Do Children with Autism Benefit from Educational Interventions Utilizing a Tangible Interface and Audio-augmented Drawings?

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ABSTRACT

In this article, we describe the development and pilot study of an audio-augmented paper drawing system which assists therapy and educational treatment for children with autism spectrum condition (ASC). We used a generative design and dynamic development method to create a system enabling paper drawings to be augmented with an audio recording of a child's voice. The system was found to support therapists in stimulating children's narrative and descriptive development. One significant finding of this work could be that hearing their voice incentivizes children to maintain their attention on comparative narration tasks. Similar audio-augmented paper drawing technologies might be used within rehabilitative and educational settings to assist children with ASC. This article reports the benefits and limits of using audio-augmented paper drawing for the educational treatment of children with ASC.

CCS CONCEPTS

• **Human-centered computing**;

KEYWORDS

Audio-Augmented Drawing, Autism Spectrum Condition, Children, Social problem solving, Tangible user interface, Technology

ACM Reference Format:
Andrea Alessandrini, Cormac Murray, and Gabriel Serra. 2023. Do Children with Autism Benefit from Educational Interventions Utilizing a Tangible Interface and Audio-augmented Drawings?. In *European Conference in Cognitive Ergonomics (ECCE '23), September 19–22, 2023, Swansea, United Kingdom.* ACM, New York, NY, USA, 8 pages. https://doi.org/10.1145/3605655.3605680

1 INTRODUCTION

Autism spectrum condition (ASC) is a developmental neurobiological condition that impairs social interaction and communication and produces restricted interests and behaviours from a young age [23]. Interventions for children with ASC usually aim to teach social and communicative strategies to assist their ability to function in real-world social settings. These interventions frequently use visual aids such as images and drawings to represent concrete and abstract real-world concepts [11]. The social story technique is commonly employed to reinforce the acquisition of new social skills and improve upon existing social behaviours [17]. In social stories, visual cues are used to assist children in their understanding of oral language; the combination of spoken language with pictures, drawings, and written words fosters children's ability to derive meaning from information [35].

We aim to provide both a novel tool and a new approach to help caregivers to present and discuss social stories and similar materials with children with ASC. This paper details the development of a tangible artefact for the situated creation of audio-augmented paper drawings that can assist with social stories. Our system was examined in terms of its utility and effectiveness amongst children, educators, logopaedists, and therapists. This work allowed us to study how educators and children might incorporate audio-augmented paper drawing technology into their regular educational activities.

2 RELATED LITERATURE

Many technologies and systems have been designed to support educational intervention for children with ASC in recent years. These computer-based interventions are grounded on the cognitive-behavioural therapy (CBT) procedure, based on applied behaviour analysis principles [20, 30]. Computer-based interventions include virtual reality [26, 32], robotics [12, 25], tabletop computer interfaces [22], tangible artefacts [2, 3, 15, 27], and mobile applications on tablet computers [16, 41].

Researchers have reported an increase in cooperative behaviour by children with ASC using tangible technologies. Farr et al. [16] highlighted the advantages of Topobo, a 3-D constructive assembly system embedded with programmable kinetic memory, in fostering collaborative and cooperative behaviour among children with ASC. Additionally, Farr et al. [15] highlighted the positive impact that augmenting configurable objects with the child or therapist's voice could have, indicating the positive and reassuring role played by the child's caregivers. Alessandrini et al. [2] explored the role of audio-augmented paper in supporting cooperation in educational activities with children diagnosed with ASC. Ringland et al. [37] found evidence of improved body awareness, sensory tolerance, and socialization amongst children with ASC who interacted with their SensoryPaint system. The positive impact of tangible systems has also been demonstrated on children with intellectual disabilities rather than ASC specifically, with Falcão [14] highlighting the low accessibility barrier and ease of exploration that physical systems offer compared to digital or audio systems.

Other technologies and works have similarly looked at the assistive potential of tangible prototypes for children with ASC. Such

ECCE '23, September 19–22, 2023, Swansea, United Kingdom

ACM ISBN 979-8-4007-0875-6/23/09…$15.00
https://doi.org/10.1145/3605655.3605680

prototypes include Simm et al.'s [38] Clasp application, augmenting the ability of patients to communicate anxiety. Hayes et al. [21] examined three different prototype systems to provide visual support for language production among children with ASC. Assistive robots have also been designed and prototyped for therapy for children with ASC. Billard et al.'s [7] Robota system was built to teach autistic children simple coordinated behaviours and gestures, engaging in imitation games to help children develop a set of motor patterns. Robota's tangible and embodied nature was considered an especial asset, as it allowed for a display of bodily orientation and experience that an on-screen simulation would have lacked. In a similar vein, Zhang et al. [42] engineered a simple robot which detected a child's emotional states through facial expression detection and encouraged further expression of these emotional states by playing appropriate audio cues and emotional music. The importance of preserving simplicity of use in designing tangible interfaces for children with learning difficulties was examined by Keay-Bright and Howarth [24], which found that easy modes of interaction promoted engagement with the system and fostered happiness, social communication, and learning amongst child participants through easy modes of interaction.

The role of paper as an active medium has also been explored in several works in the existing literature. Bauminger-Zviely et al. [6] studied the impact of collaborative tasks in imparting social skills to children with ASC and employed both computer games and paper-based drawing tasks as collaborative activities. Piper et al. [33] proposed using a digital pen for audio annotation of paper-based materials, such as drawings and photos. TinkerLamp [43] used fiducial markers to build paper-based interfaces for tangible simulations. LuminAR also uses fiducial markers to build tangible interactions [28]. Raffle et al.'s [36] Jabberstamp tool allow for repeated audio imprinting on a sheet of paper, enabling children to attach recorded audio cues to drawings and encouraging users to communicate, create narratives, and even devise games outsiders can interact with, whether singly or collaboratively with other children. Such studies should be considered in light of Prieto et al.'s [34] review of augmented paper systems in educational settings, where their ability to accommodate a variety of classroom settings and activities was noted. Our work wants to fill the gaps in the knowledge about the advantage of using audio-augmented paper educational environments for the treatment of ASD children.

Although these studies demonstrate a vibrant field of study and present interesting opportunities to design future TUI technologies, scarce information exists regarding the benefits of using located and situated audio-augmented social stories for the educational intervention of children with ASC. To address this gap, we have designed an audio-augmented drawing, a tangible interactive environment to support and promote paper locate audio, narrative and descriptive activities for children diagnosed with ASC. In our research, we investigate the roles and benefits of using located and situated audio recording in narration and description tasks and the advantages of using physical-digital artefacts to support educational sessions. Through this, we endeavour to expand the knowledge base regarding the use of audio-augmented paper in educational environments for the benefit of children with ASC.

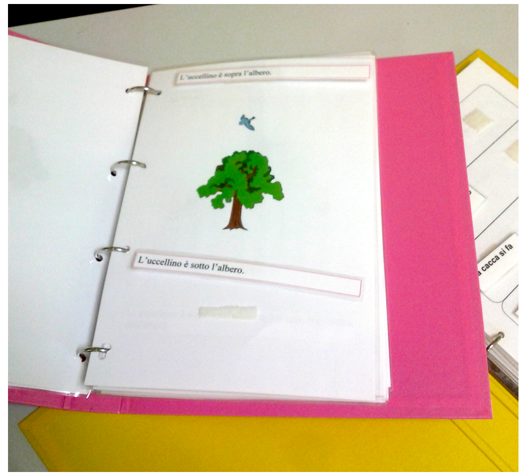

Figure 1: Example of stories book with sheets of paper with the interchangeable text

3 OUR APPROACH TO DESIGN FOR CHILDREN DIAGNOSED WITH ASC

Our design process was grounded on user-centred design (UCD) principles and scenario-based design [10]. We used an iterative methodology that combined concept generation, technology benchmarking, and activity design into continuous, enriching, and gradual actions. We involved a diverse range of people at all stages, which allowed us to receive valuable feedback and insights for guiding, reviewing, and challenging our design process.

3.1 User field research

Our project began with a field research study conducted via participant observation at three centres for the education of children with ASC (Fig. 1). We observed that all the centres regularly used variations of the social story approach, organized around drawing and story sequencing activities done together by the child and therapist to introduce and discuss examples of social problems. Often either the child or the therapist wrote a description of the social story cards' contents on the sheet of paper or the child's notebook. These descriptions were intended to act as a memory aid for continuing the activity later or for parents to become aware of their child's educational rehabilitation activities. The observation participants were children ranging from 7 to 14 and therapists ranging from new to expert. After observation, informal interviews were conducted with the therapists regarding their activities with the children and their experience with the prototype.

3.2 User scenario and design objectives

According to the therapists, handling physical-digital artefacts rather than digital computer representations offers several benefits for children with ASC and their therapists. Therefore, we focused on sheets of paper and other simple artefacts. Using the data coming from the user research, the team defined three design objectives.

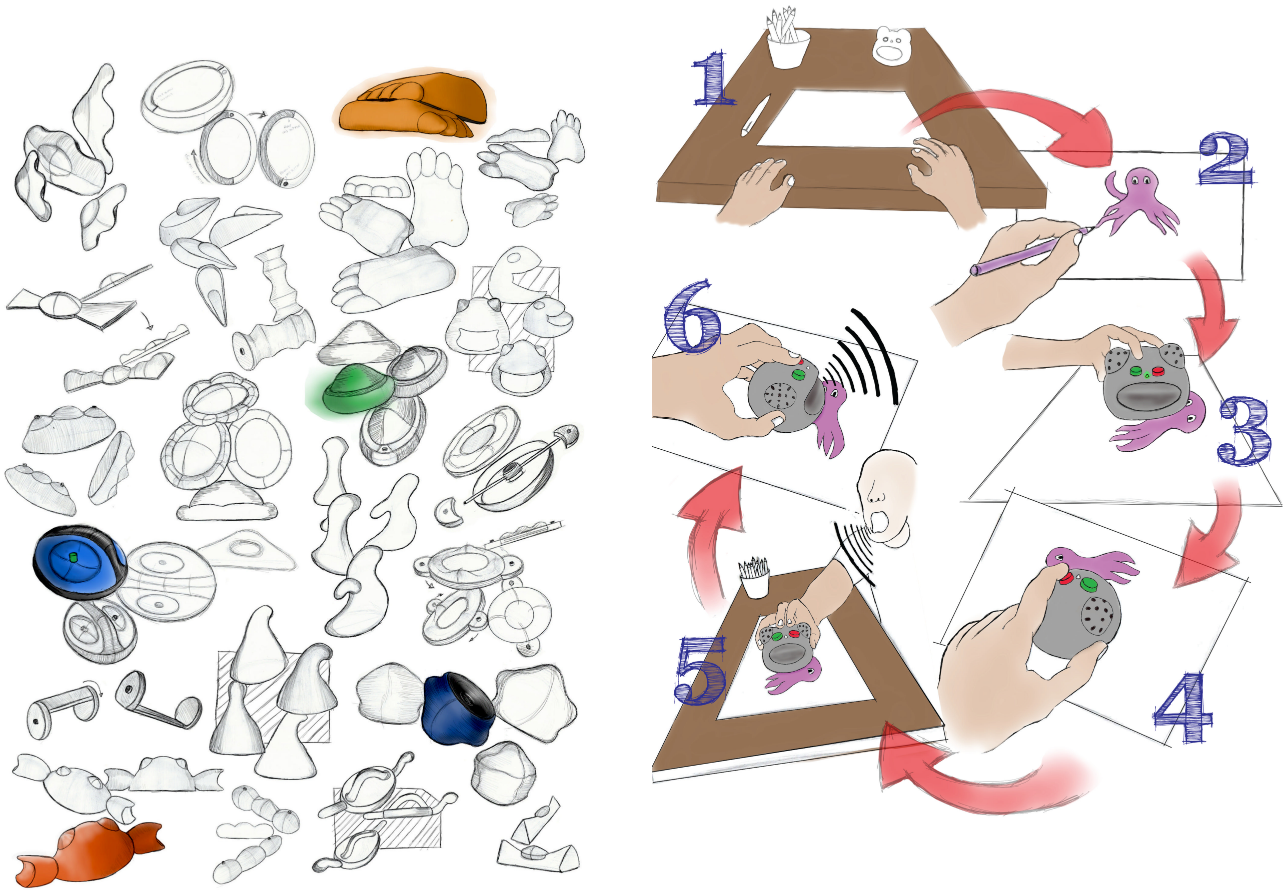

Figure 2: Early Design Concepts (left); Our final model of interaction (right)

Design objective 1: Augment standard paper drawings with audio from the child and therapist's vocal narrative to create educational activities involving the child narrating depicted stories on the paper.

Design objective 2: Embed computation functionalities into tangible artefacts to preserve natural collaboration between the child and the therapist.

Design objective 3: Ensure simplicity of use. The therapist should be able to easily configure the artefact to adjust it to the child's needs.

With these objectives to guide our overall vision, we conducted several design concept generation sessions (Fig. 2 left). Parallel to concept generation, we investigated potential enabling technologies appropriate for the project and generated seven concepts based on available technologies. The concepts were produced and visualized into concept scenarios. We selected a concept for further elaboration, as it was deemed compatible with all our objectives.

3.3 The model of interaction

We produced a proof-of-concept prototype which we presented for review at a workshop with therapists. During the review, they raised concerns about the visual recording feedback, which they felt was unclear, but they recognized that it was simple enough to be explored and learned quickly by the children and them. We redesigned our prototype to incorporate multiple artefact anchor points on the sheet of paper and shareable artefact controls by users. Our new model of interaction introduced a new dimension related to the space of interaction, requiring social abilities such as negotiation and cooperation to take full advantage of our artefact.

The refined model of interaction reorganized the space of collaboration in several ways: (1) a sheet of paper is used to anchor and initiate the interaction with the system; (2) the tangible artefact interacts with the areas of the sheet of paper selected by users; (3) the tangible artefact enables privileged behaviours between the users and those areas of the paper they selected; (4) the audio playback functionality allows the users to create a sequence, enabling the concatenation of audio files by successfully placing the tangible artefact over the previous audio enriched areas on the sheet of paper. Refining the tangible artefact's interaction was accomplished with the creation of the storyboard (Fig. 2 right) and video scenario, and the development of a new interactive prototype. With the first two, we highlighted three key aspects of the model of interaction. Firstly, the system requires a sheet of paper, whether blank or with pre-drawn content. Secondly, the system's functions must be easy to use by the child in collaboration with the therapist. Thirdly, users should be able to create an audio sequence by using multiple sheets or multiple areas and placing the physical-digital artefact over the enriched audio areas in successive order. Finally, the user interface was refined to be more consistent, fluid, and error-resistant.

3.4 Design

We went through a selective process from an initial sketching phase by elaborating and developing a selected number of ideas. The sketch we chose for modelling was based on a "cat head" shape. We realized that a smaller form factor was required to make it easy to use in the hand of a child. The new prototype was subject to a heuristic evaluation [31] by experts on ASC, which welcomed the shape and form factor because it was appropriate, attractive, and not distracting for the children and the therapist, but recommended enhancing the audio. The prototype was re-elaborated for 'graspability' and weight by reducing the prototype's volume. Through several iterations, we settled upon eight kHz (sample rating) for the quality and one minute for the time, privileging the audio quality over the recording time. We tested speakers that could offer better audio quality, considering the prototype's small form and the requirements of the sound to be able to propagate through the surface in contact with the prototype. The software's system, running on an embedded microcontroller, detects and recognises drawings with minimal latency. We gave a defined directionality, privileging the front side of the form over the other sides. The shape of the "cat head" and the underlying enabling technologies were placed in front of the "cat head." The sensors recognize the presence of a sheet with a drawing under the base and assign a unique state to each drawing section located under the prototype before recording audio. Mapping the base of the body so that the field of view matches the front view of the "cat head" gave the prototype a more "human look and feel."

The finalised prototype, dubbed ReduCat can be grasped and handled with one hand due to a compact form factor, an appropriate weight, and rounded and "soft" shapes, also imparting a sense of sturdiness and solidity. Without giving any specific cue for one privileged point of access, we designed a shape that is perceivably graspable from any direction, and the front of the prototype was privileged by placing the user interface in the shape of the "cat head." The prototype's audio resonates through the material in which it is placed over, and hard or soft materials resonate differently. The prototype has a drawing detection feedback LED to communicate to the user that a drawing is detected. The feedback is positioned as a "nose" close to the recording red and playback buttons, creating a face (Fig. 3). Recording a snippet of audio is performed by placing the cat head onto a drawing by pressing the red button which turns a red LED feedback on. The recording and playback functionalities are only operative when the system detects a drawing on the sheet of paper. The prototype can detect a drawing or section of a drawing depicted on a sheet of paper or any surface. If the sheet of paper already has audio, the new audio is appended to the end of the previous one. The playback of the audio files recorded for a drawing could be initiated by pressing the green button on the prototype. When the prototype is placed on top of a drawing with audio, pressing the record button for over three seconds will erase that particular instance. If the prototype is placed over an empty section of the paper and the button is pressed for more than three seconds, all audio contents in the prototype's memory will be erased.

4 PILOT STUDY

Two education centres in two different countries were employed during the prototype evaluation. This evaluation was intended as an ecological pilot study aimed at exploring the strengths and weaknesses of our prototype in authentic conditions. We investigated how the therapists in each centre used the prototype, how the prototype supported the therapists' learning objectives and the degree to which children engaged with the prototype. The pilot study began with theof the prototype by the children and therapists in sessions, with each session lasting ten to thirty minutes. The therapists had prior experience with the children and were already conducting educational activities based on social problem-solving and story sequences. The therapists were introduced to the prototype's functionalities during the study planning meetings. The children involved consisted of one eight-year-old subject with verbal ability led by one therapist, and two subjects with verbal ability between eighteen and seventeen. The eight-year-old was involved in two sessions led by the same therapist, while the two older subjects were involved in one session each with the same therapist. The therapist was free to choose those activities that best responded to the child's needs. All sessions were video-recorded for further analysis. After each session, semi-structured interviews were conducted by the study facilitator with the therapists. We conducted the analysis focusing on thematic coding. We didn't start with codes developed in advance; instead, we used data-driven coding, which implies that we started without codes and developed them through reading the material. We moved from descriptive to more theoretical levels during the analysis phase, leading to a saturation of the material insight and interpretation. Therapists used three different tasks throughout the study: describing pre-printed visual cards detailing a social story; describing pre-printed, social problem-solving visual cards; and describing the content of large-format colour flashcards [4]. During the analysis of the data gathered in the pilot study, the following themes emerged.

4.1 Physical-digital tangible artefacts and "human" interaction

We observed that several behaviours, and instances of language used by the therapist and the child towards the prototype were "human-like." For example, the therapist called the green feedback "Little nose" or she said "It did not hear" if the recording volume was too low, or "It can see it". Similarly, the child spoke to the prototype. For example, they said, "You heard my voice?", "I did not hear, please, could you repeat it to me?", "Well, it heard almost all of it" or "Understood!". The kids also produced behaviours like covering the prototype's "ears" to make it not listen and turning the cat's head towards the listener's direction suggesting that the design might have stimulated anthropomorphization of our tangible prototype and inspired behaviours that treated it as a human.

4.2 Narrative collaboration and comparison

We observed that the therapist used the situated audio recording of the child's voice to enhance their re-engagement in elaborating

Figure 3: Advanced prototype

Figure 4: Written and verbal comparison activity

upon the story's description. For example, the therapist said, "I asked you to describe how the child on the bench feels, but you did not describe it . . . let's listen again to what you said". There were several recordings attempts of card descriptions, and each time the child changed some small particulars. The therapist reported that the child did not change the story features she asked them to change, and the child was very focused on the artefact. In the second pilot, the child was much more responsive and more likely to change the story characteristics according to the therapist's feedback. For example, the therapist enquired about the two figures depicted on the card, "How are the children?". The child recorded the story again and added that they were worried about throwing their football up a tree. Initially, the child focused more on the artefact than on the therapist, and the increased collaboration might be due to the novelty effect exerting less influence. The therapist reported that during the second section "the [prototype], was as an everyday tool. . . today, it was as it was part of the therapeutic section".

The child usually has a personal notebook to transcribe the description of the story sequencing cards to be further elaborated upon. We observed that the therapists used the prototype and the personal notebook to engage the children in a comparison activity between the audio of the sequencing card story recorded by the prototype and the written version of the story in the children's notebook (Fig. 4). For example, the therapist asked, "Better what you said or what you wrote?". The therapist asked the child to check the people's emotional states depicted on the sequence story

Figure 5: Simultaneous recording with an ad-hoc black square card

cards and re-listen to check if they had accurately described the depicted character's emotional state. The therapist emphasised that our prototype was helpful for comparison with what the child wrote in their notebook and reported, "It's something we never tried before, today I saw that it was useful to him. For the comparison between what he says and what he writes". This activity shows an interesting use of the prototype and demonstrates its flexibility and ability to support appropriation by educators.

4.3 Relationship contents and physical-digital artefacts

During the pilot study, we observed that the therapist introduced an additional component to the cards, a black piece of card. The cards were photocopied from a book, enlarged and coloured in some areas (Fig. 5). The therapist used the black card as a shared external anchor point to the story sequence cards. The therapist reported that the child could describe and record it all with a central point, while their ability to describe it all would be impaired by recording piece by piece. The advantage of the central point over piecemeal recording might be due to the therapist still learning how to use an unfamiliar system.

We observed that the child indicated to the therapist the social problem story card they felt would solve the problem by placing ReduCat over the card and started to describe and record it. The therapist appreciated the use of the paper for its simplicity and ease of use, for its expressive potential, and for its ability to be shared in collaborative activities. However, they most often used the prototype to engage the children in description activities rather than storytelling activities. This might be due to the therapists' limited experience with the system or the system being too limited for a storytelling activity.

4.4 Constraints for focusing

The therapist exploited the recording length limit as an opportunity to accomplish the objectives. For example, the therapist said, "*You should be shorter. The story is too long.*" or the therapist reminded the child, "*Be very careful that it must all fit in the memory.*" Interestingly, after a few tentative attempts, the child became aware of the prototype recording length limit. For example, the child said, "*The story, it´s too long!*", or the child cut off his narration to stay within the memory limit, "*. . . and that´s it.*" At the same time, the child showed satisfaction and appreciation when they managed to condense their narration. For example, when the child successfully described the cards, they said "*Well, it has listened to almost all the story.*"

In some cases, the therapist asked to describe the cards in more detail, after which the child pointed out, "*Then it will not enter all in the memory*" demonstrating awareness. The child improved their synthesising skills, incrementally condensing the story sequence as a result. The therapist reported "*In this right situation, it was much more useful that it had a short memory. The child tends to be verbose.*" The therapist elaborated, saying, "*The child would tend to say too much on each card. Instead, the fact that the memory is short, the child should try to focalize the attention on the most important* *things*". The therapist also indicates that this is an advantage over a normal recorder, where the recording would never stop and instead record indefinitely.

5 DISCUSSION

The prototype's short recording time constraint may help develop skills such as narrative synthesis and narration focus and be of special use to children who tend to be easily distracted from the surrounding environment, unfocused on a clear narration line, and verbose. Educators and children were able to exploit the time constraints and incorporate audio-augmented paper drawing into their activities, particularly for narration and description tasks. Other researchers have demonstrated the benefit of designing digital-physical environments which improve linguistic and narrative capabilities for children with disabilities [1]. This result might be explained by the fact that time constraints might sustain their attention on the main focus, facilitating the development of language knowledge for children [18]. The constraints might also have fostered maintaining focus on the story, which supported the narration tasks [13]. We could speculate that the attention and focus required during the social cards' description task might be encouraged by the temporal constraints, one of the most important narrative elements. Facilitating the ability to construct narratives is an essential focus of the interventions for ASC children [8]. Our prototype showed it could be a valuable tool for supporting educational and therapeutic narration activities with children.

The therapist's narrative work objectives included elaborating on the casual consequences between content depicted on the cards and elaborating on the emotional states of subjects depicted on the social cards. This was supported and scaffolded by the narrative comparison activity between the story audio recorded by the prototype and the written version of the story in the children's notebook. These results also showed how our system supported the children's engagement in narrative tasks. We designed the system to allow social stories to be presented without writing on paper, but the potential for and benefits of using *ReduCat* as a bridge between written and oral narrations was demonstrated. *ReduCat* supported the narrative learning objective set by the therapists and permitted the generation of new exercises. The benefits of letting children with ASC input contents into digital-physical environments have been described by other researchers [3, 16].

The benefits of listening to children's author stories to engage in more significant social interaction with others is important for children with ASC. Explanations for this use might be connected to the fact that ASC children use a limited amount of causal language to explain events during narration [29]. According to Capps [9], ASC children use less complex syntax and are inclined to simply label affective and cognitive states with limited narration skills. They use fewer narrative evaluative devices and are less likely to use sound effects, character speech, emphatic stress, and repetition. One significant result of this work could be that hearing their voice might motivate children's attention on comparative narration tasks, which would not be possible with a typical, unaugmented sheet of paper drawings. These results suggest *ReduCat* could be a valuable educational and rehabilitative support tool for evaluating situated narrative activities and stimulating sound effects, character speech, and emphatic narration for the benefit of children with ASC. As the audio is the principal channel, *ReduCat* might also be used to rehabilitate and educate prosody and control spoken utterances (e.g., pitch and intensity) with the support of standard social story tools, but with sufficient flexibility to accommodate other paper-based solutions and needs.

The results of this work suggest that the audio-augmenting tangible technologies that enhance narration might also be used within rehabilitative and educational settings to improve the social, verbal, and narrative skills of children with ASC. This study also suggests that the personalized co-located-audio paradigm, which couples the children's digital voice audio with pictorial elements drawn on paper, might be used to enhance and support the therapist-led narrative and verbal rehabilitative educational activities of children with ASC and other cognitive disabilities. Its use could even be extended to other contexts outside of rehabilitation and education, such as everyday domestic and social contexts [5, 19]. Our initial results suggest that co-located audio-tangible interfaces like *ReduCat* can offer an environment that supports children's sensory, verbal, and narrative needs [39, 40]. Consequently, it might support social, verbal, and narrative interventions for children with ASC. The results in this article might be considered preliminary due to the number of subjects involved and the duration of the study. This might have limited the types and number of activities that were possible. However, significant findings were obtained and are highly promising. A more extensive long-time pilot could have shown additional appropriation dynamics.

6 CONCLUSIONS

The use of audio-augmented paper drawings for social story tasks presented stimulating lines of investigation in terms of evaluating the benefits it may bring to rehabilitative or educational interventions for children with ASC. The study suggests that technologies that enhance communication could be introduced in educational contexts to improve children's social communication and interaction with autistic spectrum conditions. *ReduCat* shows the potential to be a flexible educational tool that therapists could easily appropriate. The implementation of new prototype functionalities discussed in this article is planned for the near future.

ACKNOWLEDGMENTS

We wish to thank all the children and therapists that took part in our study.

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