Multisensorial tangible user interface for immersive storytelling: a usability pilot study with a visually impaired child

Federica Somma[a], Raffaele Di Fuccio[b], Lavinia Lattanzio[c], and Francesco Ferretti[c]

[a] *Natural and Artificial Cognition Laboratory, Department of Humanistic Studies, University of Naples Federico II, Naples, 80138, Italy*
[b] *Istituto di Scienze e Tecnologie della Cognizione – Italian National Council of Research (ISTC-CNR), Rome, 00185, Italy*
[c] *Roma Tre University, Rome, 00154, Italy*

Abstract
Haptic and multisensory exploration helps blind children to create mental images and abstract mental processes; it is crucial, then, to organize the learning environment so that they can interact with objects through different sensorimotor channels. Storytelling and narratives are useful practices to develop linguistic, cognitive, emotional and social skills and visually impaired children need to participate in the narrative experience using their body, manipulating objects, listening but also smelling and tasting. New methodologies for interactive storytelling, such as a multisensory Tangible User Interface (TUI), could sustain innovative educative and cognitive interventions to listen and stimulate narratives of children with visual impairments, since the residual senses and abilities are supported and compensated. The purpose of this article is both to describe a multisensory TUI-based methodology developed for the enhancement of the storytelling activity and to present a first usability and engagement pilot study based on a prototype. One 6-years old visually impaired child participated in the study. The procedure involved a TUI pre-training phase and the storytelling phase, in which the participant listened to and interacted with a TUI-augmented story. Data, such as participants' behavior, satisfaction, engagement and TUI's usability, were collected through observations and specific questionnaires adapted to the participant. Results of the pilot study showed a good level of usability and overall engagement, but above all it allowed us to highlight strengths and weaknesses that we need to address for the improvement of the technology. Future studies' directions are discussed.

Keywords [1]
TUI, Storytelling, Usability, Engagement, Multisensory approach, Visual impairment, Technology Enhanced Learning

1. Introduction

The International Classification of Diseases (ICD-11) defines visual impairments as "any diseases of the visual system, which includes the eyes and adnexa, the visual pathways and brain areas, which initiate and control visual perception and visually guided behaviour" [1]. It is estimated that, globally, at least 2.2 billion people have visual impairment [2]. According to the most recent ISTAT / INPS survey on the number of blind people in Italy in 2016, it emerged that, out of 60,589,445 of the total population, 116,932 are blind [3]; moreover visual impairments account for 3.7% of the total disability conditions present in Italian primary schools (ISTAT, a.y. 2018/2019) [4].

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EMAIL: federica.somma@unna.it (F. Somma); raffaele.difuccio@gmail.com (R. D. Fuccio); lavinia.lattanzio@gmail.com (L. Lattanzio); francesco.ferretti@uniroma3.it (F. Ferretti)
ORCID: 0000-0003-4341-3393 (F. Somma); 0000-0001-6478-3604 (R. D. Fuccio)

As stated in the International Classification of Functioning, Disability and Health (ICF) adopted by the World Health Organization (WHO) [5], the disability experienced is determined not only by the condition of the eyes, but also by the physical, social and attitudinal environment in where the person lives, and the ability to access quality eye care, assistance products and rehabilitation services.

A characteristic aspect of visual impairments is the strong variability of etiology and causes, but also of the conditions and development paths. Children often have different functional visual residues, different learning strategies and styles, and so on [6]. In addition, young children with severe and early vision disability may present with multiple impairment and experience associated delays in motor, linguistic, emotional, social and cognitive development [7], with lifelong consequences. Sight impaired school-age children may also experience lower levels of academic achievement [8] [9] [10], with possible negative consequences on self-esteem compared to their peers with normal vision.

Tactile perception is the tool through which people with visual disabilities know the world. Children with blindness or limited vision know the world mainly through the residual senses, through touch and hearing, smell and taste. Tactile or "haptic" exploration [11] is active and systematic, it involves specific and organized movements of the hands with respect to the object to be known: this provides information on shape, size, position, weight, texture and texture, helping the blind person to create mental images and abstract mental processes [7] [12] [13]. This exploration takes longer than visual exploration and is more tiring because it is reduced to a single perceptual and attentional channel. Before interfacing with the two-dimensional representation of objects, blind children must become familiar with three-dimensional objects by manipulating them [14].

Furthermore, the language developed by blind children is peculiar as it reflects their particular sensorimotor experience, so it is grounded in their concrete experience [15]. This implies the importance of organizing the environment of blind children so that they can interact with objects through different sensorimotor channels. For example, Vinter and colleagues [15] observed that blind children did not refer to olfactory and gustatory perception more often than sighted children, although even these perceptual modalities could compensate for lack of vision and object recognition. Therefore, interventions that train them to use these perceptual modalities could be useful. Increasing the perceptual-motor experience in these children, accompanied by verbal descriptions, would help them ground the meanings of words in a solid perceptual and bodily experience, thus reducing their dependence on other people for language acquisition.

Therefore, there is a clear need to design, develop and evaluate specific and personalized tools, educational and rehabilitation paths for the individual needs of young people and adults with visual disabilities. The attempt is to provide them with innovative technological tools that leverage their residual senses.

1.1. New hybrid solutions for visual impairments

Most of the technologies accessible to blind children exploit the residual senses of listening or touch, such as reading via Braille or relief images, or the residual sight, such as optical magnifiers and environmental changes (e.g. improved lighting). The reduction in visual function can be partially compensated also by adequate digital assistive technologies, both for a specific personalized rehabilitation intervention, and to allow a good adaptation to daily life: text-to-speech, screen readers, display braille, direction indicators for smartphones.

Technical progress, however, has made it possible to develop several innovative assistive technologies to support educational, rehabilitative and playful activities. Some technologies are primarily digital, others, such as Tangible User Interfaces (hereafter TUIs), allow interaction with the digital world using physical artifacts, making use of touch and manipulation [16], providing new possibilities to build innovative technology-enhanced learning (hereafter TEL) environments. TUIs for sighted people have been extensively studied in the field of human-computer interaction (HCI), however, although visually impaired people demonstrate very efficient manual exploration strategies, there is little work and study on TUIs designed for visual impairments. The review by Klingenbert et al. [17] on mathematics teaching tools and e-learning in mathematics for visually impaired students highlights how promising are the audio-based learning aids and interactive e-learning tools that enable auditory and tactile learning. However, the researchers also point out the paucity of scientific evidence among many of the studies reviewed.

The developmental literature starting from the more classical psycho-pedagogical theories, such as Piagetian theories [18], up to the most recent ones [19] [20] tends to favor embodiment, especially in the early stages of development. The level of understanding of the abstract and concepts is built on sensorimotor and concrete operations. An embodied learning approach based on the use of the sensorimotor system when learning new words and concepts, new narrative skills, is also effective for typically developing children [21], but even more so in children with visual impairments.

TUIs, therefore, allow interaction with the digital world through the use of physical objects. These physical artifacts represent both the input to the digital event and the output as they provide users with feedback on the action and manipulation they are doing, through digital information (audio or visual) from the associated device. Touching and manipulating objects is an important, if not primary, aspect in interacting with TUIs. TUIs technology designed and developed to be used by children with visual impairments is mainly suitable for developing spatial skills or learning spatial concepts, maps, diagrams, see for example [22] [23]: the results of using it are promising to think at TUIs as a support for activities, such as storytelling, accessible to people with low vision, to enhance their cognitive, social and emotional development.

1.2. Storytelling

Storytelling is a practice that is embodied by participants, both those who perform the narration of stories, and those who receive the narrative production of others. Storytelling has always been present in human experience in every field and can be represented in various forms (individual or collective) that connect thought and culture. For this reason, it is also a situated experience, because it occurs in a specific context, culture and language and is influenced by them [24].

The practice of storytelling improves the development of children in different areas such as language. Several studies have shown how repeated exposure to listening to stories contributes to the development and improvement of lexical, phonetic, morphological, syntactic and pragmatic skills [25] [26] [27]. Listening and producing stories can improve the representation of the structure of events, the organization and planning of the narrative speech [28], but also the construction of self [29], the ability to listen, attention and memory processes[30] [31], social skills [32], imagination and creativity [33]. Narrative understanding and narrative production include short stories, generation of personal or fictional stories, social stories and event stories: stimulating children in these activities can help them develop an adequate linguistic ground and serve to support the acquisition of other important skills for life, such as academic skills, self and emotional expression, social interaction.

Researchers and professionals have included, and continue to do so, storytelling and narrative production in their toolbox, as useful assessment and intervention tools in educational and rehabilitative contexts [34] [35], for example to stimulate narrative abilities and grammar skills: narration has been used as a means to sustain the deficits in auditory processing exhibited by some children with speech disorders, or even to stimulate better auditory and verbal attention [36].

Alongside traditional storytelling, digital storytelling has emerged in recent years as a powerful teaching and learning tool [37]. Among the advantages of use this practice in educational and learning contexts, there is certainly that of let young students create their own digital story, individually or in groups and developing digital, technological and computer literacy, but also global literacy, the ability to understand, produce and communicate through visual images [38] [39].

The technologies that exploit TUIs, thanks to their intrinsic characteristic, seem to offer great potential for storytelling. Thus, for a long time, TUIs for storytelling have been developed and one example is MIT Media Laboratory's *Storymat* [40] which offers the ability to record children's stories and their movements as they play on an augmented mat. Stories can be played back on the playmat when other children tell other stories. *Storymat* requires children to play freely and use soft plush toys. Playback of the previous story can be stopped at any time, allowing the child to edit or find an alternative ending to the story.

Blind or visually impaired children need to participate in the narrative experience using their body, manipulating objects, listening but also smelling and tasting. Traditionally, to get in touch with narratives and concept learning, children with visual impairments use multisensory tactile storybooks [41], which aim to enhance the ability to construct mental images and involve the child in the discovery of concepts (such as shape and size) and stories through the tactile exploration of objects or pages decorated with relief figures made up of different materials (paper, feathers, etc.); they can also listen to stories through audio books. The integration of these sensory, auditory and tactile channels can enhance the learning experience as well as make it more motivating.

Narrative experience must be aimed at exploring and understanding the individual elements of a story, in order for it to be a meaningful experience. TUIs could be valuable tools for facilitating and enhancing an effective storytelling experience for children with visual impairments, not only because they are more dynamic and flexible than the representations in relief, traditionally used by people with visual impairments, but because they can be a versatile tool that can be used in different contexts, such as the educational one building an innovative TEL environment, and facilitate the inclusion process. Some limitations of TUIs need to be considered and addressed, including user fatigue resulting from manipulating physical objects or that only a limited number and type of elements can be represented, since tangible objects are usually relatively large.

Tangible technologies have been developed for children with visual impairments, however, only a few interesting TUIs have recently been designed and studied to enhance visually impaired story mapping [42], story reading [43] or story listening experience [44], but even more research is needed to develop and evaluate innovative methodologies and tools for multi-sensory narrative experience of visually impaired children.

1.3. Multisensory TUI-based storytelling approach

As recently stated by Kamei-Hannan et al. [45] the promotion of multisensory approaches for visually impaired people is not based on research, that is needed to evaluate the effectiveness of a multisensory storytelling approach. In a three-single subject AB design, Kamei-Hannan et al. [45] evaluated the effectiveness of a multisensory approach to storytelling for three 7/8-years old visually impaired children, integrating tactile objects (e.g., elements of the story) and sensory supports (eg sounds, smells, textures) during the narration. The effectiveness of this approach was evaluated with respect to story retell, language skills and reading comprehension and the results suggest that the multisensory storytelling approach is a promising intervention for children with visual impairment to increase their language and comprehension skills, however research with more individualized approaches and additional strategies are needed.

Since multisensorial learning extends the richness of an interaction by engaging the haptic, auditory and visual senses [46] [47], tailored TUIs for multisensorial storytelling could generate haptic learning, due to the connection to meaningful objects, but also enhances media content, augmenting the narrative experience of children with visual impairments, facilitating caregivers and special education staff. The main objective of this approach is to create a stimulating environment for active learning which relies on the strengths and residual senses of blind or visually impaired children, that could also enhance the acquisition of fundamental cognitive skills, but also let them benefit from all the potential that storytelling activities offer and which we have discussed previously.

Based on these evidences and reflections, the aims of the present paper are: to provide a description of a multisensory TUI-based methodology developed for the enhancement of the storytelling activity; to describe a first usability pilot study with a visually impaired child, also including an evaluation on the satisfaction and the involvement in the interaction with the story; finally, to bring out reflections for future developments. Usability is the main criterion for evaluating the degree to which the interactive systems technology meets the needs of the target for which it was designed [48] [49]. Fun and enjoyment are fundamental to any play or learning activity: they represent the key motivation for being emotionally involved and creating a meaningful learning experience [50] [51].

Our goal is to develop a technology that is as customizable and as possible, which respects the educational needs, and not only, of children with visual disabilities. For this reason, single-case pilot studies are necessary to evaluate the specific user interaction with the TUI and evaluate the degree of usability and satisfaction of the experience. This study was designed with the aim of highlighting the strengths and weaknesses of the tool, as well as reflections on possible improvements and future developments.

2. Materials and methods

Below we describe our prototype of TUI for storytelling and subsequently a first interaction experience of a visually impaired child.

2.1. Our prototype

The present paper concerns a pilot study carried out with a visually impaired child on the usability of a hybrid (digital and tangible) technology for the enhancement of storytelling activities [52]. The paradigm from which the chosen methodology draws inspiration is that of pedagogical models focused on TEL and game-based learning [53] [54] [55], an approach to the design of educational materials in which the protagonists of the educational process are represented as interacting agents, according to a Situated Psychological Agent Model, which will be described later.

The technology, developed as part of the collaboration between the University of Naples Federico II, the Institute of Cognitive Sciences and Technologies of the Italian National Council of Research (ISTC-CNR), the University of Roma Tre, is aimed to allow children to live an augmented experience of storytelling through the natural and multisensory interaction with objects, sounds, smells and tastes.

Our tool for immersive storytelling is composed of software and some hardware components (please, check Table 1). The software used to create the story is STELT platform [56] that combines the management of hardware components (as sensors) and software components (programming and developing environment, programs and activities for users, database for tracking user behavior and an adapting tutoring system). STELT implements augmented reality systems based on RFID (Radio-Frequency Identification) and NFC (Near Field Communication) technology. The RFID/NFC tags are thin and can be applied to any type of object and are detected by small readers. Our reader, called the Multi Activity Board [57], is a board that can be connected to a computer with either a wired or wireless connection or integrated into standard equipment on smartphones and tablets (NFC sensor). STELT combines communication protocols with the various hardware devices (readers and output devices). Then the device provides feedback based on the user activity with objects (for further information and previous experiences, please, see [58] [59] [60].

Table 1
Components of our TUI prototype

Component	Description	Features
Software	App of Storytelling	STELT platform
Hardware	Device	Portable PC
	Board	RFID-NFC WI-FI multi-tags desktop reader
	Objects	Bracelet, 3D characters, textures, smells, tastes
	Sensors	RFID-NFC

The storytelling kit (Figure 1) was then composed of: the storytelling app running on a PC, the Magic Board connected to the PC through a USB port, and the objects related to the story: a bracelet, a fairy doll, four lizards (all covered with different skins: normal lizard, feather, synthetic grass and wool), three jars with smells (apple, soap, burnt), two candy containers (one with cherry and one with strawberry candies).

Figure 1: A picture of our TUI prototype

The story proposed with the prototype has a central topic, which is that of the transformation of the main character, a lizard, which allows children to explore various textures of the different skins of the character and to train their tactile discrimination skills. The story's main character is Smilzon, a lizard who dreams of changing its skin and having it soft like that of a sheep, to make his friends like him more. Smilzon asks Sugar Fairy for help; after some mistakes caused by her cold, Sugar Fairy grants his wish. Eventually, Smilzon realizes that the new skin does not suit him, so he asks to have the same skin as before.

The story, in addition to various descriptive elements of animals and textures, has a final moral, encouraging to always be oneself. So, it is a prototype of a story that lends itself to many learning activities by children with, but also without, visual impairments.

2.1.1. Structure of the interaction with the story

As mentioned previously, in order to structure the story, we followed a model for designing educational games, the Situated Psychological Agent Model [55]. The application starts only when the child places the bracelet on his wrist on the Magic Board. The choice to also include the bracelet is motivated by the goal of allowing the users to increase their level of autonomy. The plot of the story includes 10 different scenes and for each scene an image, an audio and a request are played (for example: "Find the smell of apple and place it on the Magic Board"). To move forward in the story, therefore, children must explore the available objects, the various textures, smells and tastes and place the key object on the Magic Board to unlock the scenes. The story will therefore be lived, in line with the hybrid approach, both digitally (through audio stimuli reproduced by the tablet / computer) and through exploration, manipulation and direct experience with the physical learning environment.

The strengths of the tool are represented by:

- An integrated system for learning stories and contents through touch, hearing, taste and smell; the integration of all the senses is often not exploited in technologies developed for the blind; moreover, the interaction is more motivating thanks to digital feedback.
- The most active role in building narrative knowledge and in the process of understanding the story. Each object is in fact necessary to move forward in the story, and, as if it were a game, could stimulate and involve more.
- The narration is carried out by real people who are experts in acting, therefore more attractive.

- The software platform is very intuitive, even for users with low digital competences.
- The materials are not expensive (puppets, cards, odorous bottles, candy boxes) and are enhanced with RFID tags, which are also very cheap.

3. A first trial

The present pilot study was conducted in October 2020. The study was carried out in accordance with all current anti-Covid19 regulations set by the Italian Ministry of Health.

3.1. Participant

We carried out the first pilot study on usability with a 6-year-old visually impaired child attending the first year of primary school. Written informed consent was obtained from participant caregivers.

From the medical records it appears that on the right the child wears an ocular prosthesis, so he is completely blind, while on the left he has a residual vision, so that the vision of primary colors is preserved. The field of view was found to be significantly limited. Despite his visual problems, it turns out that the child still uses the visual channel to move around the environment with a fair amount of visual attention for stimuli placed in the different spatial areas. The child doesn't show multiple impairments or other disabilities. Clinicians also report excellent understanding of tasks and excellent memory skills.

3.2. Procedure

The procedure consisted, first of all, in the compilation by parents of questionnaires on child's personal information and on his daily use of technological tools, including previous experience with TUIs. The special education teacher was then briefly interviewed about the child's discrimination and comprehension skills. Parents confirmed that the child had never used TUI tools. The teacher confirmed the child's good cognitive abilities, especially in understanding, memory and language.

The study took place inside the primary school attended by the child, in an isolated room from the other classrooms. The room is bright and equipped with a table and a chair. Before the session, it was necessary a first phase of knowledge and familiarization between the experimenter and the child, to let him feel more comfortable and confident.

During the trial there was the child, the experimenter and the child's special education teacher. On the table was a portable PC, the Magic Board connected to the PC and positioned in front of the child, at a distance easily accessible with his arms. First of all, a pre-training session was carried out: the intent was to create a baseline in the understanding of the use of the TUI system, therefore, to ensure that the child learned how to interact with the objects and the digital environment. A discrimination exercise was then created between 3 different shapes of the logic blocks set positioned between the child and the tablet; the digital system asked the child to place the circle-shaped block in the center of the tablet. After exploring the space proximal to their body, the child identified the center of the tablet and placed the correct shape on the tablet. The system then gave positive feedback of correct action to the child. The action was repeated two more times with other logic blocks shapes, until the child has sufficiently understood the functioning of the tool.

After that, the shapes were moved off the table and replaced with story-related objects. According to indications, previously provided to us by an expert in the field of visual impairment, the objects were positioned so that the child could easily explore them and divided by categories, therefore characters, smells and tastes. Initially, the experimenter invited the child to explore objects in front of him. At the end of the exploration, the child listened to the story of "Smilzon and the Sugar Fairy" (please, check Figure 2 for examples of interaction). After listening to and interacting with the story, the experimenter asked the child some questions about usability, satisfaction and involvement in the story, as well as some memory and comprehension questions.

Figure 2: Two interactions between the child and the storytelling TUI.

3.3. Observation and measurements

In order to record the most of participants' behaviors and facial expressions during his interaction with the TUI-enhanced story, the experimenter both videotaped the session and took notes on an observation checklist created for the present pilot study. The experimenter observed whether the child took the objects and placed them on the board when required, whether the child manipulated the objects before placing them and kept the attention focused on the activity. In addition, the following behaviors were observed: if the child stopped the activity without warning or asked for a break, any unsolicited actions, facial expressions, mistakes when interacting with the story and, finally, if the child completed the story. Everything that was verbally expressed by the participant was recorded and transcribed.

Since the main objective of the study was to measure the overall satisfaction of the activity and the usability of our TUI prototype, we decided to administer simplified questionnaires, to ask the child once the activity was ended, to receive his personal considerations. The child was asked to answer questions such as:

- "How much did you like it?" and responses were recorded on a 5-item Likert scale from "little" to "very much";
- "What did you like most?" and the answers were "Listen to the story", "Touch objects" and "Smell and taste".
- To measure the usability of the TUI, the child was asked to answer the question: "What was it like listening to the story and choosing objects together?" and to choose between 3 different answers: "Easy", "So and so", "Difficult".
- Read and colleagues [61], in order to identify signs of engagement and enjoyment with respect to the new interface, linked the engagement with a desire to repeat the experience. Therefore, the question "Would you like to do it again?" was asked to the child, to measure his interest in repeating the activity.

Finally, to briefly assess the participants' memory and understanding of the story, some questions related to the story were asked. Therefore, we divided the questions into multiple choice questions and open questions, as well as into two categories: context questions and action questions. The former refer to events that occur during the story (such as “what does Smilzon ask the fairy?”), to evaluate the attention to the story itself, excluding the direct intervention of the user; the latter refer to tasks that the user must perform in order to interact with the story, for example choosing among the odor jars (such as "what did you smell near the fairy house?"). The possible answers of the multiple questions were three and were divided into: one correct and two distractors (one stronger and one weaker distractor). The open questions were chosen because they require to activate the memory process more; a question also evaluated the deeper understanding of the final moral of the story "Happiness is certainly not achieved by trying to change oneself to please others" (the question was "Why is the fairy happy that Smilzon is back to having the skin he had before?").

4. Results

Starting from the initial exploration of the objects related to the story, the child began to touch and manipulate some characters and boxes, even moving them in position and leaving out only one on his left (the character made of wool). In general, he explored more the right side than the left, mainly using his right hand. Particularly, when he touched the character covered with grass (synthetic lawn) he expressed interest and exclaimed: "How it stings!".

The child was very focused on listening to the whole story. At first it took longer to position the objects correctly in the center of the board, but after the instructions from the teacher, he subsequently performed the gesture more easily. The requested objects have been identified and positioned correctly, except for the smell of apple and the request for the character made of feathers, for which he placed the one made of grass (closer to the right at that time and more stimulating). At the time of the request for the character made of wool (not explored on the left), the child was prompted by the teacher to explore more with his left hand and, finding it, he then positioned it. Finally, when asked to place the cherry flavor, he first interacted with the jars of smell and placed one on the tablet. Upon negative feedback he was suggested to consider the other kind of boxes as well. He didn't want to taste the candies but he smelled them again. Again, he had more difficulty exploring the left area to find the second candy box.

The child answered the questionnaire and stated that he enjoyed the activity "very much"; he expressed more pleasure in smelling than in hearing or touching objects and he "very much" enjoyed using items to unlock the story; he also found the activity itself easy and expressed a desire to repeat it. Then, the child answered all the multiple-choice questions correctly, instead of the open-ended questions he did not give the right answer or expressed that he did not remember.

5. Discussion

From the first experience with this pilot study, some reflections and notes for future improvements emerged. First of all, the presence of the special education teacher in the room was fundamental, not only because he represented a trusted person for the child, but also for the indications he gave to the child and the experimenter.

The more stimulating objects are, the more they engage the child, so accentuating the differences in textures is important for a greater engagement in the manipulation of objects. In addition, it would be useful to stimulate the child even more in the initial exploration of all the objects on the scene, so that he would be completely aware of which objects he can use and facilitate the interaction process. Also, it would be useful to place objects inside an agile container divided into sections for the categories of objects.

The need for positive, and not just negative, feedback is emphasized; currently, the positive ones have not been included in the story, that simply continues when the correct object is placed on the board. Again, a longer pause or stronger feedback should be introduced when the correct object is placed, as the child may not immediately understand that this is the correct choice.

An important note concerns the adaptation of the story and the narration to the blind child: explanations, for example of movements and scenes, should be more accurate, so that the blind child can learn motor patterns necessary for a correct representation of the performance of the characters. In addition, there is a need for a more descriptive language, both for lexical enrichment and for a greater understanding of the experience.

Regarding the open questions, they may have required too much cognitive effort for the child, especially the last question regarding the story's moral; another hypothesis is that wrong answers are related to the need to make the story even more understandable and adapted to the child's age and characteristics. To understand the moral of stories could be hard for a 6-year-old child: it is necessary to modulate the questions on the basis of the skills typically associated with the specific age group. Yet, in the future, the ability to recall the story should also be assessed without subjecting the child to specific questions with predefined answers, so as to be able to better evaluate the short-term and working memory ability, without any kind of inputs. Thus, a retelling task, in addition to the questionnaire administered, could provide further useful information on stories understanding.

Some limits need to be highlighted. The study was mainly carried out to evaluate the usability of the tool, therefore there was no previous assessment of child's comprehension, memory and linguistic skills; information was only obtained from medical records and from an informal interview with the special education teacher. Another limitation is the lack of an analysis to evaluate the real effectiveness of augmented stories compared to audible stories; in the future the difference between the recall of only audible stories and the recall of stories augmented by TUI should be measured. Then, our study included a single evaluation session, but it would be necessary to set up several sessions presenting different stories with different characters and objects to broaden the assessment and analyze the effects of multiple interactions with augmented stories; it is therefore necessary to extend the experimentation in future studies. Furthermore, the sample consisted of a single 6-year-old visually impaired child: although studies involving participants with disabilities fit into single-case studies, a future study could envisage a larger sample to carry out several single-case studies and understand the effects of TUI technology for storytelling across a broad spectrum of participants and, possibly, different ages.

6. Conclusions and future directions

Storytelling is a valuable learning and skill development tool, it can improve communication and language, social intelligence and emotional expression. The present study aimed to evaluate the usability and involvement of a digital and multisensory tool for immersive storytelling with a 6-years-old visually impaired child. Although the study is preliminary and underlies several methodological limitations, it was useful for highlighting critical aspects of the participant's interaction with TUI technology. The results of this very first pilot test showed a good level of usability and overall engagement, with some limits that were underlined, but above all it allowed to highlight strengths and weaknesses that will be the starting point for the improvement of technology.

Digital devices have opened up an attractive and stimulating world which, however, presents some barriers for partially sighted or blind children. Innovative interactive systems allow children to learn starting from the physical objects of our world (tactile, smells, tastes), to enhance the ability to reflect on the real environment by interacting with it together with the digital world, supporting physical and cognitive development. These essential characteristics of the TUI make it suitable for people with visual disabilities, especially for the multisensory nature of the objects and the possibility of exploiting different sensory channels, so that the senses and residual abilities are supported and compensated. The methodology explained in this paper allows a possible application of this prototype as TEL platform used both in the classroom both outside the school. Nevertheless, the importance of the caregiver in support of this activity, the system could be used applying a blended approach.

No one has systematically studied the effects that practice with TUI can have on improving narrative understanding or production in children with visual impairments. Therefore, a future goal will be to evaluate the effects of our TUI technology in storytelling interventions for children with visual impairments. It is also possible to study comprehension and retelling of stories in relation to skills that could influence them, such as attention, memory, ability to understand inferences, or to design interventions to strengthen autonomy with everyday life stories but also to allow them to tell augmented personal stories.

A further objective will be to widen the TUI's functionalities, to make it suitable for the creation of stories by the children themselves and by the caregivers or teachers who will be able to use it in care and educational practices. Visually impaired students must rely on accessible tactile materials to learn. However, these compensating materials offer students fewer opportunities to engage in practice and do not allow students to collaborate with peers. Studies, see [62], illustrate strategies and tools that facilitate inclusive learning using the "enactivism" paradigm and radically reinventing perceptual-motor tools and solutions, to optimize usability for all students, with and without disabilities. Another interesting area of intervention may be that of the inclusion and development of collaborative skills within the classroom context.

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