A Participatory Design Process of a Robotic Tutor of Assistive Sign Language for Children with Autism

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Abstract— **We present the participatory design process of a robotic tutor of assistive sign language for children with autism spectrum disorder (ASD). Robots have been used in autism therapy, and to teach sign language to neurotypical children. The application of teaching assistive sign language — the most common form of assistive and augmentative communication used by people with ASD — is novel. The robot's function is to prompt children to imitate the assistive signs that it performs. The robot was therefore co-designed to appeal to children with ASD, taking into account the characteristics of ASD during the design process: impaired language and communication, impaired social behavior, and narrow flexibility in daily activities. To accommodate these characteristics, a multidisciplinary team defined design guidelines specific to robots for children with ASD, which were followed in the participatory design process. With a pilot study where the robot prompted children to imitate nine assistive signs, we found support for the effectiveness of the design. The children successfully imitated the robot and kept their focus on it, as measured by their eye gaze. Children and their companions reported positive experiences with the robot, and companions evaluated it as potentially useful, suggesting that robotic devices could be used to teach assistive sign language to children with ASD.**

I. Introduction

Autism spectrum disorder (ASD) is a disorder characterized by impaired language and communication, impaired social behavior, and narrow flexibility in daily activities [1], [2], [3]. Therapeutic interventions for children with ASD can be applied by therapists to improve communication skills. Improving communication can improve quality of life, self-care and social skills [2]. Previous research has shown that children with ASD are more interested in communication therapy when it involves robotic components [4], which has encouraged researchers to explore robots as communication therapy tools [5], [6], [7].

This study examines a robot in the context of assistive sign language teaching. Half of children with ASD remain functionally mute in adulthood [8], which is why Augmentative and Alternative forms of Communication (AAC) are used, with assistive sign language being the most common [8], [2]. People with ASD learn assistive signs early in life, making children the ideal user group for this research.

We designed a robotic tutor of assistive sign language for children with ASD with the Participatory Design (PD) method [9], where providers of autism therapy acted as designers along with the roboticists. In this paper, we present the robot's design process, including the design considerations and choices made with regards to the robot's environment, form, interaction and behaviour. We introduce five design guidelines selected for children with ASD — based on the therapy providers' knowledge and literature. The robot's design had the goals of successfully prompting assistive signs, and being socially appealing to the children to keep their attention.

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The designed robot was evaluated in a pilot study. In the study, the robot prompted children with ASD (n=10) to imitate 9 assistive signs. Children were successful in imitating the robot's signs and focused most of their attention on the robot, indicating that the use of a robot as an assistive sign language tutor is a viable application area.

Contributions - We present the participatory design process and design decisions of a multidisciplinary team designing a robotic assistive sign language tutor for children with ASD. We present design guidelines and ethical considerations followed during the design process. The resulting robot design is evaluated for effectiveness in a pilot study. Recommendations for future research are presented.

The paper structure is as follows. First, we survey the related work. The participatory design process is then presented in its three parts: use case, design guidelines, and design of the robot. The pilot study is presented in Section IV and its results discussed. Recommendations for future research are finally discussed.

II. Related work

In this section, we survey the literature on robots as an assistive tool for children with ASD and the concept behind the participatory design process.

A. Robots as assistive tools for children with ASD

Robots have been previously explored in communication therapy use with children with autism. The rationale behind using a robot for this type of therapy is that the robot's social behavior can be consistently controlled, which may make it less overwhelming for autistic people [10]. Additionally, children with ASD have been observed to show more attention toward objects than to humans, and to be more interested in treatment when it involves robotic components [4].

Broad research has been conducted to explore robots as tools in communication therapy for autistic children [5], [6], [7], [11], [12], [13], [14], [15], [10], [16], [17], [4], [18], and separately to teach sign language to neurotypical children [19], [20]. Combining these two elements serves as the motivation to conduct this research.

B. Participatory design of assistive robots

User-Centered Design (UCD) methods are used in Human-Robot Interaction (HRI) to understand the needs of users within specific contexts, which are then translated into design choices [21], [22]. Participatory Design (PD) is a practice of UCD which involves users and other stakeholders as co-designers, and through this challenges assumptions, encourages reciprocal learning, and creates new ideas [9]. PD has previously been used in HRI for designing robots for older adults with depression [23], as well as older adults with dementia [24]. PD has also been used to design therapeutic intervention sessions for children with ASD with the robot Kaspar [25]. This study focuses on the PD of a robot which has the user group of children with ASD, and the task of teaching assistive sign language.

III. Design process

This section presents the participatory design process with the following structure: defining the use case, defining design guidelines, and designing the robot.

A. Process overview

The goal of the co-design process was to create a robot that could successfully teach assistive sign language to children with autism. The decisions made during the design process aim to increase the robot's appeal to the children to capture their attention, as well as increase usefulness as a tutor by successfully prompting the children to imitate.

The design team included three roboticists who built the robot and programmed interactions, and three providers of autism therapy — a speech therapist, a neuropsychologist, and the health care district's quality manager — who shared knowledge about the use case, aided the creation of design guidelines, and advised during the implementation of modifications. Children with autism or their parents were not available for the problem definition or development phases, however they participated in the design by evaluating the final outcome.

The robot InMoov was chosen for this pilot study due to its human-like appearance, its easily modifiable structure, and its hands with five fingers which enable signing. The original InMoov schematic was designed by Gaël Langevin [26]. Modifications to the InMoov's original hardware and software were designed with the PD approach.

B. Use case

The team analyzed the use case through three themes: the *user group's characteristics and needs*, the *user's goal* and *the robot's task*, and *safety and ethical considerations*.

1) User group's characteristics and needs: As discussed in Section I, ASD is characterized by impaired language and communication, impaired social behavior, and narrow flexibility in daily activities [1], [2]. The team discussed that due to the characteristics of ASD, the children needed to have a well-structured experiment, where they could feel safe. Without meeting these needs, the experiment could be too scary, and thus unsuccessful.

2) User's goal and robot's task: Learning assistive sign language and applying it into everyday situations is a long process, which is done through practice with therapists and loved ones [2].

Structured therapy sessions of assistive sign language often focus on practicing a few signs at a time. For this pilot study, we decided that successful imitation of signs was a sufficient measure to indicate the start of the learning process, and that nine signs would be a sufficient amount. The child's goal would be to imitate nine signs by the robot. The robot's task in turn was to perform the nine signs, and to be sufficiently socially appealing in its form, behaviour and interactions to capture and keep the child's attention.

3) Safety and ethical considerations: The team focused on implementing an ethical application of robotics early in the process, early in the use case's discussion. Roboethics are realized in the interaction between the robot and its user [27], which means ethics need to be taken into account during the design of the interaction, and not as an afterthought.

To ensure physical safety of the child, we agreed that there should be a barrier between the child and the robot, such as a table. We decided that the speech therapist should remain in the room during experiments, to ensure the child could not get too close to the robot and hurt themselves, or damage the robot.

The child's data should be kept secure, which was ensured by encrypting all recorded footage. Safety of data is especially important in applications where users are vulnerable, such as education, health care, and elderly care [28].

The team's neuropsychologist was concerned that the child may potentially learn bad behaviours from the robot and generalize them to humans, if there is no negative feedback to the child's bad behaviour toward the robot. We determined that the speech therapist in the room would facilitate correct behaviour enforcement, by intervening if the child tried, for example, to hit the robot.

The therapy providers found it important to treat all children equally, irrespective of gender. During a discussion of the robot's appearance, and whether to give it clothes, we agreed that the robot should have no clothes — both to make it more simple looking, and gender-neutral. The robot's voice was decided to be as gender-neutral as possible.

The speech therapist wanted to make clear to the child and their companions that the robot was not intended to replace human contact for the child, but to act as a tool to assist learning. This strengthened the reasoning behind keeping the speech therapist in the room during experiments. Especially in applications where users are vulnerable, the balance of assisting and replacing human-human interaction with robots should be carefully considered [28]. Users have a tendency to form emotionally close bonds with robots, which can lead to falsely personifying the robot to a harmful degree [29]. Here, these potential emotions are taken into consideration with the speech therapist's presence.

The roboticists wanted to ensure that children and companions did not come to the wrong understanding about the state of robotics and its application to autism therapy.

To ensure transparency, the children and companions were explained the Wizard-of-Oz nature of the experiment after it was completed.

C. Guidelines for autistic children in HRI

Design guidelines have been previously used in HRI design [30], [31]. Guidelines for design reflect the team's information processing and building common understandings during co-operation [32].

Five design guidelines were selected for the robot, based on the team's discussion about the use case. For example, a concern about the child potentially getting distracted during the experiments was brought up by the therapy providers. We agreed that the robot's behaviour needs to be clearly defined for this case, so that the child does not become confused by the robot suddenly behaving differently, which could happen due to the children's impaired flexibility in routines. This led to further discussion on the robot's behaviour, and the definition of the guideline that behaviour should be "consistent, structured, and simple". To ensure this, we determined that a roboticist and the speech therapist should design the interaction structure together, with every utterance of the robot clearly defined. The determination of other guidelines followed a similar process.

The team validated the guidelines after their creation, by examining literature to determine which previous studies of robots in autism therapy for children had followed similar guidelines. The literature presented after each guideline indicates that the design guideline is explicitly mentioned in the study.

We chose the following design guidelines:

1) **Simple form** [6], [7], [33], [11], [1], [12], [34], [4], [10]
2) **Consistent, structured, simple behavior** [30], [6], [7], [35], [33], [11], [1], [12], [14], [15], [10], [34]
3) **Positive, supportive, rewarding experience and environment** [5], [6], [7], [36], [12], [25], [15], [10], [37], [16], [17], [34], [18]
4) **Modular complexity** [5], [35], [38], [33], [11], [12], [16], [34], [4], [2]
5) **Modularity specific to child's preferences** [33], [38], [12], [34], [2]

The five design guidelines defined in this section can be used to guide the design of robots for use by children with ASD in general. While the design guidelines emerged from the participatory design process, it is important to note that they have a strong basis in the literature. The reasoning behind the guidelines is detailed below.

1) Simple form: People with ASD have problems with forming a holistic perception of their enviroment, meaning they have problems integrating different stimuli into a "wholesome" experience, and may instead fixate on isolated features [33], [1], [12]. To avoid overstimulation, social robots designed for use by autistic children should be kept simple and predictable in their appearance [33], [10], [34].

2) Consistent, structured, simple behavior: People with ASD have difficulty predicting other people's behavior [39], [1]. Robots that behave consistently and predictably could potentially bridge the gap for people with ASD confused by human complexity, and help them learn communication skills [33], [34]. A large number of features in behavior could even be overwhelming [33], and result in overstimulation [33], [10]. A consistent set of behaviors [30], as well as a structured sequence of actions and positive behavior reinforcement is recommended [34].

3) Positive, supportive, rewarding experience and environment: Involving the people present in the child's everyday life, and practicing in familiar environments, can help aid learning and creates a supportive experience [36], [2]. An encouraging and supportive environment congratulates the child when they are doing well, but is not too critical if the child should respond incorrectly [37], [34]. A sensory reward for participating in the therapy is recommended to keep the child motivated and the experience positive [37], [34]. The robot should be a companion to the child, and be receptive and responsive to the child's actions [34].

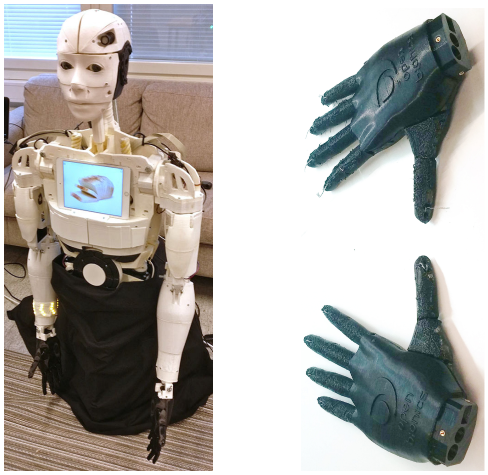
4) Modular complexity: Due to the level of functioning among individuals with ASD being highly variable [3], the individual's social and cognitive skills and needs should be taken into account when designing the complexity of the robot for long-term interactions [38], [33], [2]. Initial interactions should use a simple design, and complexity should be modified over time according to the needs of the child. The robot's behavior needs to be structured so that it is predictable, but also gradually evolve to keep the child interested [33], [37]. Built-in capacity to gradually increase complexity of interaction is recommended to promote learning [33], [34]. This can be done through different interaction modalities, such as lights and sounds [34]. Complexity of the robot's form can also be increased over time [34], for example by making it appear more human-like with clothing, although the initial form should be simple. Modularity enables the implementation of incremental improvements to the robot, minimizing the disruption during the interaction.

5) Modular specific to child's preferences: This guideline can be thought to include the previously mentioned modularity of complexity, which takes into account the child's preexisting social and cognitive skills. However, the distinction is made that this guideline targets incorporating a child's personal interests. This is recommended for communication therapy interventions for children with ASD [38], [2]. Personal preferences can be used to modify interactions [33], [34], e.g. by discussing the child's interests during the therapy, incorporating music the child likes into the therapy, or adapting the robot to a familiar environment.

D. Design of the robot

We used the guidelines defined in the previous section to design the robotic tutor. Ethical considerations defined in Section III-B.3 affected the design when needed.

The design of the robot was divided into four dimensions based on the themes that emerged in the co-design discus-



(a) (b)

Fig. 1: InMoov robot (a) with modifications to improve interaction modalities: Open Bionics hands [40], chest-screen, and lights on the right hand. Close-up of Open Bionics hands shown in (b).

sions: the *environment*, *form*, *interaction* and *behavior* of the robot. The dimensions are overlapping and inter-dependent, however the separation into dimensions aims to make the interlinked decisions taken during the design process apparent. Each dimension is examined through qualities, which depict explicit design decisions made by the team.

The guidelines mainly impact the following parts of the robot's design:

- (1) guides the *form* dimension
- (2) guides the *behavior* dimension
- (3) guides the *environment* dimension
- (4) and (5) affect all dimensions.

In this paper, the guidelines "modular complexity" and "modular specific to child's preferences" are specifically explored in the interaction dimension, without affecting the other dimensions. This is further discussed in Section IV. In a fully functional clinical solution, these two design guidelines should be realized in all dimensions.

The selection of the InMoov posed constraints for the design of *form* and *interaction*, however modifications were made to improve interaction modalities. The original schematic of the InMoov was modified by adding Ada hands designed by Open Bionics [40]. Additionally, a screen was attached to the chest, and lights were attached to one of the hands. The final InMoov design is shown in Fig. 1a.

1) Environment: The environment refers to all factors surrounding the robot's operation. The team examined environment through four qualities: *experiment flow*, *simultaneous users*, *human facilitation* and *role of the robot*.

We designed the *experiment flow* rigidly. What happened before and after the therapy session was predefined, since people with autism prefer routine and unexpected situations may upset them [1], [2]. The child was accompanied by their companion and the speech therapist during the experiment, in order to support them during what may be a stressful experience. This follows design guideline (3). The Wizard-of-Oz nature of the robot was introduced to children and their companions after experiments, to preserve transparency and avoid misconceptions of the robot's technical abilities.

As the pilot study aimed to observe and measure the interaction between the child and the robot, we decided to observe *one child at a time*.

Human facilitation describes whether the end-users participating in the interaction require the support of other people, such as in [12]. This use case required human facilitation due to the discussed safety and ethical concerns. Intervention by a human facilitator was the primary way of preventing the child from getting too close to the robot, and risking physical safety. Additionally, the therapist's presence supported correct behavior enforcement, and emotional consideration by ensuring that the child understood that the robot did not replace human care.

The Wizard-of-Oz operation of the robot from the control room was aided by the human facilitator. The speech therapist signaled to the operator how the robot should behave. A companion of the child, i.e. a parent or other caretaker, was also present to help the child feel safe and calm. This followed design guideline (3).

The *role* of the robot is defined in the context of its environment (i.e. the robot can not have any role if it does not exist in the context of a certain environment). The role of the robot was discussed through how friendly it should be, and how much it should co-operate with the child. We posed the robot as an *authority* for the child. Becoming more of a friend would require physical contact (as with for example Probo [16], a robot used in ASD communication therapy), which was not possible due to the fragility of InMoov. Additionally, framing the robot as an authority helped the child focus on the task, and not on "becoming a friend" with it. The robot was also fitting the role of *co-operator*. The robot and the child took turns making assistive signs, thus working together.

To create a supportive and rewarding experience as a co-operating authority, the robot rewarded the child when they signed correctly, following design guideline (3). If the child signed incorrectly or did not react, however, the robot was not critical, and was supportive of the child.

2) Form: The form of the robot refers to its externally perceptible qualities. We use six qualities to describe form: *appearance*, *movement*, *voice*, *sounds*, *tactile sensations* and *olfactory sensations*.

A well-known measure of a robot's form is "familiarity to life". All qualities of the robot's form contribute toward its lifelikeness. It is argued that a robot should not be too lifelike, or it will fall into the "uncanny valley" of negative familiarity, appearing like an animated corpse. A safe familiarity can be produced with a design approaching lifelikeness, but not too close to it [41]. Additionally, if a robot's form is sophisticated, the user will assume a similar level of sophistication in its skills [30], [33]. We designed *form* with these observations in mind.

The *appearance* of the original InMoov robot was modified (new hands, lights, and chest-screen), to realize different interaction modalities of the robot.

The *anthropomorphic* appearance of the InMoov was suitable for this solution, as the goal of the children was to imitate the robot's signs to practice their skills. The *mechanical* appearance of the InMoov was also suitable for this solution, as robotic appearance was considered more simple than a lifelike appearance. The robot was not modified to appear more lifelike, which could have been accomplished with clothing or a wig as in [25]. This follows design guideline (1). The InMoov's simple face — with no ability to perform facial expressions — was also not modified. A simple face helps prevent overstimulation, confusion and avoidance [12].

The speech therapist recommended for the robot to have smooth *movements*, in order to perform assistive signs as accurately as possible. The InMoov's base level of movement was machine-like, and difficult to modify. To accommodate, the InMoov's original hands were replaced with new hands which enabled smoother movements, shown in Fig.1b.

The robot's voice and the sounds it makes contribute to its lifelikeness [42]. The original *voice* of the InMoov was human-like and male. To keep the robot gender-neutral, we modified the text-to-speech engine. A female human-like voice was used, and its pitch lowered to make it neutral. The neuropsychologist advocated for a robotic voice, since the children might confuse the robot with a human if it were too lifelike. The voice of the robot was slowed by 10%, in order to make it more robotic, and understandable to the children. In addition, the robot played a short congratulatory *sound* through its speaker when a child signed successfully. This provided a sensory reward [34], [37], which follows design guideline (3).

Tactile and olfactory properties were predefined by the choice of using InMoov as a solution platform. The material used to construct the InMoov was a cold, hard plastic with no smell. However, as the interactions with the robot did not include close contact, tactile and olfactory sensations did not play a role.

3) Interaction: The interaction dimension defines the manner in which a user interacts with a robot. The design team analyzed the interaction through three qualities: *modalities*, *leadership*, and *goal*.

Modalities of interaction define the different ways a user can interact and communicate with the robot. The robot has both input and output interaction modalities. Informed by the literature on HRI for autistic children [5], [16] and previous communication therapy with autistic children [43], [37], [2], the following output interaction modalities were implemented: speech, sounds, gestures, digital visuals, lights and signing. Input modalities the children could use were speaking and signing. In the context of the pilot study discussed in Section IV, the effect of different interaction modalities on the robot's effectiveness is examined. These modalities could be used to realize design guidelines (4) and (5) in future studies with the robot.

Signing is a novel interaction modality. To avoid confusing the child, other movements were kept to a minimum. In addition to the signs, the robot used only three communicative gestures: waving hello when the child arrived, waving goodbye when the child left, and showing a thumbs up when the child succeeded in signing correctly.

The *robot led* the interaction by explaining the rules of the exercise to the child at the beginning of the experiment. The robot signed and asked the child to imitate. The robot closed the interaction with goodbyes. The *interaction goal* was for the child to complete the task of signing. This is in contrast to a more exploratory interaction [44], [10], where social interaction is the goal.

4) Behaviour: The behaviour dimension describes how and why the robot acts. Behaviour is one of the primary determinants of the user's attitude toward a robot, and also contributes to its lifelikeness [33].

Behavior was examined through four qualities: *contextual adaptation*, *motivation*, *social awareness* and *autonomy*.

The behavior of the InMoov had no *contextual adaptation*. The signs and speech of the robot were pre-programmed. Hard coded behavior is more consistent and structured than adaptation, and avoids confusion in the child. The speech therapist noted that children could learn to imitate the robot more easily, by making the robot's imitation prompts repetitive. This followed design guideline (2).

We considered whether the robot should have an internal *motivation* system for its behaviours, such as the robot Kismet, in which behaviors were influenced according to internal models of drives and emotions [45]. We determined the InMoov should only respond to the child's behaviour in the pilot study, in order to keep behaviour simple, following design guideline (2).

Social awareness describes how well the robot follows social conventions, such as greeting a new person when they enter a room. Social robots should adhere to generally accepted social norms, in order to create the impression social intelligence [30], [33]. The team decided that sophisticated social abilities were not needed, as autistic children themselves have limited social abilities, and would be confused by a robot operating on the social level of a human. The InMoov did adhere to simple social norms, in order to teach them to the children. It greeted upon meeting, said farewell when the user left, and acknowledged the user's presence by asking their name. Keeping the level of social norms simple follows the design guideline (2).

In the pilot study, the InMoov was not *autonomous*, and was operated with Wizard-of-Oz methodology. This kept the speech therapist in the loop and, if necessary, allowed modifying the robot's behavior at runtime.

IV. Pilot study

The design process presented in the previous section involved many choices which may have affected the performance of the robot as a sign language tutor. Resources were not available to examine the effectiveness of all of those choices. The interaction dimension, specifically different interaction modalities, were chosen as a likely candidate to influence tutoring effectiveness.

The aim of the study was to examine whether children successfully imitate the robot, and if they focus attention on the robot. Additionally, survey data was used to examine the attitudes of children and companions toward the robot.

A. *Methods*

The pilot was framed as a comparative design study, where three different design conditions — consisting of different combinations of interaction modalities — were compared with each other for effectiveness. In the future, combinations of different interaction modalities could be used to increase complexity, or selected specifically to suit a child's preferences, following the design guidelines (4) and (5). In the context of this pilot study, the conditions were examined in isolation, to better assess their differences.

Three different conditions were implemented: the robot signs and speaks the word in question (abbreviated as "Sign only"); the robot signs, speaks the word in question and shows an image of the word (abbreviated as "Image"); and the robot signs, speaks the word in question and flashes lights (abbreviated as "Light"). Nine assistive signs were randomly paired with the design conditions.

Quantitative measures used were imitation success rate and attention direction as measured by eye gaze. As discussed in Section III-B.2, this study examined the children's imitations of the robot's signs. Assessing the learning of signs over time is outside the scope of this paper. Imitation has been used as a measure of success in previous studies examining the use of robots in autism therapy with children [17], [4], [13], [11], [7], as well as teaching sign language to neurotypical children [19], [20]. Eye gaze is a measure indicative of attention direction, previously used in studies examining the success of using a robot in autism therapy [5], [11], [13], [10], [16], [17], [18]. Eye gaze was annotated from videos of the interactions, with the method validated by a second annotator. Additionally, qualitative data on the children's and companions' attitudes toward the robot were collected through surveys administered after the experiments. The effect of the three design conditions on imitation success, eye gaze, and children's and companion's attitudes was examined.

Ten children attended with their companions. The children were seated in front of the robot together with the speech therapist, with the companions in the room, as shown in Fig. 2.

B. *Quantitative analysis*

Seven out of ten children imitated the robot at least once. A one-sample Wilcoxon signed rank test reveals that the median number of total successful repetitions was significantly greater than zero ($p = 0.011$). This indicates that the robot was successful in prompting children to imitate it.

Children focused their eye gaze on the robot for the majority of the duration of the experiments (mean = 73.89%, SD = 29.80%). This indicates that the robot was successful in capturing the children's attention and keeping it throughout the interaction. This signals that the robot's design was socially appealing to the children.

The design conditions had no statistically significant effect on the success of imitations, or eye gaze.

Fig. 2: The experiment set-up. The speech therapist is signaling a thumbs up to the camera, which indicates to the operators of the robot that the child's sign was correct. The child's companions are also in the room.

C. *Qualitative analysis*

1) Children's surveys: All 10 children were asked to answer a short survey conducted by the neuropsychologist after the experiments. Due to the communication difficulties present in ASD, the psychologist evaluated the reliability of the children's answers on a case-by-case basis. Six children were able to answer questions about how the robot felt, and five were able to give their opinion on the robot, its lights and images.

Children had a generally positive outlook on the robot and its qualities. Five out of six children said the robot was fun, although one said it was also scary. One child thought the robot was only scary. Five children regarded the robot, and its "Image" and "Light" conditions, as "good". The children did not express preferences for a particular design condition.

2) Companions' surveys: Out of 10 companions present in the experiments, 8 completed a survey with 12 questions about the robot, its design conditions, and usefulness.

Companions had a generally positive outlook on the robot. Seven out of eight companions reported that the robot seemed to feel fun to the child, although 2 of them said it also seemed scary. The perception of the robot was aligned between children and their companions — in both cases where a child answered that the robot felt scary, their companion had the same perception of the child's experience.

Companions had a preference for the "Image" design condition, rated best by seven out of eight companions. Additional positive remarks about the "Image" design condition were that it "grabbed the child's attention", and "helped them understand what was meant by the sign".

All of the companions thought the child had a connection with the robot, although one also said no. This supports the result of a mean of 73.89% eye gaze focused on the robot, in indicating that the robot was successful in capturing and keeping the children's attention throughout the interaction.

The robot was considered potentially beneficial. Six out of eight companions said the child could benefit from use of the robot, with only one companion replying negatively. Companions made positive comments about the robot's potential, e.g. that the robot was "interesting to the child", and the "robot's positive feedback encouraged the child". This indicates that there is general interest from the children's companions in the robot as a tool for assistive sign language tutoring.

D. Discussion and recommendations for future research

The results indicate that the robot was successful in capturing and keeping the children's attention, and in prompting imitations. Children's and companions' attitudes toward the robot and its potential usefulness were generally positive.

While the effect of the design guidelines on the effectiveness of the robot was not directly examined, the robot's design, shaped by such guidelines, was successful in its intended purpose. Additionally, children and their companions had positive attitudes toward the designed robot. This supports the effectiveness of the design.

Future design modifications to the robot and future research interests indicated by quantitative and qualitative results are discussed below.

1) "Image" design condition should be further developed: The companions' answers showed a clear preference for the "Image" design condition. In further design of this robot, images should be made an optional interaction modality to support the teaching of signs. This is supported by the speech therapist's remark that multiple methods of AAC are sometimes combined in therapy sessions, discussed in [2].

2) Reduce robot's scariness: The scary qualities of the robot should be identified and altered for future experiments. One companion suggested that the robot's black hands and their noise when moved could be scary for their child with sensory sensitivity, a characteristic of ASD. The servos' noise was also regarded as an issue for understandability of the robot's speech by two companions, as it sometimes drowned out the speech. For future iterations, these and other qualities should be investigated for potential scariness.

3) Performance of signs needs to be improved: One companion noted that the signs the InMoov performed were somewhat stiff. Furthermore, the speech therapist noted that that the children were imitating the robot's stiffness. In order to avoid this behavioural artifact, the smoothness of signing needs to be improved (e.g. with better hardware).

The speech therapist remarked that the implementation of robotic facial expressions could also improve performance. Expressions could communicate the emotional tone of the signs, if they were to be used in full sentences in future experiments.

4) Understanding of signs needs to be examined: One companion questioned whether their child connected the sign with the word the robot was saying, since the child does not understand speech well. This raises an important concern for future research: verifying whether the children are understanding the signs, or merely imitating them. To measure long-term learning, a long-term interaction study with the robot is needed.

5) Examine who would best benefit from the robot: Three out of 10 children performed zero successful imitations of the robot's signs, suggesting that the robot is not suitable for all autistic children. Further studies should be conducted in order to determine who would benefit from this intervention.

6) Examine methods for speech therapist's control: For this study, the robot was operated by roboticists, who followed the speech therapist's signals. The design team discussed that in future use of the robot, it would be useful if the speech therapist could directly control the robot in real-time, for example with a hidden remote control. This could potentially enable longer or more focused therapy sessions, if the robot performing sign repetitions reduced the therapist's task load.

7) Examine guidelines (4) and (5): Realizing guidelines (4) and (5) was out of scope for this study, and should be researched in the future. There were several requests for modularity specific to children's preferences, matching design guideline (5). One companion would have liked to have the experiment in another room, due to their child already having an inflexible routine relating to the experiment room. One companion would have preferred the robot to have no images or lights. One companion would have liked for the robot to play music, to help their child focus. One companion remarked that their child was "slightly suspicious with new people, until trust is achieved", and their child usually established contact through touch. These children's preferences should be taken into account in future studies. Enhancing the robot's interaction modalities by children's preferences would also enable better realizing guideline (4) of "modularity of complexity", by combining different modalities to create increasing levels of complexity.

V. Conclusions

We presented the design and evaluation of a robotic tutor of assistive sign language for children with autism. Our findings support that the designed robot was successful in capturing the children's attention, and successful in prompting assistive sign imitations. Our results suggest how robotic devices could be future tools used in assistive sign language therapy. The presented five design guidelines, as well as ethical considerations, are a contribution for future design of HRI for children with autism.

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