Technology For Improved Health Services: Virtual Reality For Pain Management In Paediatric Patients

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ABSTRACT

In health treatment processes, patients must often endure painful procedures for various medical conditions. However, with advancement in technology and the advent of affordable consumer-grade equipment, clinicians now have access to various interventions for pain management especially for pediatric patients. In this work, we review, design, implement and test an immersive virtual reality (VR) software solution for pain management in pediatric patients. The immersive VR allows the user to become an active participant in a virtual world, as VR captures the visual, auditory and tactile senses, as well as the limbic sense of emotion. When someone is fully engaged and immersed in VR experience, their body releases endorphins that can produce an opioid-response that markedly reduces pain-related activities in the brain and consequently the patient's subjective pain. Our results show that there exists a viable market for VR solutions in the health sector as users report substantial immersion and distraction during painful procedures.

Keywords: *Virtual reality, Augmented reality, Pediatrics, Pain Management,*

1. Introduction

Immersive virtual reality (VR) was introduced into the health sector to serve as an alternative to the use of harmful substances and drugs in the treatment of patients, due to its ability to create distraction. It is well known that most children tend to be carried away or develop excitement for games of “pretend”, such that they are able to ignore painful (aversive) stimuli [1]. In this work, we study how a virtual environment can be used to distract children from their present environment characterized by pain during drug administration or painful procedures. Specifically, by leveraging on hormones released by the body when fully immersed in a virtual world, we show that the brain can indeed be distracted from the action of the pain [2]. In order to reduce the challenges and pains (chronic, acute and procedural) that children go through during medical treatment, a virtual reality based immersive environment is designed to help distract the patients from the real situation into a virtual world. This technology with its immersive effect, distracts the brain, hence leading to a momentary relieve and enhancing the treatment of the patient.

Technology based health interventions are gradually taking the place of traditional methods of pain management including the harmful use of opioids. Importantly, with this advent of affordable consumer grade V.R boxes and software applications that work with them, clinicians now have access to a promising and engaging intervention for pediatric pain [3]. Immersive virtual reality has enabled an efficient transformation that has changed how pediatric patients perceive their body during medical treatment [1]. It has produced an effect that is found in no other device or medium. Virtual reality has the potential to familiarize children with the operation environment in a safe, controlled and playful way and potentially decrease pain and anxiety. Beyond this, VR has produced a corrective psychological and physiological environment that has enhanced and fastened rehabilitation for pediatrics going through pain (chronic, acute and procedural) and also neuro-rehabilitation for children suffering from stroke

and cerebral palsy. The immersive environment can be similar to the real world or it can be fantastical, creating an experience not possible in our physical reality. A person using virtual reality equipment is able to "look around" the artificial world, move around in it, and interact with virtual features or items. The effect is commonly created by VR headsets consisting of a head-mounted display with a small screen in front of the eyes, but can also be created through specially designed rooms with multiple large screens. In contrast to the less complex audiovisual distraction, VR uses advanced programs and system, such as head set, wide field of view; 3-dimensional head mount displays (HMDs) and motion sensing systems that measure the user's specific body positions. Immersive virtual environment is perceived to have an upper hand to traditional distraction because it offers more immersive experience due to the occlusive headsets that project the images right in front of the eyes of the user, blocking out physical (visual, auditory, or both) stimuli. The VR also combines audio, visual and kinesthetic sensory modalities for a holistic immersive experience. Depending on how immersive the presented stimuli are, the person's attention will be more or less "drained" from the physical realities, leaving less attention available to real world processes, including aversive stimuli [4].

A basic VR system consists of the VR headset that is worn like a pair of eyeglasses and a mobile phone running a VR application, which is clipped to the front of the headset. Advanced VR headsets are connected to a computer running the application or game of interest. Additional peripherals for a more immersive experience include headphone, hand controller, treadmill etc. Fig. 1 shows a VR system used for gaming.

The scope of this work is limited to the design and development of a 3D mobile application (game) for use with a VR headset. The developed application is fully immersive and suitable for pain management in pediatric patients.

Fig. 1: A VR system consisting of headset, headphone, hand controller and a computer for gaming. *[Source: https://www.modbee.com/news/business/biz-columns-blogs/biz-beat/article232751457.html]*

The main contributions of this work include:

1. Design of an immersive virtual reality software application
2. Integration of 3D user interface
3. Design of a roller coaster interfaced with local environment, using custom made primitive 3D models and indigenous sounds

2. Related Works

The use of VR for pain and anxiety attenuation during burn care procedures and rehabilitation of burn survivors is one of the most widely researched uses of VR technology. Clearly, burn wound care causes a tremendous amount of pain, anxiety and discomfort to patients. Hoffman *et al.*, [5] examined the efficacy of VR compared with a standard video game for two adolescents (16 and 17 years old) undergoing burn wound care. VR was found to decrease pain levels, anxiety and time spent thinking about pain. In [6], Das et. al. conducted a randomized control trial, comparing standard of care (analgesia) with analgesia plus VR for children (5–18 years old) during burn wound care. Analgesia coupled with VR was more effective in reducing pain and distress than analgesia alone. More recently, a water-friendly VR system was investigated during wound debridement for 11 patients (9–40 years), demonstrating that VR lowered pain ratings and increased fun ratings for those who reported feeling engrossed in the VR game [7]. Sharar *et al.* [8], reported results across three studies and concluded that VR in addition to standard analgesia reduced pain intensity, unpleasantness and time spent thinking about pain. Fig. 2 shows a young boy immersed in a virtual world while undergoing dressing changes.

Fig 2: Child undergoing burn dressing lying in hospital wearing virtual reality goggle
[Source: https://www.cnet.com/news/virtual-reality-at-hospitals-could-be-your-next-painkiller/ accessed 09 January 2019]

While most medical procedures provoke anxiety and distress, needle insertion continues to be the most frightening and bothersome medical procedure for children. Nonetheless, venipuncture is routinely requested for procedures in pediatric medical centers. Many routine medical procedures, such as a blood draw, intravenous placement and immunization can be painful and anxiety provoking. Gold et al., [9] investigated the use of VR distraction during outpatient blood draw in children. The sample consisted of 100 children (8–12 years old) stratified for age and gender into four conditions: no distraction, cartoon distraction, VR via computer or VR via HMD. The children in all conditions placed their arm through a pass wall for the blood draw in order to control for visual occlusion. Children in the VR HMD group reported a lower frequency of moderate-to-severe pain intensity levels compared with the other three groups. Accordingly, virtual reality helps calm children before they receive medicine intravenously or undergo endoscopies or colonoscopies [10]. While there is growing evidence supporting VR's effectiveness in managing acute procedural pain, little is known about the use of VR for treating patients with chronic pain and/or for long-term pain rehabilitation. To date, only a few studies have investigated VR for chronic pain management and the data are preliminary.

It is worthy to note that only few theories have been proposed regarding the pain reducing effects of VR beyond distraction. From the gate control theory that was brought forth by [11] it postulates that certain conditions such as level of attention paid to the pain, the emotion associated with the pain, the patients past experience of pain and the clinicians' care style contribute to a patient's interpretation of pain. Other authors like McCaul & Malott [12] has contributed towards the gate control theory to state that humans have a limited capacity of attention and an individual must attend to painful stimulus in order for it to be perceived as painful. Therefore, if the individual is attending to other stimuli away from the medical procedure, they will perceive the painful stimulus as less intense. Wickens [13] proposed the Multiple Resources Theory, which states that resources in different sensory systems function independently. This supports the nature of VR technology, which is based on integrating multimodal (visual, auditory, tactile and olfactory) sensory distractions.

3. Understanding the Hardware and Software Aspects of Virtual Reality

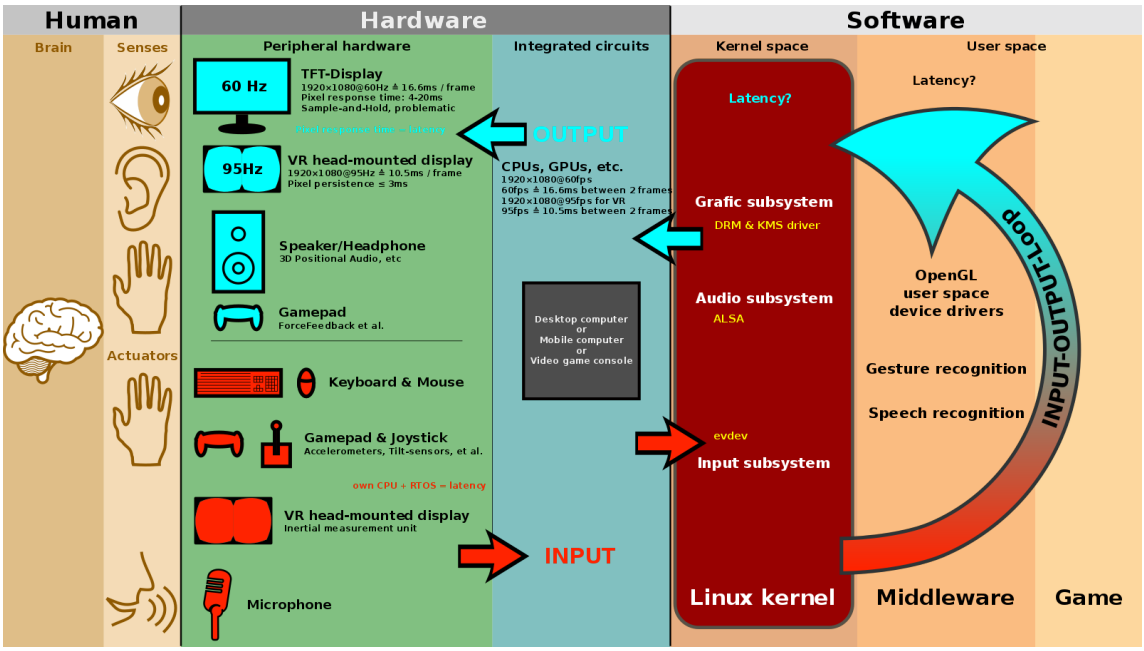

Fig. 3: Human hardware and software interface in a virtual reality: Linux kernel input and output latency:
[Source: https://commons.wikimedia.org/w/index.php?title=File:Linux_kernel_and_gaming_input-output_latency.svg&oldid=345857840]

Fig. 3 shows a pictorial representation of how the human sense organ i.e. virtual reality sensitive organs interact with the hardware, which is interfaced with the software. The eye focuses on the software design inside the hardware to cause distraction for the brain. In order to achieve effective immersion, the hands and the ear have to be involved. The hardware part consists of a peripheral device in this case a head mounted display (HMD), which is the basic requirement for viewing a virtual environment. It displays digital images on two screens in front of the user's eyes, the eye through the retina then sends nerves signals through the back of the eye to the optic nerve. The optic nerve carries these signals to the brain, which interprets them as visual images. The interpretation and processing of visual inputs that the eye sends is the function of the part of the brain known as visual cortex. When fully immersed in a virtual world, the body releases hormones, which distracts the brain from the action of pain. When someone is fully engaged and

immersed in VR experience, the visual auditory, tactile and the limbic sense of emotion are captured. Consequently, endorphins are released which produces opioid responses that markedly reduces the patient's subjective pain. This distracts the brain from the pain and engages the brain biologically so that the frontal lobe inhibits the signals.
In Fig. 3, we have the **output peripheral** (visual, aural and haptic) that immerse the user in the virtual environment, **input peripheral** (trackers, gloves or mice) that continually reports the position and movements of the users. The **graphic rendering** system generates the virtual environment, the database construction and virtual object modeling software for building & maintaining detailed realistic models of the virtual environment. A software application is used to design or create the geometry, texture, intelligent behavior and physical modeling of hardness, inertia, and surface plasticity of any object included in the virtual environment. These systems follow the user's head movements, giving them the illusion of being completely surrounded by a virtual world. Multimodal (visual, auditory, tactile and olfactory) stimuli contribute to a sense of actual presence/immersion in the virtual world, thus making the VR experience distinct from passively watching television or movies, or playing a 2D handheld videogame or game console.

4. Design and Implementation

The design of our VR based solution strictly follows the waterfall model for software modeling, as shown in Fig. 4. The waterfall model is a sequential development process, where the progress of a software cycle is regarded as flowing increasingly downward through a list of phases that must be executed in order to successfully build the software [14]. The first stage of our design was **content development,** a critical stage of every VR design as the users and use cases must be put into consideration. In our design, we incorporated local features relatable by children in our immediate environment including indigenous music, local houses, trees, shrubs and grasses. Wide ranges of personality types were also considered in the design of our solution.

After the development of the concept, the **3D modeling** ensued. The 3D models were created using Blender, Autodesk Maya, and Photoshop software applications. Specifically, the scene objects (3D models) were created using Blender and Maya while the 2D and user interface was designed with Photoshop. The developed model was exported to Unity (game engine) for **binding the logical behaviors to the 3D models and encoding of VR specific attributes and settings.** The encoding and binding of logical behaviors were achieved in Microsoft Visual Studio using C# programming language. The modeled 3D roller coaster environment is shown in Fig. 5.

5. Hardware and software requirements for VR development

The following tools (or any of its variants within the same specification range) is recommended for an effective VR development project:

- A VR headset (e.g Google Cardboard[2])
- Unity Software (https://unity.com/)
- Visual Studio Code or Visual Studio IDE (Preferably)
- Android/iOS SDK
- Cardboard Unity SDK
- Windows 7 and later operating system

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

- Android: Android OS Lollipop 5.1 or higher that has gyroscope, accelerometer, orientation sensor and magnetic sensor.
- OS X: OSX 10.9+ with the Oculus 0.5.0.1 runtime.
- Graphics card drivers

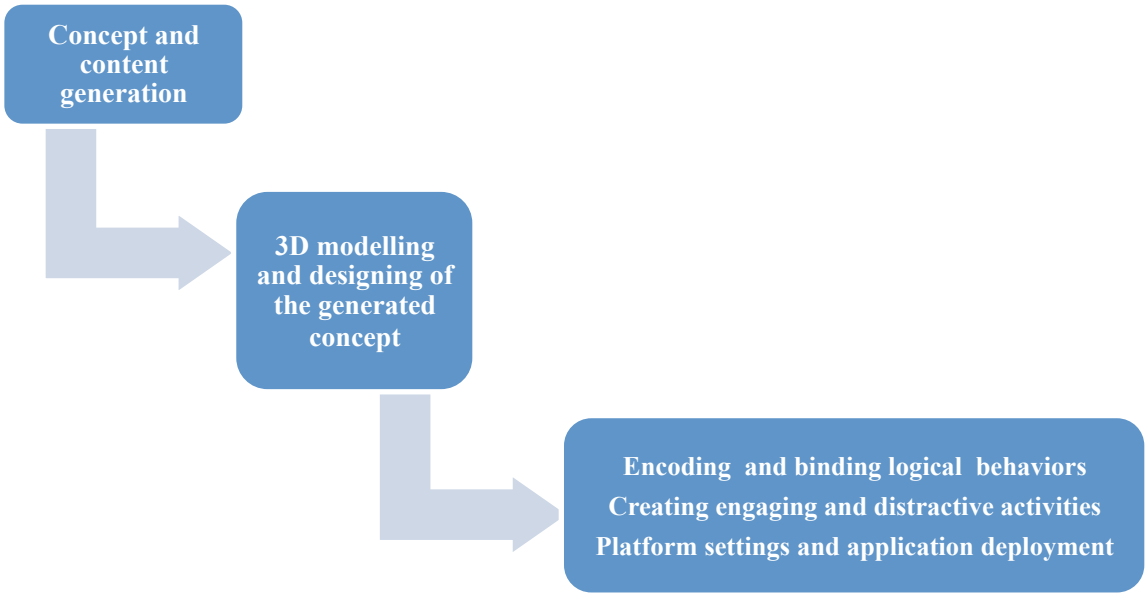

Figure 4: Water flow model of our Virtual reality design

Achieving a frame rate similar to your target HMD is essential for a good VR experience. This must match the refresh rate of the display used in the HMD. If the frame rate drops below the HMD's refresh rate, it is particularly noticeable and often leads to nausea for the player.
In addition, each VR device requires that you have appropriate runtime installed on your computer. For example, to develop and run for Google cardboard within Unity, you need to have the Cardboard runtime (also known as Cardboard) installed on your machine while to develop and run for Oculus HMD within Unity, you need to have the Oculus runtime (also known as Oculus Home) installed on your computer. Similarly for HTC Vive headset, you need to have Steam and SteamVR installed. Depending on the version of Unity one is using, the runtime versions for each specific device that Unity supports may differ. You can find runtime versions in the release notes of each major and minor Unity release (https://docs.unity3d.com/Manual/system-requirements.html).

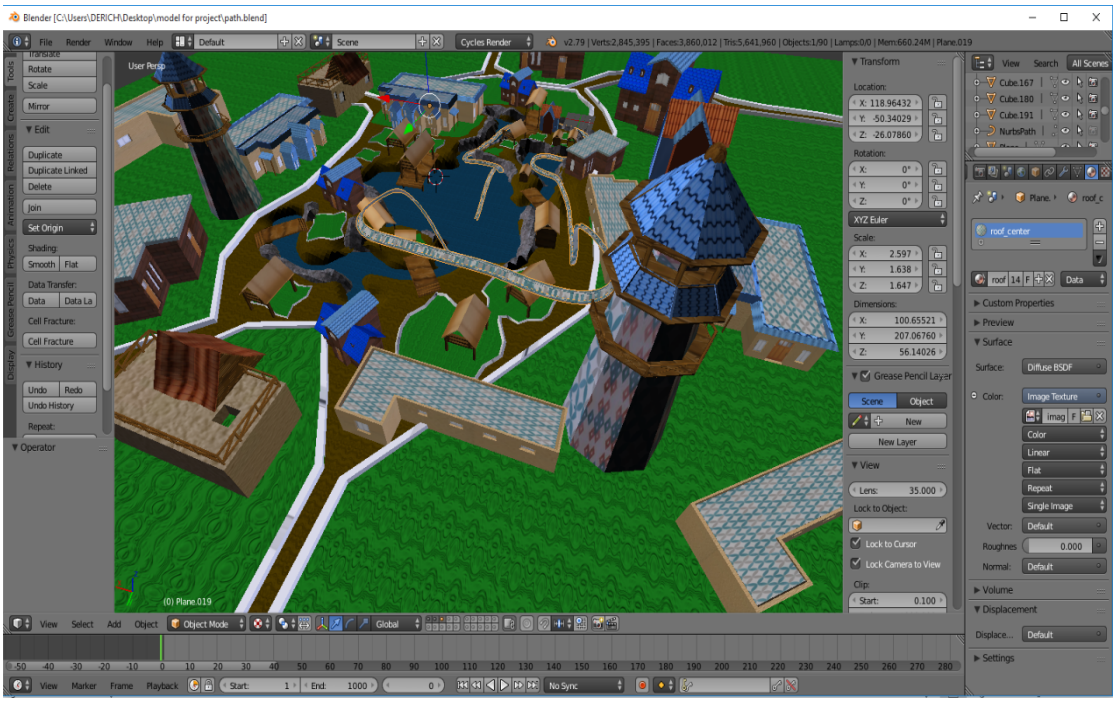

Fig 5: Textured 3D environment.

6. Software testing & analysis

Preliminary test were carried out informally to determine the usability and effectiveness of our application for pain management in children. Parental consent was obtained before tests were carried out. We had two groups of our test subjects. The first group had the VR HMD with our developed software when safe needle pricks were administered, while the control group was made to watch their favorite TV show. We used the self-reporting method of pain assessment and limited the ages of our test group to between 5 and 12 year old children. Fig. 6 shows a test subject undergoing software testing.

7. Results

Our test group consisted of a total of nine (9) individuals (aged 5- 12). Seven (7) out of the nine (9) participants reported no pain during the needle prick within the developed software application first minute. After a prolonged exposure to the application, all 9 subjects reported no feeling of pain at the prick of the needle, with four reported or showed no sign of external stimuli. The other five subjects reported a feeling of external stimuli unassociated with pain. Older test participants belonged to this latter group. Overall, all nine subjects reported a moderate to high level of immersive experience for the developed VR application. For the control group, all participants reported the feeling of pain. There was also the feeling of anxiety and fear on the sight of the needle.

Future work will focus on a more elaborate testing exercise in a typical hospital setting as well as improving interactivity through the use of additional peripherals.

Fig. 6: A test subject undergoing Software Testing

8. Conclusion

Virtual reality has consistently been demonstrated to decrease pain, anxiety, unpleasantness, time spent thinking about pain and perceived time spent in a medical procedure. In addition, healthcare providers have regularly commended the role of VR and its associated technology in increasing procedural cooperation, while decreasing anxiety and distress. We have shown in this work that locally developed software solutions depicting the environment that our pediatric patients are conversant with can pave the way for improved pain management procedures. In addition to providing relief from acute and procedural pain, emerging technologies like VR can also help to provide a corrective psychological and physiological environment to facilitate pain relief for patients suffering from chronic pain. The special qualities of VR such as presence, interactivity, customization, social interaction, and embodiment allow it to be accepted by children and adolescents and incorporated successfully into their existing medical therapies.

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