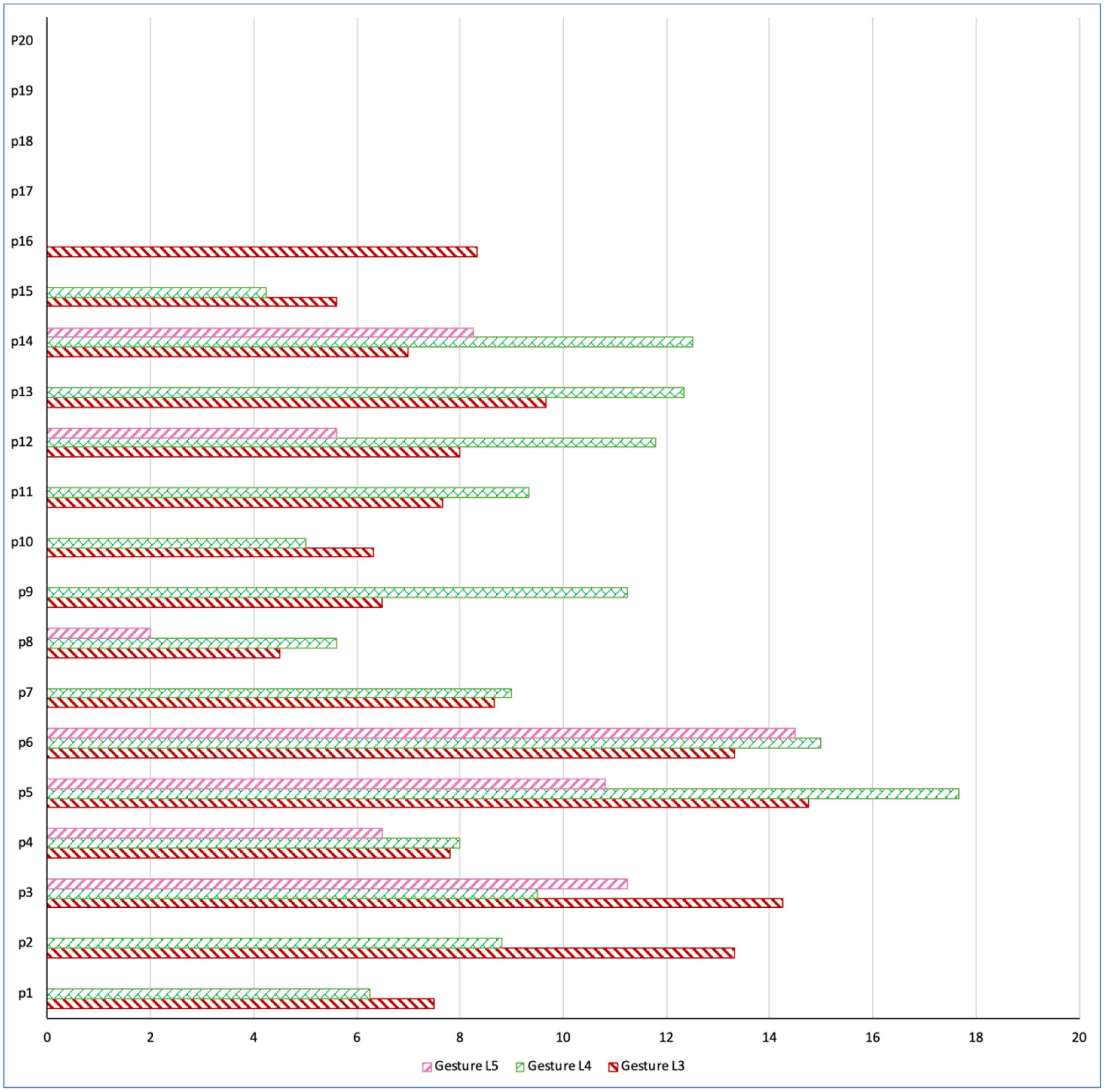

Fig 14. Average number of communications via gesture per each child for different levels. * p1-p14 represents children with mild ASD and p15-p20 represents children with moderate ASD.

design of POMA, reinforcing only upon correct answers. However, we observed that children with mild autism paid less and less attention over-time to the sensory reinforcements that were provided by the end of the game. One reason for this might be because POMA provided the same reinforcement ("sparkling animated stars and clapping sounds") at the end of the game. However, we believe that children would gain more benefits if we had included multiple different reinforcements (i.e., animated balloons, animated bubbles) generating randomly throughout POMA.

6.3. Intuitive interface and game rules enforce turn-taking and social interactions

Similar to the existing findings (Farr et al., 2010), we found that both groups of children with ASD showed some degree of social interaction through turn-taking and co-operative play during multi-player mode sessions of POMA. Percentage of social interactions via turn-taking and sharing was much higher than we envisioned during the design process of POMA. We observed that both groups of children (mild and moderate) had a high percentage of turn-taking and sharing during the initial levels and improved this skill over-time up to 75%. The main reason for such success can be due to our POMA interface, where we enforce parallel play with turn-taking through two-player functionalities. Additionally, we divided the POMA interface into two parts assigning collaborative roles to each player, which locks/unlocks the touch surface upon sharing and turn-taking. We also provided one set of toys at a given time to add the element of limited resources. Hence, children had to collaborate to succeed in the game. Compared to turn-taking behaviour, we also observed that limited verbalisation in children with ASD when playing group activities of POMA. Such behaviour is not surprising since children with ASD have limited verbal skills compared to typically developing children (Anderson et al., 2007). Despite having limited verbal abilities, children with ASD were able to engage with their partners using hand gestures while improving their verbal skills throughout the levels.

In essence, the results of the evaluation indicated issues about some

Table 7
Possible improvements to POMA to better support children with ASD.

Observations	Possible improvements to POMA	Design Implications
Children getting distracted with the iPPy toys without interacting with the iPad [related to Q1, Q2].	Play animations and audio clips on the iPad application when children are idling.	It is required to attract the attention of children with ASD when they wait for their turn to place interactive toys on an iPad
Children's fingertips touch the iPad screen (FT- placement) [related to Q3].	Add a non-conductive layer around the iPPy toys to avoid FT placements.	Interactive toys for children with ASD should have non-conductive layer so that their fingertips do not touch the iPad screen.
Children place the shape-type objects upside down on the iPad screen (UD- placement) [related to Q3].	Add cues on how to keep the toys properly using Graphics Interchange Format (GIF) in the initial levels.	Audio-visual guidance should be provided on the iPad screen so that children with ASD can place the tangible toys correctly.
Children getting confused with dog and horse [related to Q1, Q2].	Change the dog-shape toy with a smaller version of a dog-shaped toy.	It is required to provide a distinctive set of interactive toys to children with ASD to avoid confusion with similar other toys.
Children's (with mild ASD) focus towards the sensory reinforcements decreases after getting familiar with the toys [related to Q4].	Add reinforcements with animated bubbles, stars, and planets.	Add a variety of sensory reinforcements at the end of the activity without only showing the same type of sensory reinforcement.

of the design features of POMA, and the way of using POMA by children with ASD (see Table 7).

6.4. Challenges and lessons learned

We faced several challenges in recruiting children with ASD, especially children with moderate ASD. Prior studies had also reported several challenges in recruiting children with ASD, including the challenge of parents' fear of their children getting hurt during the study (Sidjaja, 2015). However, in this study, the most common challenge in recruiting children with ASD was the parents' fear of the behaviour issues of children with ASD being recorded. Since the evaluation study was conducted for 60 min, such behaviour was not feasible and excluded many children with moderate ASD from participating in the study. Several steps were taken to minimise such situations.

1 Practitioners were involved in conducting the evaluation sessions.
2 Before repeating an activity or starting a new session, the practitioner asked the children whether they wanted to continue playing with POMA, practitioners only continued to play if the child showed interest in playing POMA.
3 If a child showed any distress during gameplay, practitioners immediately stopped the sessions.

Also, some of the parents were reluctant for their children to take part in the study because of video recordings of children while playing with POMA. Another challenge encountered was the problem of losing the iPPy toys during the sessions. Since, some of the children threw the toys, or refused to give the toys back after playing POMA, several iPPy toys got misplaced. However, the POMA application was tightly bound to the iPPy toys, and it would fail to operate effectively if even one toy was missing within a specific activity. While conducting the sessions, the triangle-shaped iPPy toy and one animal shape iPPy toy got misplaced, and practitioners had issues conducting sessions until we provided them with replacements. Hence, it is recommended to provided duplicates of the toys to run the session smoothly.

Although the practitioners discussed the durability of the iPPy toys in earlier co-design sessions, the high humidity factor of Sri Lanka (Emmanuel and Fernando, 2007) was not considered during the initial development of the iPPy toys. Therefore, as a cost-effective solution, conductive ink was used as a material to make the toys interact with the iPad screen. However, when testing the iPPy toys in Sri Lanka, it was found out that conductive ink melted due to the humidity and the heat/sweat generated from holding the toys. Hence, instead of conductive ink patterns, we selected low-cost conductive foam to attach to the toys to make the toys recognisable to the capacitive touch screens, as prior studies had shown pressure-sensitive conductive foam could be used as capacitive sensors (Metzger et al., 2008).

6.5. Limitations and strengths

There are several limitations of this study that should be noted. We could not directly involve children with ASD to design POMA due to several cultural barriers. During the discovery stage of the POMA design process, we found out that both practitioners and parents were not comfortable involving such young children (age 4–7 years) in the design process. In this study, we did not compare POMA with other educational games that facilitate social interactions. A detail-controlled experiment may offer more precise and reliable information about the effectiveness of using POMA to improve social cognitive skills of children with ASD. Furthermore, we did not collect baseline data in this study and conducted any follow-up evaluation to determine the skill transfer of Children with ASD. Although children with ASD in our study improved their performance on the subsequent levels of POMA, this could be due to learning and practising POMA levels. Further study is required to validate the generalizable skills of children with ASD using POMA. Finally, our study has unequal sample sizes with fewer children with moderate ASD and more children with mild ASD. Also, it is worth noting that we had more boys ($n = 14$) compared to girls ($n = 6$). This may have an impact on the generalizability of our results. During the study period, due to the unavailability of female participants at the therapy centres, we were not able to recruit more female participants.

7. Conclusion

This paper presents an investigation of how children with ASD use a TUI-based autism intervention called POMA in a Sri Lankan therapy setting. Children were able to play up to level 2 of POMA and were able to play with it within the allocated time without much help from their teachers. This study showed that children with moderate ASD required more help and time in the initial levels of POMA as compared to children with mild ASD. However, as children with moderate ASD moved into more advanced levels, they needed less help and time to play POMA. Based on the findings of this study, we identified several improvements to POMA software and tangible components. For the software component, we found out that further animations and audio clips were required during the gameplay of POMA to keep the child's attention while providing a variety of multi-sensory reinforcements at the end of each activity. Finally, we also found out that when designing tangible objects, it is essential to design them in a more graspable form with uniquely identifiable properties, so that they could be easily handled and identified by children with ASD. In our future work, we aim to improve POMA based on the findings and investigate the long-term impact of POMA on children with ASD in a Sri Lankan therapy setting.

CRediT authorship contribution statement

Abdullah Al Mahmud: Methodology, Writing - original draft, Writing - review & editing, Resources, Supervision. **Amani Indunil Soysa:** Writing - original draft, Formal analysis, Investigation, Software.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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