Wearable Immersive Virtual Reality for Children with Disability: a Case Study

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Abstract

Our research explores the potential of Wearable Immersive Virtual Reality (WIVR) as learning tool for children with disability, particularly Neurodevelopmental Disorder (NDDs). NDD is characterized by severe and often co-existing deficits in the cognitive, emotional, and motor areas. The paper discusses the learning potential of WIVR and presents the design and preliminary evaluation of Wildcard, a novel WIVR system designed in cooperation with NDD specialists. Virtual environments are displayed on a smartphone placed inside a commercial low cost VR viewer while children interact with the virtual world through gaze focus and direction. An exploratory study performed at a care center sheds a light on the behavior of children with NDDs in wearable immersive virtual reality environments and highlights the learning potential as well as the possible difficulties of using this technology with this target group.

Author Keywords

Accessibility; Neurodevelopmental Disorder; Immersive Virtual Reality.

ACM Classification Keywords

• H.5.1 Multimedia Information Systems: Artificial, augmented, and virtual realities. • J.3 Life and Medical

WIVR – Wearable Immersive Virtual Reality: virtual reality applications on wearable viewers to enhance users' immersion in the virtual environment.

NDD – Neurodevelopmental Disorder: NDD encompasses ID (Intellectual Disability), ADHD (Attention Deficit Hyperactivity Disorder), and ASD (Autistic Spectrum Disorder) [1].

HMD – Head Mounted Display: currently, there are two types of HMDs. Embedded solutions (e.g. Oculus, HTC Vive) provide a complete VR experience without any external devices. Embedded solutions usually ensure a more accurate user interaction and a better graphical quality, but at a much higher cost. Modular solutions exploit external devices, mostly smartphones, as enabling technology for displaying the simulated world, and are much cheaper.

Sciences: Health. • K.4.2 Social Issues: Assistive technologies for persons with disabilities.

Introduction

Wearable Immersive Virtual Reality (WIVR) enables users to experience 3D virtual spaces using Head Mounted Displays (HMDs) and establish a feeling of presence in the simulated environment. This technology has recently been hit by a new wave of popularity triggered by the price reduction of modern HMDs together with the advances in virtual reality development tools. This situation opens up new opportunities for creating and experimenting WIVR applications in different domains. Our research explores the use of WIVR as a support tool in therapies for children with NDD – Neurodevelopmental Disorder. NDD is a group of conditions that are characterized by severe deficits in the cognitive, emotional, and motor areas and produce serious impairments of social functioning [1]. Little is known about how WIVR technology works for children with NDD and how WIVR applications can be designed for these target users. This paper offers the following contributions. After an overview of the literature on virtual reality technologies for subjects with NDD, we investigate the relevant issues in this field. We describe our WIVR application, named Wildcard, that aims at complementing traditional educational interventions for children on the NDD spectrum, particularly to practice attention skills. We explore the acceptability of WIVR and the usability of Wildcard; we investigate the potential of Wildcard in promoting attention skills – an aspect that, to our knowledge, has never been addressed by prior studies in WIVR. Our results shed a light on the benefits and drawbacks of using virtual reality applications with children on the NDD spectrum.

Related Work

Several studies highlight the potential of interactive technologies for children with NDD, and the importance of introducing them in regular educational or therapeutic practices [3][6]. In what follows, we review the state of the art in this field ranging from Virtual Reality to Immersive Virtual Reality and Wearable Immersive Virtual Reality.

For most subjects with NDD, thinking is visual and many traditional learning approaches for these users use visual (often paper based) supports [7]. VR contents are centered on visual representations and therefore capitalize on these visual skills [11]. In virtual environments, behaviors and responses can be practiced in a safe and repeatable environment built-upon a visual context that shares some similarities with the real world. This is thought to help children with NDD learn about real life situations. Similar benefits can be found in the reviews described in Pearson & Cobb (2011) [9].

Some systems (e.g. CAVE) add immersion the VR interaction. Immersion induces the feeling of actually being in the environment. Outside the virtual experience, the user is expected to capitalize and link the representation of the virtual environment to the real world applying skills learned in the virtual space [5]. According to some studies, authors found a positive correlation between immersion and improvement of social and practical skills in low-medium functioning children with ASD [4].

Being wearable, the HMD maximizes the immersion effect removing the distractions of the outside world. In the past, the technological limitations of VR headsets

Figure 1: View on smartphone and secondary screen by mirroring with Google Chromecast over Wi-Fi.

Figure 2: Stereoscopic effect and virtual environment perception on Google Cardboard.

(e.g., poor viewing angles, high latency, and weight) and their high cost prevented a widespread adoption of WIVR in educational programs for children with NDD. The study performed by Strickland and al. in 1996 [11] explored the acceptability of this technology with two autistic children: authors defined the HMD as "heavy and awkward". Today's HMDs are more comfortable and some of them (e.g., Samsung Gear VR[1] and Google Cardboard[2]) are commercially available at an affordable cost, triggering an increasing attention to WIVR by research and industry, and creating a space for Wildcard development.

Few studies to date investigate the use of new WIVR devices among subjects with NDD. Most of these studies explore the questions raised by Strickland et al. [11] surrounding acceptability and willingness to engage with VR viewers. Few publications explore modern WIVR technology as learning tool in the NDD domain. The VR game for Oculus Rift described in [2] aims at preparing individuals with ASD to use buses for transportation to reach specific destinations.

Wildcard Design

We designed Wildcard in close collaboration with caregivers who actively participated in the following phases: i) eliciting the key requirements, ii) evaluating iterative prototypes, iii) performing an empirical study evaluation.

Before starting to design our system we participated as observers to the children's activities in their normal context. This approach enabled us to understand what happens in a typical session and where the opportunities for WIVR technology lay. Then, specialists familiarized with WIVR technology, trying Google Cardboard and interacting with VR contents (360° videos, VR games). Together we identified the main requirements for a WIVR application for NDD interventions, from the perspective of both the child and the therapist:

- provisioning sense of presence by effect of the viewer isolation and real-time feedback on gaze orientation,
- triggering engagement through gamification,
- promoting cause-and-effect reasoning through interaction with stories,
- enabling therapists to receive real-time feedback of the child's view focus (**Figure 1**),
- gathering data automatically on children's performances exhibited during the session.

Specialists also suggested to create virtual worlds that evoke the visual contents of story books used in regular interventions and provided us with 2 stories that they use as learning material in therapeutic sessions.

Interaction Modality

Wildcard exploits Google Cardboard as VR viewer. We opted for this device because it is low cost, is available in different shapes, colors, and materials. Therapists can select the option which is more appropriate for each child. The smartphone set inside Google Cardboard provides the VR environments. The visual content appears as two near-identical bi-dimensional images on the display. What creates the illusion of 3D depth and immersion is the stereoscopic effect generated by the biconvex lenses on the VR viewer and the human vision system. The human brain combines

[1] http://www.samsung.com/us/explore/gear-vr/

[2] https://vr.google.com/cardboard/

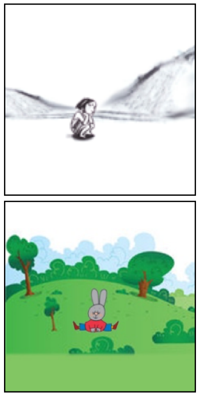

Figure 3: Story 360: view from user perspective - Main characters: Suzy (top) and Giulio (bottom).

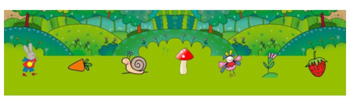

Figure 4: Unfolded Virtual World: 360° flat overview of the virtual environment "Story360: Giulio".

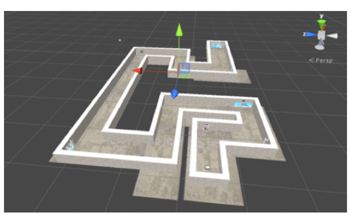

Figure 5: Exploration - top view in Unity game engine.

the two near-identical images and gives the perception of a single planar representation (**Figure 2**). Conceptually, interaction is based on gaze orientation and focus. By changing gaze direction, the child updates her/his view of the virtual environment and has the illusion of moving in different directions or changing perspective in the virtual space.

Virtual Environments and Children's Tasks
The visual "themes" of the virtual environments are inspired to the fantasy tales of two books used at the care center during regular therapy (**Figure 3**). We used Unity game engine to implement two types of tasks for each theme: Story360 and Exploration. In Story360 the goal is to explore the space "together with" the main character and "collect" the items encountered along the way. The main character is initially placed at the center of the user's field of view while the other elements are distributed in the entire 360° panorama at equal distance from one another (**Figure 4**). The character will advance in the story only when focused and will collect items from the narration when positioned over them. In Exploration, the virtual environment is shaped as an irregular 3D path that requires several changes of gaze direction to be traversed (**Figure 5**). The goal is to reach the "exit" of this non-linear space in the minimum amount of time. Images related to one of the previously defined themes indicate the direction to follow and are the active elements that must be pointed at in order to move towards the "exit".

Exploratory Study

We focused on the *acceptability* of WIVR, the *usability* of Wildcard, and the effects of Wildcard experiences on *attention.*

Acceptability was investigated in terms of the main parameters adopted in the current literature on WIVR for subjects with NDD (e.g., [8]: children's willingness to use the visor, motion-sickness, double vision and digital eye strain). U*sability* of Wildcard was measured in terms of "*task accomplishment"* (number of completed tasks in a session) and "*support from caregiver"* (number of times the caregiver provided *prompts,* i.e., helped the child to interact or to orient the head properly). *Attention* was the most difficult variable to operationalize because of the wide spectrum of definitions and measures of this construct. Considering the context of the children's experiences, therapists desired a concise representation of the fluctuation in user focus (**Figure 6, 8, 9**) and defined as attention measure "how long children were concentrated on relevant items in the VR spaces". We therefore measured attention as the percentage of time during which relevant items were focused on compared with the total duration time of the task. The study involved 5 children with NDD and their 4 therapists (**Table 1**). The children were aged 6-10 and attended the center on a regular basis. They had different forms of NDD at mild or moderate severity level and comparable intellectual functioning level.

ID	Age	Main Diagnosis	Severity level
C1	6	ASD	Moderate
C2	7	ASD	Moderate
C3	8	ASD	Mild
C4	10	SLD	mild
C5	8	Motor disorder	mild

Table 1: Participants' profiles. ASD = (Autism Spectrum Disorder), SLD (Specific Learning Disorder)

Variables Operationalization

AT – Accomplishment Time: the actual time of "gameplay" i.e. the total time to complete a task.

#FC – Number of Focus Changes: sum of attention-switches from relevant to non-relevant items, they represent the fluctuations in user focus during a task.

Attention levels: binary values tracked by the system during the session (1 the child focuses on a relevant object; 0 otherwise.

SA – Sustained Attention: percentage of the amount of time the user's focus stays on a relevant item over the Accomplish Time.

Main Results

The data about *acceptability* and *usability* were extracted from the video analysis performed by therapists. The information about other variables were extracted from interaction logs.

Concerning *acceptability,* C1 and C2 (the two youngest children, with ASD) had an initial resistance to wear Google Cardboard but only at the beginning of the first session. They accepted to wear it after the therapists wore it and invited them to manipulate it. C3, C4 and C5 were not bothered by the viewer. The physical discomfort effects are reported **Table 2**.

ID	Session 1	Session 2
C1	DES, DV	n/a
C2	DES, MS	DES
C3	DES, MS	n/a
C4	DES	None
C5	DES, MS	DES

Table 2: Physical discomfort. DES = Digital Eye Strain; MS = Motion Sickness; DV = Double Vision.

Concerning *usability,* the reduction of the *number of prompts* in the second sessions (**Table 3**) pinpoints a reduction of the need for therapist's support from the first session to the second one. **Table 3** also reports the values for *Task Accomplishment*, indicating if both Story360 and Exploration could be performed in a session.

The analysis of the *attention* variables considers only the children who attended both sessions (C2, C4, and C5) to enable a comparison between the two sessions.

Table 4 summarizes the main results concerning Sustained Attention (SA), Accomplishment Time (AT) and Number of Focus Changes (#FC).

ID	T S1	P S1	T S2	P S2
C1	1	25	n/a	n/a
C2	1	19	1	12
C3	1	16	n/a	n/a
C4	2	4	2	1
C5	1	9	2	5

Table 3: Usability results (T S_i Accomplished tasks in Session *i* – P S_i Therapists' Prompts in Session *i*).

ID	SA S1	SA S2	AT S1	AT S2	#FC S1	#FC S2
C2	52%	33%	229	233	92	122
C4	59%	76%	124	95	56	52
C5	44%	51%	134	155	34	80

Table 4: Sustained Attention (SA), Accomplishment Time (AT) and Number of Focus Changes (#FC) results in Session 1 (S1) and Session 2 (S2)

The graphical representation of Attention Levels for the Story360 task are reported in **Figure 6 , 8, 9**. Caregivers inspected these data and pinpointed some valuable insights: C2 usually takes a break from the task at half of the story and dedicates this time to asking questions on the story to the specialist. C4 is very concentrated at the beginning of the task but loses interest in it with time. C5 attention levels are sparser in the first session, meaning that in the second session there are longer periods of sustained attention.

Figure 6: C2 attention levels. S1 top, S2 bottom. (time on x-axis).

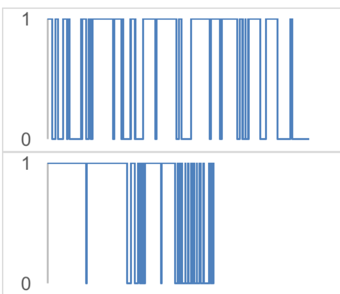

Figure 7: C4 attention levels. S1 top, S2 bottom. (time on x-axis).

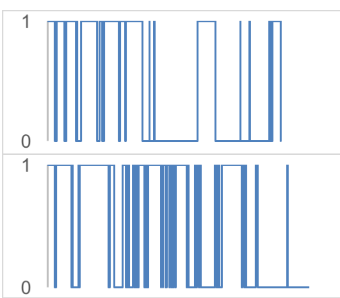

Figure 8: C5 attention levels. S1 top, S2 bottom. (time on x-axis).

Conclusion and Future Work

Wildcard is an example of WIVR application that exploits last-generation cheap VR viewers, has been created for children with NDD and has been designed in cooperation with NDD specialists. Because of its affordable cost and design features, Wildcard could be integrated in regular interventions. However, our findings highlight some limitations as well. Due to the variability between the subjects in this target group, children with different needs and abilities from those who participated in the study may not benefit from using Wildcard. We do not know to which extent children generalize skills acquired in VR to the real world, this aspect could be investigated in a broader study. Wildcard may suffer from the side-effects of physical discomfort that are typical of WIVR technology. Concerning our future research, the natural follow up of the exploratory study will be a larger one. In addition, Wildcard needs some improvements in order to be used extensively. For example, the virtual environment should support more diversified and incremental contents. Finally, Wildcard data gathering capability will enable the creation of a vast body of data unique in the NDD field that will deserve an in-depth analysis to mine valuable information for clinical research.

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