Non-Participatory User-Centered Design of Accessible Teacher-Teleoperated Robot and Tablets for Minimally Verbal Autistic Children

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Non-Participatory User-Centered Design of Accessible Teacher-Teleoperated Robot and Tablets for Minimally Verbal Autistic Children

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robot placed in front of child | teacher selects activity | child selects face feature | "These are my eyebrows." | robot demonstrates feature
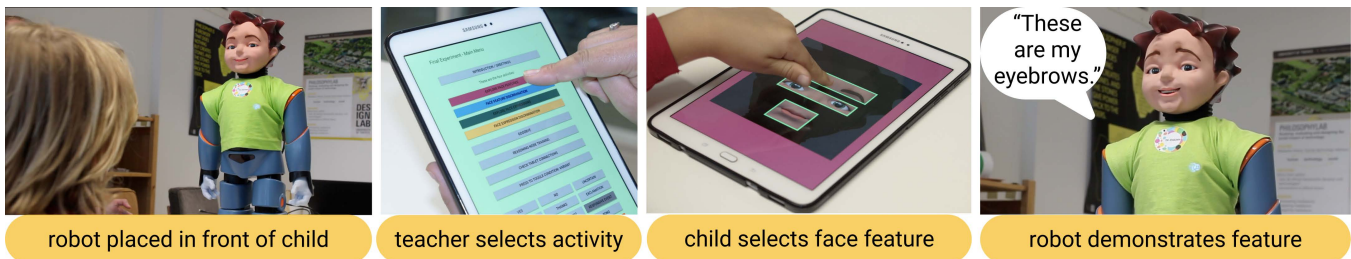
Figure 1: Interaction sequence for a face feature activity that uses an adult's tablet, a child's tablet and a humanoid robot.

ABSTRACT

Autistic children with limited language ability are an important but overlooked community. We develop a teacher-teleoperated robot and tablet system, as well as learning activities, to help teach facial emotions to minimally verbal autistic children. We then conduct user studies with 31 UK and Serbia minimally verbal autistic children to evaluate the system's accessibility. Results showed minimally verbal autistic children could use the tablet interface to control or respond to a humanoid robot and could understand the face learning activities. We found that a flexible and powerful wizard-of-oz tablet interface respected the needs of the children and their teachers. Our work suggests that a non-participatory, user-centered design process can create a robot and tablet system that is accessible to many autistic children.

CCS CONCEPTS

• **Human-centered computing** → **Empirical studies in HCI**; *Usability testing*; *Accessibility design and evaluation methods*; • **Social and professional topics** → **Children**.

KEYWORDS

Human-robot interaction; assistive technology; robot; tablet; minimally verbal autistic children; Autism Spectrum Disorder; teleoperation interface; limited language; facial expressions

1 INTRODUCTION

An emerging goal in human-robot interaction and autism research is to have robots successfully help autistic children[1] learn about

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[1]We use this term in accordance with preferences of the UK autism community [1].

emotions. Robot-assisted therapy has advantages such as data collection potential and hygiene compared to existing therapies focused on animals and other objects (cf. [2]). Typically, robot technologies are developed to help autistic children who are cognitively able (i.e., use verbal language). Minimally verbal autistic children (i.e., with limited language ability) are often neglected as users of assistive technology, despite the fact that 30% of autistic children are minimally verbal [3] (cf. [4]) and that this subgroup may need more help than other autistic children [5–8]. Developing a robot and tablet system for minimally verbal autistic children could help designers make similar technologies targeted to this neglected subgroup of the autism community.

Robots and tablets are leading technologies being used with autistic children [2, 9–11]. Past user studies explored how autistic children respond to robots and tablets, but have not looked at minimally verbal autistic children's responses. Given that few if any robots have been developed for minimally verbal autistic children, an evaluation of how this important subgroup of autistic children respond to robot and tablet systems can aid technologists interested in autism and autism researchers interested in technology aids.

Robots that play learning activities with autistic children often require either a trained researcher to operate, operate autonomously or operate autonomously with a teacher being able to cancel any undesired actions. However, trained researchers are impractical for everyday use, while autonomous or supervised autonomous robots run the risk of automation errors negatively impacting interactions with autistic children [12], cf. [13]. Giving a teacher the ability to teleoperate the functions of a robot could improve the quality of activities delivered to an autistic child.

Most past work that develops robots or other technologies for minimally verbal autistic children evaluates their designs implicitly through the process of participatory design, or explicitly through usability tests with only a few minimally verbal autistic children. Co-design methods and case studies might not be suitable to evaluate a technology across many autistic children. As participatory co-design is a *de facto* design method catered to a single or small group of autistic children, yet also potentially challenging for autistic children with limited verbal communication [14], it would be interesting to see whether a different user-centered process could produce a robot system suitable for a large number of minimally verbal autistic children. Given that the minimally verbal children in our usability studies did not overtly know that they were being involved in a design process, we do not claim to use participatory design (at least in the traditional sense). We also question the validity and appropriateness of participatory design for individuals who do not understand the context and reason for the research, as was the case with our user group. Nevertheless, the involvement of the autistic children in our research had a significant impact on our process and design outputs. In the spirit of past participatory methods involving autistic children, our method was nonetheless designed to create "user-focused and user-oriented" outcomes and "elicit feedback...to improve the system" [14]. For example, our focus on evaluating system accessibility rather than child performance was a deliberate methodological choice we made to undertake research *with* autistic children rather than *on* them (cf. [15]).

Our work contributes: (1) a novel robot and tablet system for face learning activities catered to minimally verbal autistic children; (2) user studies with 31 minimally verbal autistic children that assess how they respond to a robot, a tablet and face feature activities; (3) a validated tablet interface for teacher teleoperation of the robot; and (4) empirical evidence that a non-participatory, user-centered process can produce learning technology that accommodates a large number of minimally verbal autistic children.

Compared with existing studies on robot therapy for autistic children [16, 17], our work focuses on minimal verbal children, develops a tablet so the teacher and child can lead the robot (i.e., fully-interactive system instead of a system to test children, e.g., [17]), looks at accessibility of a fully-interactive system instead of child performance on a test (e.g., [18]), and is evaluated with a large sample of autistic children (31, some past studies only test with 4 [16] or 11 [18], which limits generalizability of results).

2 BACKGROUND

2.1 Assistive Technology for Minimally Verbal Autistic Children to Learn About Faces

About 30% of autistic children have limited or no verbal language (i.e., "minimally verbal" [4, 19]). These children have differences in communication compared to autistic children with verbal language. This subgroup may need technology to be catered to them [7].

Past work has designed smart devices but not robots for minimally verbal autistic children, despite the potential robots demonstrate for verbal autistic children [2]. [20] built a tangible ball prototype to explore joint attention and imitation with minimally verbal autistic children. [21] explored how a tablet training program could improve minimally verbal autistic children's manual and oral motor skills. [22] built a tablet app that stored photos to help minimally verbal autistic children learn the alphabet and words for household items. [8] constructed a tablet to train minimally verbal autistic children to work with graphics and objects. However, these technologies for minimally verbal individuals did not use a robot.

Moreover, the aforementioned work did not explore how face features and emotions can be taught through technology, perhaps because technologies for minimally verbal children tend to focus on trying to improve verbal skill (cf. [20]). One important skill for interpersonal interaction is understanding facial expressions [23]. Autistic children, including those with limited language, often have difficulties in recognizing and processing facial expressions compared to non-autistic children [24, 25]. Past experiments find autistic children show no advantage in recognizing face emotions from seeing one face feature compared to another (e.g., just seeing eyes versus just mouth to identify fear), although which features are seen in piecemeal presentation of faces does matter for typically developing children [26]. Moreover, autistic children show improved recognition with slowed down facial expressions [25]. These studies suggest technology manipulation of faces may be an initial step for face learning programs for autistic children. While it is therefore unsurprising that many robots have been developed to help autistic children learn about facial expressions and emotions [16, 18, 27, 28], none have been catered to minimally verbal individuals, who may have difficulty with language. For example, [18] asked autistic children to have a conversation with the Zeno robot (also used in this work) and verbally answer what emotion

the robot was showing, which might not be possible for those who are minimally verbal.

Thus, a robot that can deliver face learning activities catered to minimally verbal autistic children can help broaden pedagogical and interaction possibilities for minimally verbal autistic children.

> Research Objective 1: Design a robot to address face feature and emotion learning for minimally verbal autistic children.

2.2 Autistic Children's Responses to Robots and Tablets

Past work finds autistic children respond well to a robot. [29] found autistic children spontaneously approach and interact with a minimal creature-like robot, finding pleasure that they share with their caregiver. [30] found autistic children are not afraid of a non-humanoid robot and spontaneously interact with it. [31] found an autistic child managed attention better when interacting with a humanoid robot Nao compared to his regular class behavior. However, these works did not look at minimally verbal autistic children. An evaluation of how they respond to a humanoid robot can better assess the suitability of robots for this group.

> Research Objective 2a: Observe how accessible a robot activity is for minimally verbal autistic children.

Tablets are a leading technology for activities with autistic children [9]. Past work on tablets or touchscreens finds no strong evidence that the devices are detrimental to autistic children, that autistic children prefer tablets to traditional learning methods, that parents of autistic children report 97% of their children use an iPad 4.6 days per week on average and that 65% of autism professionals use iPads as rewards or interventions (cf. [32]). (We note that learning outcomes with tablets, rather than the usability results above, are much more varied; for reviews, please see [9, 32].) Only one past study we are aware of explored tablet usability for minimally verbal autistic children. [33] found three autistic children with limited or no verbal language able to use an iPad as a speech generating device in academic and social situations. However, it remains unknown whether autistic children who are not verbal respond well to a tablet used to interact with a robot, rather than a teacher or a peer as in [33]. An empirical study of this could aid designers of robots for minimally verbal children.

> Research Objective 2b: Observe how accessible minimally verbal autistic children find using a tablet to "converse" with a robot.

Face learning activities for autistic children primarily teach facial expressions using pictures, movies or tablets (for a review, see [24]). Robots have also been used to teach facial expressions. [27] and [18] asked autistic children to identify the emotion expressed in different robots' faces. [34] had the Zeno robot used in the current work mirror one autistic child's face expression; [16] and [28] had robots make expressive faces that children could imitate. However, past face learning activities with either robots or other media have not been designed for minimally verbal children, who may require simpler tasks. As evidence of this, all past work mentioned here use whole face expressions instead of separate face "features" (e.g., just eyes, just eyebrows; for a review of face processing, see [35]). A

face-feature-based learning strategy, which starts out with separate facial features and then moves onto whole facial expressions, could cater for minimally verbal people.

> Research Objective 2c: Observe how minimally verbal autistic children respond to face feature learning activities.

2.3 Robot Teleoperation Interfaces for Teachers

Past research explores different levels of autonomy in robots for autistic children. [36] developed a fully autonomous robot and showed autistic children's social skills could improve after learning with it. [13, 37] designed a "supervised autonomy" robot for learning activities with autistic children, in which the robot's actions could be approved or rejected by a teacher prior to its execution and additional brief actions such as gaze behaviors could be sent to the robot. One reason to have the teacher supervise the robot's behavior is that full autonomy will not be perfect and any mistakes it makes may be critical to child interaction [37]. However, these past works did not explore a teleoperated robot, in which a teacher has control over the robot actions, rather than just approving them. A teleoperator interface for teachers may avoid errors in autonomy and support context-driven robot behavior, which could be important for autistic children with limited verbal language.

> Research Objective 3: Design a teleoperator tablet for accessible control of a humanoid robot.

2.4 Evaluation Methods for Autism

A key challenge in designing technology for autistic children is the generalizability of designs to multiple children. Currently, a leading method of designing robot systems for autism is participatory co-design, which creates designs that account for an individual child's needs [38–41]. However, with participatory methods, it is unclear whether a design from a single child can be extended to other children. Notable efforts to pursue participatory evaluation (i.e., in which the child helps evaluate the technology they designed) has so far only been used to evaluate with one or two other children [41], so has not yet been shown to have broad applicability. Non-participatory user-centered design (i.e., researchers design the system and test it with users) has created technology systems that are accessible to large groups of people, but it is unclear whether a non-participatory user-centered process can create accessible technologies for minimally verbal autistic children.

> Research Objective 4: Use a user-centered process to create a robot that is accessible to a large number of minimally verbal autistic children.

2.5 Facial Expression Perception & Recognition

Facial emotion recognition research in HCI has primarily explored how various machine learning techniques can be used to understand a person's emotions based on social science literature [42, 43]. One tension in the state-of-the-art is between universal face emotions and ambiguity across individuals (cf. [43]), which may be particularly important for autistic children [44]. State-of-the-art

facial emotion recognition systems (e.g., [45]) account for individual differences in how a person expresses face emotion and the situational context of their expression, but may also need to account for tasks and other sources of variation [46]. Facial emotion recognition systems that adapt to individuals have been applied to autistic children [47]. These systems have also been used to classify individuals as autistic or not autistic, by looking at facial attributes such as action units, emotion expressions and valence/arousal [48].

Past literature also suggests automatic recognizers output activation-evaluation (i.e., arousal-valence) measures instead of categorical emotions, which are more manageable for computational systems but less usable by laypeople (cf. [43]). Recent state-of-the-art face emotion recognition systems for autistic children output valence-arousal (e.g., [47]) or a blend [48].

3 DE-ENIGMA ROBOT AND TABLET FOR FACE LEARNING

3.1 Design Process

The authors are 4 autism experts, 2 autism therapists and 4 robot researchers. We held collaborative design sessions over 1.5 years.
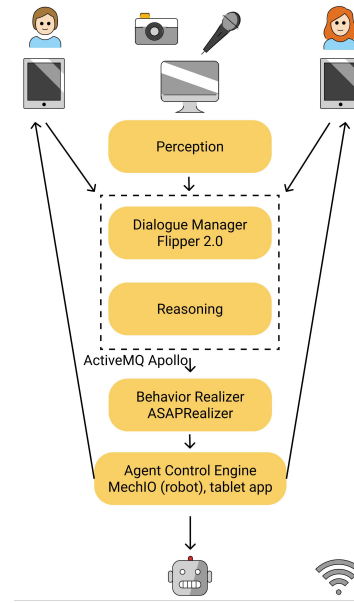
3.2 Design

We present "DE-ENIGMA", a humanoid robot controlled by an adult with a teleoperator tablet that helps the adult play face activities with an autistic child, who communicates to the robot via a tablet.

3.2.1 Software Architecture. The architecture of the child-robot interaction component of the DE-ENIGMA system (same as [34], except ours adds tablets) features a Dialogue Manager, Behavior Realizer and Agent Control Engine (Figure 2). The dialogue manager responds to user events and generates appropriate behaviors (stored as behavior markup language, BML, representations). The behavior realizer converts the behaviors into platform-specific commands, which it schedules and executes accordingly. Verbal scripts were audio-recorded as mp3 files in Audacity in English and Serbian. The agent control engine then executes the commands on the specific platform (robot or a custom tablet application). This architecture is designed to support fluent, responsive, top-down and bottom-up behavior generation and execution (cf. [34]). Software modules (e.g., Flipper 2.0 [49], ASAPrealizer [50]) are configured to communicate either through ROS or Apollo middleware.

The perception systems were not used in this work, but are briefly described here. Microphones, RGB cameras and depth cameras sense the child's actions, which are interpreted by perception algorithms as emotional valence, arousal, presence of laughter, etc.

3.2.2 Activities. We developed a set of four activities (Table 1). The teaching strategy focused on designing activities that relied less on verbal language and focused on facial features rather than full faces. These attributes were selected based on previous usability studies [34], in particular the finding that some children in our target user group experienced challenges with language and full faces. The initial script design session resulted in four distinct game activity steps that focused on teaching individual facial features, how facial features could be composed into emotional facial expressions and discrimination of emotional facial expressions. Game scripts (i.e., spoken lines and actions) were subsequently written

Figure 2: System architecture. All emojis designed by Open-Moji - the open-source emoji and icon project. License: CC BY-SA 4.0

for the dialogue between therapist, child and robot according to existing dialogue composition strategies [34]. For example, based on the strategies of simple language & key phrases, we used short phrasing like "Look and listen" already used in the schools; based on scaffolding, we began with a simple face feature activity before moving to more difficult face emotions.

Giving autistic children greater control over the behaviors of a robot could be more engaging and motivating for them compared to passive listening, and therefore facilitate better learning. Supporting this idea, autistic children spontaneously request certain robot behaviours and sometimes attempt to press the teacher's buttons to control the robot or touch/manipulate the robot directly [51, 52]. Providing children with more input and control over the interaction could be achieved by giving children a tablet interface, which might also help with the desire of children, particularly those with limited expressive language, to touch the robot by redirecting them to touch a tablet. We therefore included an activity step to support children's exploration and control of the robot (Steps 1 and 3) prior to testing children's knowledge (Steps 2 and 4).

3.3 Apparatus

The robot is Robokind's 56-cm-tall male cartoon R25 robot "Zeno", which has 5 degrees of freedom in its face, 2 in its pupils for gaze, 3 in its neck and 6 in its body (we used arm and torso movement only) (Figure 1). The face of the robot is made of synthetic skin.

The child and adult teleoperator tablets are Samsung Galaxy Tabs S2 (9.7 inch) with Android 6.0. A tablet case was used over the child's tablet to prevent pressing the home button. The adult tablet displayed buttons that could be used to directly trigger robot behaviours and initiate game activities (Figure 3). The child tablet

Table 1: Activities for face learning

Step	Color	Activity	Sample Script	Lead
1	Pink	Teach face features	Adult: "[Adult]'s turn." [adult touches tablet] Robot: "These are my eyes"	Adult
			Adult: "[Child]'s turn." [child touches tablet] Robot: "This is my mouth"	Child
2	Blue	Test face features	Robot: "Find my eyes." [child touches tablet] Robot: [repeats if wrong, cheers if right]	Robot
3	Green	Teach face emotion	Adult: "[Adult]'s turn." [adult touches tablet] Robot: "Happy. My mouth is up. I am smiling."	Adult
			Adult: "[Child]'s turn." [child touches tablet] Robot: "Happy. My eyebrows are up."	Child
4	Yellow	Test face emotion	Robot: "Find my happy face." [child touches tablet] Robot: [repeats if wrong, cheers if right]	Robot

displayed learning content and let the child answer the robot's questions or select actions for the robot to do (Figure 3).

4 USER STUDY

We evaluated how minimally verbal autistic children responded to the robot and tablet activities in a UK and Serbia school study.

4.1 Method and Materials

4.1.1 Participants. 31 autistic children (8 girls) aged 4 to 14 ($M = 12$ yr, $SD = 2$ yr 1 mo) with Autism Diagnostic Observation Schedule (ADOS) [53] scores between M1 and M2/M3 ($M = 1.5$, $SD = 0.6$) participated in user tests in UK and Serbia over a 9-month period between April and Dec 2018. One round of tests was run in Serbia with 11 children (2 girls, $M = 9$ yr 4 mo, $SD = 2$ yr 2 mo, ADOS not used in Serbia), while two rounds were held in UK, 1st round with 8 children (2 girls, $M = 9$ yr, $SD = 1$ yr 1 mo, ADOS module $M = 1.3$, $SD = 0.5$), 2nd round with 16 children (4 girls, $M = 9$ yr, $SD = 2$ yr 4 mo, ADOS module $M = 1.6$, $SD = 0.7$, therapist-assigned language score $M = 2.8$ out of 4, $SD = 1.1$). (Note 4 UK children in the 2nd round participated in the 1st round.)

4.1.2 Procedure. After attaining parent/caregiver assent, children were scheduled for 1-5 sessions of up to 25 minutes over a 3-week period. Each session involved a triadic interaction between the child, the adult and the robot. The child sat in front of a desk on which the robot was placed facing them and a tablet was placed between the child and robot (Figure 4). The adult teacher sat next to the child either with the teleoperator tablet beside them or with a second adult in a separate room using that tablet. Sessions also optionally included free-play with tangible blocks, puzzles or other objects, at the therapist's discretion. Serbia sessions were held in an autism center while UK sessions were held in a school. Sessions were audio- and video-recorded with assent. All procedures were approved by a UK and Serbia ethics committee.

4.1.3 Analysis. We reviewed all sessions with 1-2 researchers to make observations categorized by child's response to the robot, tablet, activity and miscellaneous. For each round, observations in each category were sorted and merged into themes for that category. To compile data across rounds, we looked at themes and observations in each category across all three rounds, in order to synthesize into the final themes presented below. For the teleoperator tablet (which was not used by children), we self-reflected on its usability. Observations were catered as much as possible to our experience with each child (e.g., to interpret his or her responses).

4.2 Results

4.2.1 Child Response to the Robot. All participating children engaged with Zeno and with the tablet content at some point, with many highly engaged throughout. Children were very individual in what aspects they engaged with, and for how long, though overall they paid more attention to what Zeno was doing than what he was saying. Some children's attention to the robot and to the activities differed (e.g., high interest to interact with the robot but lower interest in the activity used to interact with it). One Serbia child was afraid of the robot. Overall, the robot was accessible to most children.

Children appeared to enjoy sensory-based (i.e., nonverbal actions like the robot dancing, making faces or cheering) actions by the robot. For example, a UK child enjoyed and repeatedly requested a Twinkle Twinkle song and dance by the robot. Several children with limited language (e.g., at least four in the UK 2nd round) appeared to treat the non-verbal sensory actions of the robot as their main source of interest and means of interaction.

The ability of the robot to make context-based actions separate from the activity flow (i.e., "Yes", "No", "I don't know", "Thank you", [Praise move] and "Wow", bottom buttons of teleoperator tablet in Figure 3) was valuable for children who attempted to converse with the robot (e.g., a UK child asked the robot questions).

4.2.2 Child Response to the Tablet. Serbia children responded well to the tablet. They appeared familiar with touching it but were not so distracted by it that they didn't attend to the adult or robot. One child did not want to use the tablet, maybe because he knew it would make the robot move.

UK children responded well to the tablet. All children except one seemed to find the tablet accessible for their use. Some children expected immediate reactions after they touched the tablet, and were impatient when they did not occur immediately. For one child, the tablet itself was so distracting that they did not engage with the content; however, most other children were not as distracted by it. One child mixed up the image of the robot with the robot itself: this child attempted to point at the robot's face on the robot itself in response to its question, rather than touching the tablet (although this was resolved in the child's third and subsequent sessions). Overall, the tablet was accessible to most children.

Children pressed the tablet only enough to select their option. This suggests the feedback system we used, which removes the green outline around face features and darkens it so the face is consistently dark (Figure 3), appeared to be a clear signal to children that their choice was registered (although some younger children
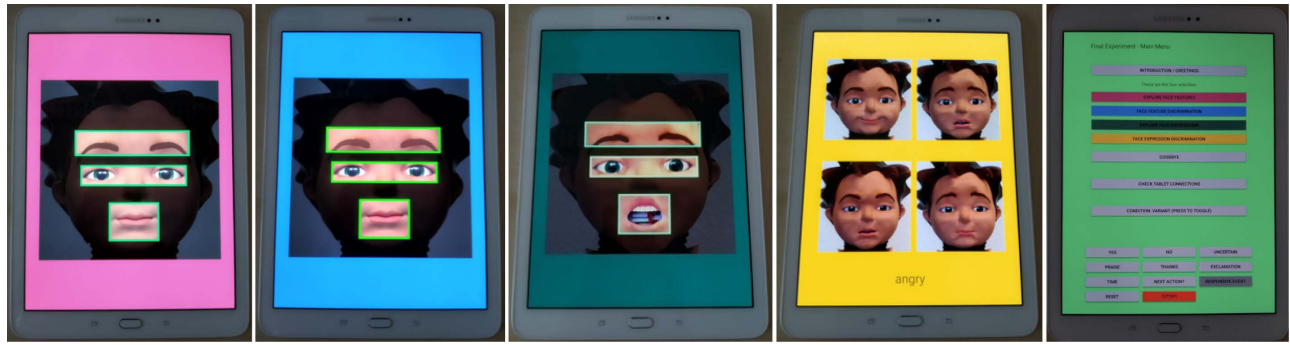
Figure 3: From left: screenshots from child tablet during pink, blue, green and yellow games; screenshot of adult (teleoperator) tablet with high- and low-level action buttons.
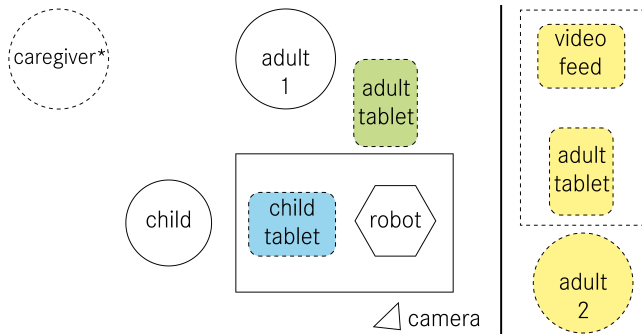
Figure 4: Study setup. Either the teacher (adult 1) or another adult (adult 2) controlled the robot using the teleoperator adult tablet. Caregiver may be absent.

continued to press). Children also spontaneously directed their attention to the robot when the buttons disappeared.

4.2.3 Child Response to Face Feature Activities. In the UK, most children eventually understood all the activities, as demonstrated by their responses and participation. One child did not. Similarly, most children in Serbia were guided quickly through each activity. They participated in the activities by selecting options on the tablet and looking at the robot. These children were able to understand when specific face features (e.g., the mouth) were referred to.

Although the activities were accessible to children, they did not seem to be very fun or engaging, as we observed children behaving disinterested or passive. (An exception was the robot dancing or cheering, which was a contextual action and not directly part of the activity.) An increased game or reward aspect may help.

Color coding of games (in the child's tablet screen, robot's speech and adult researcher's script) was effective in allowing children to identify what game they wanted to play. Some children asked for games of other colors (e.g., a UK child asked for a Black game). This color coding appeared to correctly avoided issues with children incorrectly thinking that a "teach" activity was being played when they saw a similar tablet screen during a "test" activity (left two screens of Figure 3), which we observed in an initial prototype.

4.2.4 Adult Teleoperator Tablet. We reflect on the usability of the teleoperator tablet based on our own experience. Having a separate teleoperator worked well in managing cognitive load for the adult running the session with the child. It required about half a day of training between the teleoperator and the adult teacher.

The teleoperator design, with buttons for activity-level execution at the top and quick one-off response buttons at the bottom (Table 3), allowed the operator to issue quick robot actions based on the situation while directing the overall activity flow.

4.2.5 Cross-Cultural Effects. Overall, we observed children in the UK and Serbia to respond similarly (for example, both groups had accessibility issues with the pacing and lack of tablet feedback, which we subsequently resolved for the second round of UK tests). The primary differences that we noticed were in the interactions between robot, therapist and child across regions. Serbian therapists sometimes used the robot sparingly and instead delivered content using their own teaching and switched tasks quickly as compared to the UK therapists; these actions appeared to motivate children. Serbian therapists were also very skilled at directing child attention to the robot, tablet or another location, whereas the UK therapists focused more on evaluating the child's spontaneous or "natural" response to the robot.

5 DISCUSSION

5.1 Summary of Results

We developed a novel robot and tablet system for face feature activities that was catered to minimally verbal autistic children. User studies with 31 minimally verbal autistic children found that the robot and tablet system was accessible, particularly the robot's non-verbal actions, the tablet's button feedback, the activity's color coding and the teleoperator tablet's inclusion of both activity-related and context-based buttons. We find a user-centered process can result in a robot system accessible to a group of minimally verbal autistic children.

5.2 Design Implications

Table 2 presents preliminary design guidelines for tablets and robots for minimally verbal autistic children based on this work. The main design implication is that we successfully designed tablets,

Table 2: Summary of Results and Design Implications

Result	Design Implication
Robot	
Children engaged with robot	Can use robot
Children liked dance/cheer	Include sensory, nonverbal robot actions
Some children converse with robot	Allow contextual responses by robot operator
Child Tablet	
Tablet is accessible	Can use tablet for child to control and respond to robot
Children touched buttons only once	Include tablet button feedback, e.g. button removal, fade into background image
Face Activity	
Activities understood	Can use face features in activity
Activities not fun	Add game or rewards to activity
Colors understood	Give each activity a color
Teleoperator Tablet	
Teleop. tablet usable	Include both activity-level and quick-response buttons on adult's tablet
Separate operator worked	Can reduce therapist load with separate operator for adult tablet

robots and face feature activities that were accessible to the autistic children (and their teachers) in our study.

5.3 Methodological Implications

We show that a non-participatory user-centered process can demonstrate a robot system's accessibility across a large ($N = 31$) group of minimally verbal autistic children. Although participatory design methods are valuable to involve autistic children in creating systems they would use, user-centered evaluation may have value as a means to show general accessibility of a system.

5.4 Limitations

We do not report a user study evaluating whether our system improves learning outcomes for autistic children, as our focus was on evaluating system accessibility rather than evaluating child performance. We do not report quantitative analyses of child behavior as might be produced by an annotated, time-sequence analysis of video recordings. As our primary goal was to develop an accessible robot and tablet system for minimally verbal autistic children, we tried to identify a comprehensive range of recurring usability issues and excluded quantitative analyses from this study. We leave it as potential future work.

We did not have a baseline condition where the therapy was done without a robot and tablet. Instead, we relied on the therapists' knowledge of individual children to interpret their behavior as interest, confusion, understanding or other state. Nevertheless, we tried to support therapists to obtain in-depth knowledge of individual child differences by including free-play (without the robot) time within sessions and by having each child do multiple sessions over a 3-week period in our study protocol. Our results listed above are based on therapists' consideration of their holistic experience of each child, including during free-play sessions.

We did not use a participatory design process in the traditional sense, since the children involved were likely unaware of their participation in a design process and did not explicitly give design suggestions. We questioned, but did not explore, the appropriateness of involving children in co-design or participatory processes

that they may not fully understand. Despite using a design process that does not qualify as traditional participatory design, it is the children's involvement and responses that are important in our research and make up the bulk of our results.

We did not explore game concepts such as rewards or difficulty levels in creating the activities, which could have made them more fun and more like a game.

6 CONCLUSION

We designed a robot and tablet system for face learning targeted to minimally verbal autistic children. In an evaluation study with 31 autistic children in the UK and Serbia, children made choices on the tablet and then directed their attention to the robot, indicating they understood the interaction flow. We demonstrate a robot and tablet system that is accessible for a large number of minimally verbal autistic children.

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