

Museum for All: Wearable Immersive Virtual Tours in Museums for People with Neurodevelopmental Disorders

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Abstract. “Social stories” are used in educational interventions for subjects with Neurodevelopmental Disorders (NDD) to help them gain an accurate understanding of social situations, develop autonomy and learn appropriate behavior. Traditionally, a social story is a short narrative that uses paper sheets, animations, or videos to describe a social situation of everyday life, e.g., “going to school”, “visiting a museum”, “shopping at the supermarket”. In our research, we exploit Wearable Immersive Virtual Reality (WIVR) technology to create a novel form of social story called Wearable Immersive Social Story (WISS). The paper describes the idea of transforming paper-based social stories, written for the project “Museo per tutti” (Museum for All), into WISS to better support persons with NDD in visiting museums and thus increasing their accessibility.

1. Introduction

“Social stories” are a storytelling approach used in educational and therapeutic interventions for people with Neurodevelopmental Disorders (NDD). NDD is an umbrella term for a group of disabilities that appear during the developmental period and are characterized by deficits and limitations in the cognitive, emotional, motor and intellectual spheres. A social story is a short narrative that uses visuals and in most cases also written text to describe a specific social situation, event, or activity in a clear and reassuring manner that is easily understood by the individual with disability. Social stories are used as learning material to promote the development of autonomy and appropriate behaviors, and to teach specific social skills, such as understanding rules, routines, and expectation, or taking another’s point of view.

We exploit low-cost Wearable Immersive Virtual Reality (WIVR) technology to create a novel form of social story, i.e., Wearable Immersive Social Story (WISS). A WISS is composed of 360° videos enriched with superimposed interactive elements and visual clues (geometric shapes, images, audios, ...) that make the experience more fun and engaging, helping users gain a better understanding of the social situation. These videos are executed on a smartphone and viewed through a low-cost Head-Mounted Display (HMD) (e.g. Google Cardboard) that makes the user feel inside the virtual space.

The paper describes how we applied WISS within the project “Museo per tutti”¹, that aims at making museums more easily accessible for people with NDD. Specific paper-based social stories are written and designed for each museum. We translated them into WISSes made of 360° interactive videos recorded inside those museums, with the goal of making social stories more effective.

¹ Italian words meaning “Museum for all”. <https://museopertutti.it/>



2. Related work

Social stories have been proposed as an effective intervention for persons with NDD, particularly children with ASD (Autism Spectrum Disorder) since the early 1990s. The term “Social Story” has been trademarked by its original creator to denote a narrative characterized by 10 detailed criteria [1], guiding the story creation in order to help the individual with disability understand the situation and develop social and practical skills. In most of the existing literature [2][3][4][5] the term “social story” has a broader meaning and corresponds to the definition given at the beginning of this paper. The research on the effectiveness of this instrument is limited and highlights highly variable effects in the learning process [6][7]. Still, social stories remain widely used in therapeutic and educational interventions for subjects with autism as well as with other forms of disability in the NDD spectrum.

Originally, social stories were based on paper-based visual and textual materials only. In today’s practices, they often use digital media, like images and videos on computer displays [8][9]. In the research area of Virtual Reality (VR), there are some examples of applications created for subjects with NDD that focus on social situations and can be regarded as digital transpositions of social stories.

VR is thought appropriate for this target group to help learning about real life situations, because in the virtual space behaviors and responses can be practiced in a safe and repeatable environment, while interactivity promotes engagement and cause-effect understanding [10][11]. Strickland et al. (2007) [12] developed desktop 2D virtual environments to teach fire safety skills to young children with ASD. Josman et al. (2008) [13] used VR to teach autistic students aged 8-16 years to cross the road safely.

WIVR applications have been found to improve attention skill because the head-mounted display removes the distractions of the outside world, a feature that is important for subjects with NDD who often have severe attention deficits. Benefits in this area have been observed in the study reported in [3] where low-medium functioning children with NDD used a HMD to interact with the immersive digital transposition of paper-based fantasy tales.

Two important concerns related to the use of WIVR in interventions for persons with NDD are the acceptability of the headset and the risk of physical side-effects that are typical of wearable VR environments [14]: motion sickness (due to a disagreement between visually perceived movement in the simulated world and the vestibular system's sense of movement of our body), double-vision (a particular condition under which the virtual elements are seen twice as overlapping copies instead of being perceived as one) and eye fatigue (the feeling that our eyes are burning, itchy and tired). These side effects were frequent in first generation VR headsets, characterized by poor viewing angles, high latency, and weight [15]. Today, HMDs are much more comfortable, including those commercially available at an affordable cost (e.g., Samsung Gear VR² and Google Cardboard³). In [3] the majority of study participants using WIVR on Google Cardboard had an enjoyable experience, were fascinated by the immersive experience, and manifested the willingness to play with it again.

VR headsets are increasingly being used to view 360° videos, e.g., in tourism, cultural heritage, professional training, and regular education (see for example the Google Expeditions Program⁴ and the Immersive Education Initiative⁵). To our knowledge, the use of 360° videos has not yet been explored in learning interventions for persons with NDD, and the WIVR environments for this target group are usually created in computer graphics.

The device used in our research to view 360° videos is Google Cardboard (figure 1 – left), the cheapest WIVR headset in the market (5€ for the paper version, 30€ for more resistant plastic variants). This VR visor is composed of two biconvex lenses mounted on a plastic or cardboard structure. The smartphone positioned inside the visor displays the visual contents, splitting them into two near-identical bi-dimensional images (figure 1 – center). The illusion of space depth and immersion in the virtual environment is created by the stereoscopic effect generated by the viewer lenses (figure 1 – right).

² <http://www.samsung.com/us/explore/gear-vr/>

³ <https://www.google.com/intl/en/get/cardboard/>

⁴ <https://www.google.com/edu/expeditions/#about>

⁵ <http://immersivededucation.org/>

Interaction is achieved through gaze pointing and focus, assuming that the direction of the gaze focus is defined by head orientation (detected by smartphone sensors), and is always at the center of the screen. Users navigate the virtual world by rotating their head, which has the effect of rotating the virtual scene projected on the display.



Figure 1. Google Cardboard viewer (left), view on the smartphone screen (centre) and conceptual view during the VR experience (right)

3. Approach

Knowing the benefits of social stories in educational and therapeutic practices for people with NDD, in our research we focus on mixing the power of social stories with that of WIVR. Transforming social stories into interactive immersive virtual narratives can increase the effectiveness of the traditional approach thanks to the feeling of immersion and engagement provided by HMDs.

The design of the concept of WISSes was a collaborative process between our university group and a team of 6 NDD specialists from two local care centers (special educators, neuro-psychiatric doctors, therapists). We did not involve individuals with NDD in the design activities because of the nature and severity of the disability of the persons attending the centers. This brought also to the development of XOOM, a tool that enables anyone to autonomously develop WIVR-based social stories, play them on any smartphone placed inside a VR headset, and supervise them from another connected device [16].

During these meetings, they had the idea of using this technology for the purposes of “Museo per tutti”. In this project, they had created a set of paper-based social stories about the visits to different museums (see example in figure 2 – left) and wanted to transform these materials into WISS. The iterative co-design process comprised 4 workshops interplayed with development activities to create progressive prototypes of WISSes and the supporting technology.

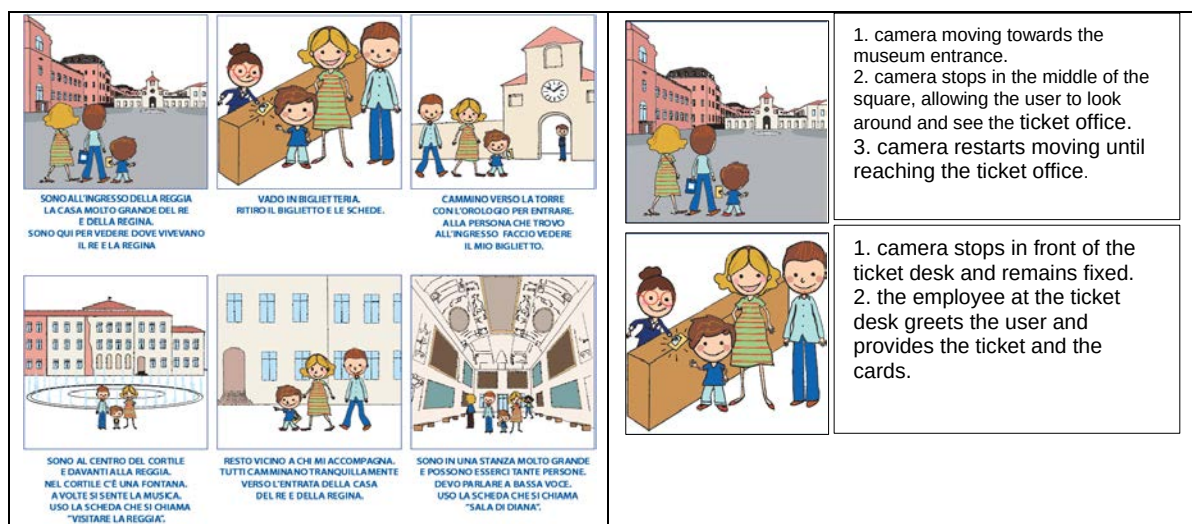


Figure 2. Left: Paper-based social story about the museum visit; Right: script for the 360° videos (scenes 1 and 2) defined during workshops

4. Museo per tutti (Museum for All)

4.1. Paper-based tours in museums

Museo per tutti is an experimental project started in 2015, supported by Fondazione De Agostini⁶ and designed and realized by L'abilità Onlus association⁷, that aims at defining guidelines, tools and paths inside famous Italian museums to support persons with NDD in their visits. In the museum context, the NDD field is still not much explored. Therefore, this project aims at starting an important experimentation with the goal of improving the quality of life for people with NDD, through their participation and involvement in local and cultural contexts, that are usually common to all citizens.

The Archeological Museum in Cremona, La Venaria Reale in Turin and the World Cultures Museum – D'Albertis Castle in Genoa are the first three museums that, together with the National Gallery in Rome, which has joined the project later, were involved in the project working with a group from L'abilità Onlus that has specific knowledge in the fields of cultural heritage, art history and museums accessibility. In this way, experts in the NDD field and each museum's staff collaborated actively during all the project phases, to realize proposals and materials specific for each museum. In the future, two other museums will be involved in the project: Museo degli Innocenti in Florence and BEGO – Museum Benozzo Gozzoli in Castelfiorentino.

Since *Museo per tutti* offers mainly paper-based material, composed of words, pictures and illustrations, that helps people with NDD to familiarize with the museums before going physically there, the idea of the experts from L'abilità was to translate them into WISSes created through XOOM.

4.2. Wearable Immersive Virtual Tours in museums

The first workshop was devoted to identifying the contents and the technology for the social stories to be rendered in a virtual environment. We discussed the trade-offs between computer graphic contents and 360° videos, and between the different VR devices. We agreed to use 360° videos and the Google Cardboard headset, for several reasons. Story contents based on 360° videos were perceived as more immersive and realistic than computer graphic applications, enabling the person with NDD to experience the social space “as it really is”. Inside the immersive digital space, the user is required to build and process a representation of the virtual environment “as a location” in order to successfully navigate it. Outside the virtual experience, the users are expected to capitalize on this generalization construct, linking their mental representation of the virtual environment to the real world in order to understand the physical environment and the social situation in it. Subjects with NDD have limited capability of generalization, and 360° videos of real contexts would facilitate this mapping. On the other side, high-end headsets (e.g. HTC Vive⁸) offer better quality VR experiences than cheaper devices, but at a much higher price. Still, the very low cost of Google Cardboard increases the potential for the adoption of WISSes among a larger number of people.

After this discussion, we selected the social story of a specific museum (La Venaria Reale) as case study, and the rest of the workshops were devoted to design the video scenes for its WIVR transposition. We explored pros and cons of recording each scene with a fixed camera (camera placed in a specific point of the environment) or a mobile camera (camera moving in the space suggesting the user the idea of walking through the scene). In the end, we generated a detailed video script, defining for each scene what the camera should record, in which mode (fixed or mobile) and which were the different possible effects and interactive elements to apply over the 360° videos as to facilitate the tour (see examples in figure 3).

Indeed, we designed XOOM as a customization tool for 360° videos, so that the same paper-based social story could be translated into different WISSes of increasing difficulty, to avoid the boredom due to the repetitiveness of the experiences. In this way, an individual with NDD can start by watching a

⁶ <http://www.fondazioneagostini.it/>

⁷ <http://labilita.org/>

⁸ <https://www.vive.com/eu/>

virtual tour full of suggestions and helpers that guide him/her through the museum, explaining everything; afterwards, when he/she has become confident with the virtual environment, he/she can switch to more difficult experiences made of the same previous videos, but with a less number of facilitators and possibly with the presence of some distractions.

Experts pinpointed the need for facilitators, i.e., visual clues superimposed on the video that attract the users' attention and help them focus on those elements in the virtual environment that would be more appropriate for understanding the current situation and the correct behavior. To make the experience more engaging and fun, some facilitators should be interactive, i.e., they generate visual (animated) effects when the user focuses the eye gaze on them. We defined the following types of facilitators: geometric shapes (e.g. arrow or circle); Highlight, that lights up a specific area of the scene "shading" the rest of the environment, to drive the user's attention on specific areas; PCS (Picture Communication Symbols), picture cards that represent objects, actions, people, or more abstract concepts like feelings and are widely used in Augmentative and Alternative Communication (AAC)⁹; sounds and textual popups, for instructions, comments and social clues.

On the other hand, reexamining the role of the stimuli acting as "facilitators", we realized that depending on the user, the contexts, and the learning goal, the same stimulus could have different meanings. For instance, the noise of a car in a city environment would act as facilitator, since users expect this sound as they see cars in the video. The same car roaring in a video of a natural landscape in the countryside would probably distract the user. An arrow pointing to a door could indicate that the user should interact with it to open it; but in case of an emergency door, the user should avoid interaction. So, we came out with the idea of "distractors", i.e., visual elements similar to facilitators in terms of attributes, but with the opposite role. Distractors could be introduced in advanced sessions to train selective attention and improve understanding of a social situation. Moreover, they contribute to reduce the gap between the quiet and safe virtual world and the chaotic and dangerous real world. In fact, the transition from the facilitated environment of WIVR to the real world, full of different stimuli and unknown events, can provoke confusion and unexpected reactions, above all in a person with NDD. Therefore, a tool that allows customization of the WIVR-based stories becomes fundamental, so that gradually more complex and verisimilar experiences can be created, adding various distractions to prepare users to face the real world. Nevertheless, we do not think that virtual reality should completely substitute experiences lived in the real world, but it can be a valid reinforcement tool to teach people with NDD correct behaviors in everyday life, if it is followed by a practical trial in real scenarios.

Finally, the experts recommended the introduction of "pause points". Suspending the video in some moments would give the user the time needed to explore the surrounding environment, to discover "facilitators" and to understand their meaning. Pause points would facilitate interaction with the interactive elements in a scene (interaction would be difficult while the video is running). At a pause point, the video could be suspended for a fixed amount of time, or could restart when the user focuses his/her gaze on an interactive element in the view.

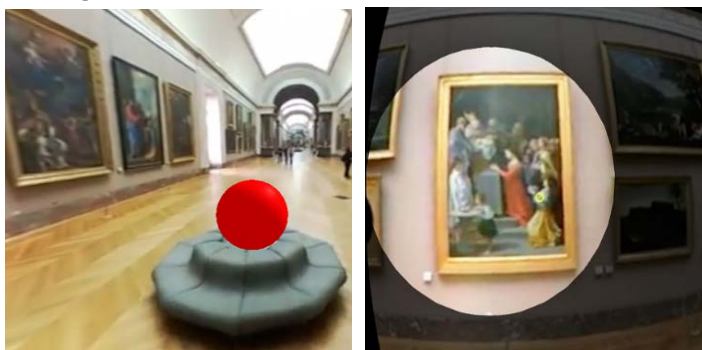


Figure 3. Examples of distractor (left) and facilitator (right): the first is a shiny red sphere that doesn't belong to the real environment and, standing out, can distract the user from going through the hallway; the second is a Highlight area that draws user's attention to the relevant painting.

⁹ Augmentative and Alternative Communication is used to describe various methods of communication that can 'add-on' to speech and are used to get around problems with ordinary speech. AAC includes simple systems such as pictures, gestures, pointing and more complex techniques involving powerful computer technology.

5. Software Platform and Video Recording

In parallel to the *Museo per tutti* project, we implemented the software platform for WISS creation, personalization and execution [16], and studied the best ways to record 360° videos, which brought us to build a tele-operated mobile robot for video shooting.

5.1. The Software Platform

The software platform – called XOOM – is *web-based* and integrates two main components: *Creator* and *Runtime Controller*. The first is an authoring tool for WISSes. It enables everyone to create a new WISS starting from a set of 360° videos, and to personalize an existing one (figure 4). The authoring functionalities include: allocation of videos on a timeline; definition of visual elements (facilitators and distractors) in terms of graphic and interactive properties and position in the videos; definition of pause points. The *Runtime Controller* manages the supervised execution of fully featured WISSes on a smartphone (they can also be played autonomously, without any supervisor, launching WISSes directly from a smartphone). This component also enables the visualization of the running WISS on an external PC and the manual control of its flow (launching a WISS, pausing/starting a video, launching a different WISS). This can be useful for a caregiver to follow a person with NDD in performing a WISS.

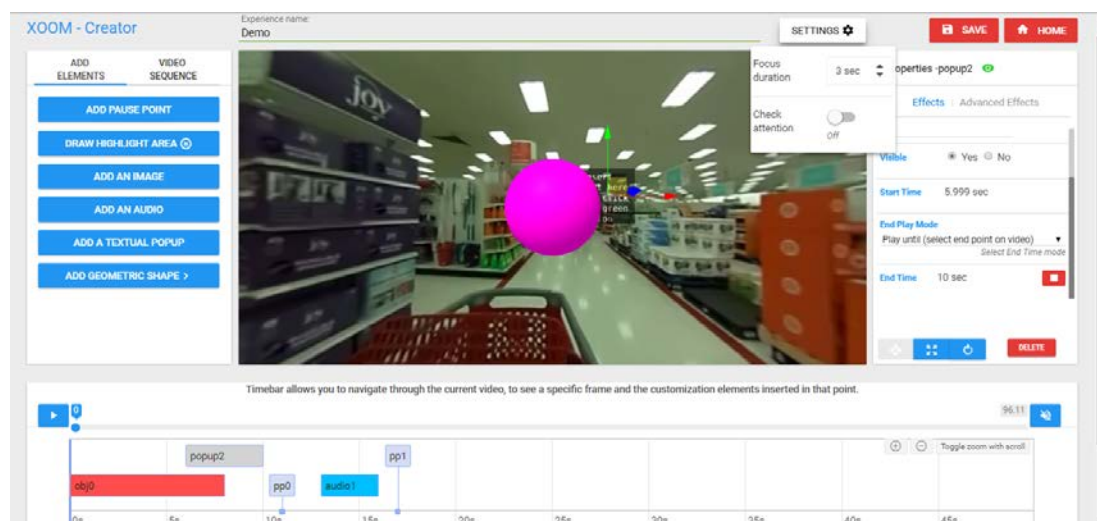


Figure 4. The Creator component of XOOM

5.2. Studies about 360° videos

We conducted some studies on how to record 360° videos in the best way. Existing guidelines¹⁰ underline that in order to make the user feel present in first person in the virtual environment, the camera must be kept at almost 160 centimeters from the floor to simulate an average person's height, and all the key elements in the scene must be roughly 1 to 1.5 meters away from the camera. If they are too close, these elements look distorted, while if they are too far away they may be indistinguishable. Vibrations and unexpected or fast movements with the camera must be avoided and the camera's front side must point towards the movement direction in case of mobile camera videos, to reduce the risk of motion sickness. For this purpose, we built a simple remotely-operated robot – called Bob (figure 5 - left) – able to shoot 360° videos with a better quality than the ones recorded manually. Bob's body is composed by a plastic pipe inserted in a hard-plastic cone and a "hat" on top of the pipe where we placed a 360 camera. The cone has the goal of stabilizing the robot movements and reducing the vibrations of the camera. It is mounted on a mobile base that exploits the commercial iRobot Create¹¹ programmable platform. The

¹⁰ <http://www.samsung.com/ae/discover/how-to/how-to-film-the-best-360-videos>;
<http://vrscout.com/news/avoid-motion-sickness-developing-for-vr/>

¹¹ iRobot Create. <http://www.irobot.com/About-iRobot/STEM/Create-2.aspx>

camera height can be adjusted based on specific needs, e.g., reduced if we want to record the physical environment with a child's eyes or increased if we decide to capture the space as seen by an adult.

5.3. 360° videos recording

Bob was just used, together with the guidelines we studied, to record videos at a local supermarket (figure 5 – left) for another project involving WISSes. In collaboration with another therapeutic center called *Fraternità e Amicizia*, we wanted to create a WISS teaching how to shop in a supermarket, to choose the correct food based on a given dish to prepare, or on the moment of the day (e.g. breakfast or dinner), and to pay the bill and get change. With the recorded videos, we created a first demo of this WISS. Since it was one of our first attempts in recording 360° videos, we found something to improve and learnt new important aspects to take into account to obtain better results from recording 360° videos.



Figure 5. Left: Bob recording outside and inside the supermarket; Right: a scene in the “Shopping at the supermarket” WISS, with a PCS card superimposed to the video as facilitator

6. Discussion and conclusion

The main contributions of our work are in the definition of the concept of WISSes for people with NDD and its application as a tool to develop autonomies making museums more accessible to people with this kind of impairments.

During the workshops and XOOM's evaluation (Creator module has just been tested with 15 therapists and educators that found it easy to use), all the experts expressed a global positive judgment about usefulness of WISSes to teach their users how to behave in everyday life situations. They confirmed that an individual with NDD is expected to navigate easily within the 360° videos and to interact with its elements. Still, the experts also pinpointed some potential drawbacks in this technology. Individuals with NDD may have an initial resistance to wear the HMD and to explore a WISS, as in general these persons feel a strong need for routine and tend to get distressed when a situation or a pattern of behavior changes. Some educators suggested that preliminary familiarization activities without the visor would mitigate this resistance: for example, wearing a cardboard-based mask like the ones used in some physical games and looking at the 360° videos on a regular PC screen. The experts also said that a WISS, and WIVR technology in general, may be not suitable for users that suffer of psychosis or hallucinations, since they already live situations of detachment from the reality and the immersion in a virtual environment could worsen their condition. With the above caveat, the experts highlighted the motivational benefit of a WISS for persons with NDD, particularly children and young adults. Once the “distress” originated from novelty is overcome, a WISS offers a playful and enjoyable experience that can promote learning. The virtual story can act as a preparation to the reality, helping users in focusing attention towards the relevant elements and in facing unexpected events. Therapists declared the intention of adopting WISSes in their practices as a complement to existing tools. They pinpointed that these stories should be offered not only at the care center but also in other contexts of a person's life and in the real locations of the social story, e.g., the museum and the supermarket.

Finally, the experts were convinced that WISSes created with XOOM have many advantages. XOOM makes it possible to create and control visual stimuli inside a WISS in a way that is appropriate for each specific subject, and to create a progressively more complex story by changing facilitators and distractions at each repetition. XOOM offers a simple and smooth way to play the same story as many times as it is desired, or to change it when the subject is bored. Individuals with a persistent state of anxiety would receive particular benefit from the possibility of repeating the experience again and again.

7. Future work

The video script translating the paper-based social stories in WIVR virtual tours of La Venaria Reale is ready. As soon as possible, following the created script, we will record the required 360° videos directly in place. Aside from this, our future work in the short term envisions the execution of an empirical study investigating the learning benefits of WISSes also compared to more traditional forms of social stories. This long term empirical study will involve 40 subjects with NDD (most of them with high-functioning autism, plus some individuals with learning disability or psychomotor deficit) at the 2 care centers we collaborate with. As evaluation tools, we will use the WISSes created for the projects *Museo per tutti* and *Shopping at the supermarket*.

In case the study will give us positive results, firstly we would like to extend WISS to the other museums involved in the project *Museo per tutti*. Secondly, we desire to propose the same approach to the Malpensa Airport, that, together with L'abilità and other contributors, has developed paper-based social stories to prepare people with NDD in visiting the airport.

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