Wildcard: a Wearable Virtual Reality Storytelling Tool for Children with Intellectual Developmental Disability

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***Abstract* — Our research aims at supporting existing therapies for children with intellectual and developmental disorders (IDD). The personal and social autonomy is the desired end state to be achieved to enable a smooth integration in the real world. We developed and tested a framework for storytelling and learning activities that exploits an immersive virtual reality viewer to interact with target users. We co-designed our system with experts from the medical sector, identifying features that allow patients to stay focused on exercises to perform. Our approach triggers a learning process for a seamless assimilation of common behavioral skills useful in every day's life. This paper highlights the technologic challenges in healthcare and discusses cutting-edge interaction paradigms.**

I. Introduction

Intellectual Developmental Disability" (IDD for short) is a broad term encompassing any form of disability (e.g., ADHD - Attention Deficit/Hyperactivity Disorder, ASD - Autism Spectrum Disorder, epilepsy, cerebral palsy, learning disability) that begins during the developmental period and is characterized by significant limitations in intellectual functioning (e.g., reasoning, problem solving, communication, and imagination) and adaptive behavior (the collection of basic operational and social skills that are learned and performed by people in their everyday lives) [2][7]. These deficits impact day-to-day functioning, and usually last throughout a person's lifetime with devastating effects on quality of life of the subject and his/her family [9]. The general goal of the current research performed at our lab in cooperation with experts (therapists and special educators) in the field is to design, implement and test novel interactive technology that can be integrated in the current therapeutic and education practice for IDD children as [1][3][6]. In this context, we have created "Wildcard", a system to manage the creation, personalization and fruition of multimedia interactive stories for IDD children that exploits wearable viewers as enabling technology. Specifically, we use Google Cardboard [10], a product that can transform any smart phone into an interactive wearable virtual reality environment (Figure 1).

Figure 1. Phone inside the Google Cardboard viewer and child interacting.

A similar opportunity is also offered by Samsung Gear VR [13], which has a much higher cost than Google Cardboard and only supports the integration with Samsung Galaxy smartphones. Other interactive VR viewers are also available, such as Facebook Oculus Rift, Microsoft HoloLens, Sony PlayStation VR, but they do not integrate external devices available in the market [12][13][14].

Several current researches adopt wearable virtual reality in the contexts of education, health or rehabilitation: Google Expeditions Pioneer Program [15] and Skype virtual field trips, for example, enable children to virtually explore natural or cultural environments. Stanford researchers are leveraging Google Glass for behavioral home therapies. Microsoft HoloLens forum is acquiring new ideas for autistic children therapies [12], depth perception and area learning to enable mobile devices in detecting their position relative to the world around them without using GPS or other external signals.

Wildcard has three components hereinafter referred to as storytelling, supervision, and personalization module.

The storytelling component is a mobile application which runs on the smartphone and enables the child to interact with a set of multimedia stories using the Google Cardboard. Stories are inspired, in terms of plot, visual contents, characters and other story elements, by books children are familiar with. The supervision component enables therapists to supervise children's storytelling activities during a therapeutic session. The personalization component is a web application that allows therapists to personalize the storytelling experience to address the specific need for each single child.

II. VIRTUAL REALITY EXPERIENCE

It is difficult to render on paper the impressions you get when trying an IVR application of a device of this kind. Yet we try to depict the user experience in Figure 2 expanding the two near-identical images displayed on the smartphone screen as a 360° panorama perceived inside the visor. Through the smartphone internet connection, the virtual environment on screen is downloaded from an external server that stores the multimedia contents.

Figure 2. 360° unrolled panorama.

We have used Unity game engine to create VR contents. Unity today supports native virtual reality applications and we exploited the Google Cardboard API delivered as Unity package format. Generation of stereoscopic images on the phone screen is achieved by adding in the virtual space scene two cameras, side by side with the same rendering frustum but at slight different positions, in order to obtain the two identical displayed images needed for an effective virtual reality experience.

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A. *Children UX*

For each story, we enforce two interaction "modes", hereinafter referred to as Story360 and Exploration.

In the Story360 the child will have to follow with his eyes an avatar to proceed in the narration, resulting in an immersive story where the user determines the tale's advancement. If the player stops looking at the main character, the avatar will stop moving and, as a consequence, the storytelling will be paused. Nevertheless, the child can still benefit from the VR experience, by just looking around in the simulated environment, he/she may find other dynamics elements surrounding the protagonist, thus realizing the space he/she can scrutinize. After acquiring this new cognition, he/she shall decide to continue with the story progression.

Figure 3. Child's view inside the Google Cardboard with mode.

Figures 3 and 4 exemplify this type of interaction using a Wildcard story based on Suzy Lee's book "Wave", about a little girl who wanders on the seashore, plays with the ocean's waves and discovers shells after a big wave breaks on the beach. A complete representation of the simulated environment is shown in the "unrolled panorama" in Figure 4, showing the exhaustive scene where the story evolves. Figure 3 illustrates what the child will really see when looking inside Google's viewer.

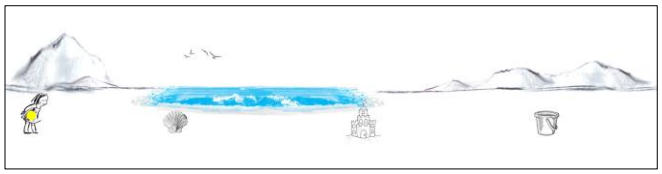

Figure 4. A 360° overview of the story360 environment.

In the Exploration mode the child explores a flow of interactive contents arranged along a path that he/she must follow.

The path renders the story's narrative flow by exposing different images at specific points in the walkway that can be interpreted as "checkpoints".

The player can proceed along the path in two ways:

- Looking at the image for a specified time lapse: the protagonist will continue automatically to the next image after a predetermined focus interval on the current illustration.
- Looking at the image to move: if the user loses concentration and stops looking at the interactive representation on the wall, the avatar will stop walking until the focus returns to the image.

The Exploration mode is more complex than the Story360 because the progression is no longer linear (the avatar does not always walk in the same direction), but unexpected turns will require the player to adapt his head's orientation to the irregularity of the path and discover the next narration step (Figure 5).

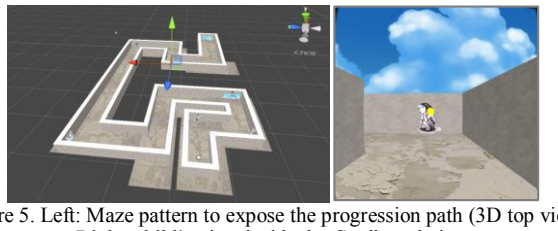

Figure 5. Left: Maze pattern to expose the progression path (3D top view) Right: child's view inside the Cardboard visor

B. *Therapists UX*

Using an external screen, therapists can observe what the child is watching and interacting with on the wearable device. As shown in Figure 6, the therapist's view is an exact replica of what is displayed on the smartphone screen, without the 3D immersive effects created by the wearable viewer

To duplicate the screen, the mobile app streams the smartphone's display via Wi-Fi using Google Chromecast HDMI plug connected to an external independent monitor.

Figure 6. Therapist UX: Supervision component.

To enable therapists to personalize a single session and to tailor it to individual children needs, we developed a web application and gave therapists the possibility to choose the following specific set of features:

- Choice of the theme/story for each interaction mode.
- Selection of predefined avatars to impersonate the main story character of the Story360 interaction mode.
- Positioning of dynamic objects in the Story360 scene.
- Insertion of personalized images for each checkpoint of the Exploration interaction mode.
- Adjustment of the avatar's speed in the Story360 interaction mode.
- Adaption of time intervals for story advancement in both interaction modes.

III. EVALUATION

Wildcard is currently being evaluated at a local therapeutic center as Figure 7 shows. The local Institution's Ethical Review Board approved all experimental procedures involving our subjects.

Figure 7. Children using Wildcard and therapist supervising the sessions on a secondary screen.

The evaluation focuses on the following research questions:

- RQ1) Children's acceptability of the device: do children with (some forms/degree of) disability accept to wear it?
- RQ2) Virtual world usability: can the children interact with the virtual world?
- RQ3) Does this technology help to improve cognitive skills such as attention, concentration, concept understanding?
- RQ4) Can this technology improve socialization and communicative skills?

At the moment, the study is in its first stage, involving 5 children: 2 children have minor forms of IDD, 2 are medium-functioning autistic children, and 1 has psychomotor retardation. We observed 8 individual therapeutic sessions in which Wildcard was used by these subjects, enabling us to explore issues related to RQ1, RQ2, and RQ3.

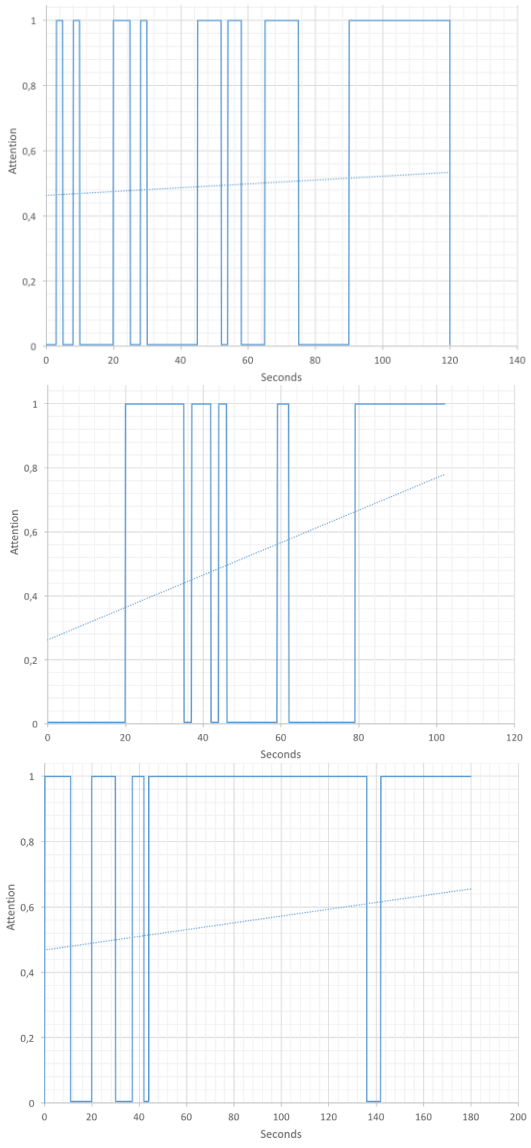

Figure 8. Attention levels for a child with autism (above) compared to a child with psychomotor retardation (middle) and a child with learning disabilities (below).

Concerning RQ3 we have so far only qualitative data, based on therapist's observations during the sessions, which pinpoints the cognitive benefits of the approach. For example: "The immersion in a virtual environment culminated in a pleasant experience for every child. Moreover, improvements were verifiable after two consecutive sessions regarding attention capacity, focalization skill and visual contact." (Elisa R., therapist)

We are still analyzing some more quantitative data, based on tracking the children's focus of attention in the virtual space.

An example is reported in Figure 8, which is based on recorded therapeutic sessions measurement of the avatar's tracking in the Story360 interaction mode. We report the attention levels plotting 1 on the graphic if the player is staring at the protagonist or its related object in a given instant, 0 otherwise (the task assignment of looking at the protagonist to follow the story is given by the therapist at the beginning and during the session). The x-axis unit of measure are seconds while the y-axis is a binary value 0 or 1 interpolated to render a continuum. Diagonal lines on graphs in Figure 8 and Figure 9 show the linear interpolation of the child attention across the session.

Figure 9 allows the comparison of attention levels during the first session of two children with respectively autism and a minor form of IDD, but comparable intellectual functioning level. As we can observe from the following graphs, they are quite different, which suggests that Wildcard technology can be used not only as a therapeutic tool, but may also be used, with caution, for diagnostic purposes in further studies.

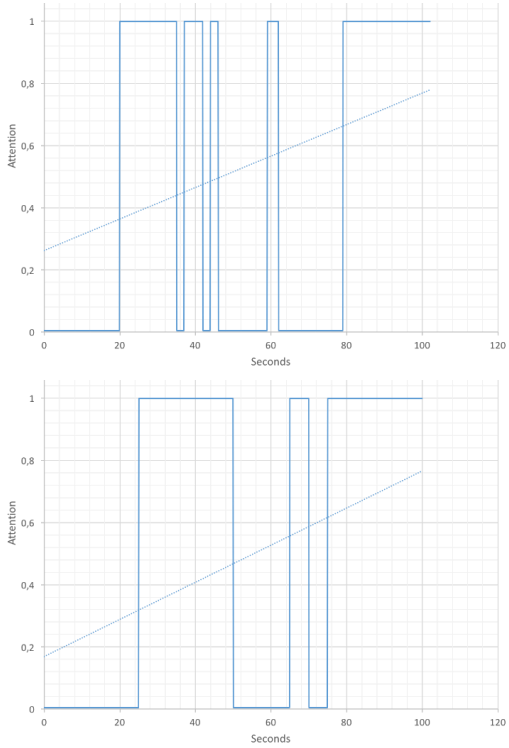

Figure 9. Attention levels of two consecutive therapeutic sessions (first session above – second session below) for the same child with psychomotor retardation

IV. CONCLUSION

The experimentation led us to collaborate with healthcare facilities and gave us the opportunity to test our system with very delicate target users, such as impaired children, however, we managed to furnish them with a tool that effectively improves their curative experience. In a case, one child recognized us as "Suzy's friends" enhancing how the simulated world marked their participation and partially boosted their long-term memory. Furthermore, Wildcard has only been superficially explored and already proves its potential, both on patient and caregiver side. Our system was willingly accepted by the children who tried it and allowed them a total engagement in the exercise they were performing. Wildcard was able to track their attention level for a subsequent analysis, but during the therapy it provided continuous feedback to the caregivers, who were indeed able to see the simulated world through the user's eyes. This way therapists supervised seamlessly entire sessions and understood what elements disturbed the most in the narration progression.

The possibility to personalize each single session was a key requirement to maintain a high engagement during the therapy. For children the curative activities are games, and it is indeed through the gaming experience they learn most of the behavioral skills therapies are trying to enforce. Two children were amazed about how they could play the same game with their favorite hero as protagonist. The child with learning disabilities wanted to continue having fun with the viewer and performed several stories by changing first the theme and then the interaction mode. In a single meeting he/she played four different times, stressing how children commitment is always present when interacting with our framework.

Wildcard is unique in terms of features it can offer: therapeutic centers have now the possibility to define completely a curative session and tailor the exercise to each child's needs through the personalization component. This affords to caregivers the necessary autonomy for not depending from external developers anymore. They can set up and update therapeutic sessions without incurring in delays that may result from a requirement gathering process. Wildcard empowers therapist with a complete, independent, modular and portable tool to support existing therapies. Caregivers were enthusiast in employing Wildcard not only for the personalization they were granted, but also for the real-time supervision during sessions. They could actively participate to children activities, asking them to accomplish more elaborate tasks than following the protagonist in some cases, or just comforting them discussing what they were experiencing in others. Finally, the possibility to adjust some in-game parameters such as speed and precision in the collision to trigger objects movement, were the add-on that therapists needed to conclude the personalization process.

All the aforementioned features are possible thanks to Wildcard's modular nature. In fact, the usage of an external device such a smartphone enables the installation and update of our framework as an "app" that can be downloaded by masses. Since parents are provided with the same identical tool as therapists, due to its low-cost implementation, Wildcard is able to smoothly migrate from therapeutic centers to children's home. Patients can thus exercise on their own devices, after a few supervised sessions, and still benefit from all advantage VR technologies can give.

Our hope is to extend this study and provide caregivers with continuously improving tools. As a matter of facts, we shall add new components to Wildcard framework and explore alternative environment creation, not only inspired by books and exploiting storytelling. Wildcard may be used for education and learning activities simulating real-life situation for which it can furnish a step-by-step guide that demonstrates how to act in such cases. We conclude our study by wondering how many novel technologies are still under-exploited, and asking ourselves which aspects we are still missing, whishing to inspire the community in order to help those who need and deserve our attention. The hope is to continue this study and provide caregivers with continuously improving tools to help those who need and deserve our attention.

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REFERENCES

[1] Bartoli L., Garzotto F., Gelsomini M., Oliveto L., Valoriani M. 2014 Designing and Evaluating Touchless Playful Interaction for ASD Children. ACM 2014.

[2] Boucenna S., Narzisi A., Tilmont E., Muratori F., Pioggia G.,Cohen D., Chetouani M. 2013. Interactive Technologies for Autistic Children: A Review. Springer Science+Business Media New York 2014.

[3] Bozgeyikli L., Bozgeyikli E., Clevenger M, et al. 2015. VR4VR: vocational rehabilitation of individuals with disabilities in immersive virtual reality environments. In *Proceedings of the 8th ACM International Conference on PErvasive Technologies Related to Assistive Environments* (PETRA '15). ACM, New York, NY, USA, , Article 54 , 4 pages. DOI=http://dx.doi.org/10.1145/2769493.2769592

[4] Cheryl-Jean L., Tsai E., Yoon A. et al. 2015. An Ant's Life: Storytelling in Virtual Reality. In *Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play* (CHI PLAY '15). ACM, New York, NY, USA, 779-782. DOI=http://dx.doi.org/10.1145/2793107.2810264

[5] Finkelstein S., Nickel A., Barnes T et al. 2010. Astrojumper: motivating children with autism to exercise using a VR game. In *CHI '10 Extended Abstracts on Human Factors in Computing Systems* (CHI EA '10). ACM, New York, NY, USA, 4189-4194. DOI=http://dx.doi.org/10.1145/1753846.1754124

[6] Garzotto F., Valoriani M., Bartoli L. 2013. Touchless Motion-Based Interaction for Therapy of Autistic Children. European Commission "M4ALL-Motion Based Interaction for All" and "Playful Learning on The Cloud" programs.

[7] Lebroyer M., Chaste P. 2015. Autism Spectrum Disorders: Phenotypes, Mechanisms and Treatments. Karger – Medical and Scientific Publishers.

[8] Tien C.,Tuck W.L et al. 2015. Exploring Gameplay Experiences on the Oculus Rift. In *Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play* (CHI PLAY '15). ACM, New York, NY, USA, 253-263. DOI=http://dx.doi.org/10.1145/2793107.2793117

[9] http://www.dsm5.org/

[10] https://www.google.com/intl/en/get/cardboard/

[11] https://www.oculus.com

[12] https://www.microsoft.com/microsoft-hololens

[13] http://www.samsung.com/global/galaxy/wearables/gear-vr/

[14] https://www.playstation.com/en-us/explore/playstation-vr/

[15] https://www.google.com/edu/expeditions/

Note: all the references to the word *Attention* refer to: *Selective Attention*: capability to focus on an important stimulus ignoring competing distractions and *Sustained Attention*: capability to hold the attention for the time needed to conclude a task.