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Studies on the Innovative Application of Immersive Virtual Reality in Medicine: The Possibilities of Full-Dive Virtual Reality

Misaki Tatsumi
Belmont High School, United States
misakisak@icloud.com

Abstract

In Sword Art Online (SAO) animation and light novel, Full-Dive Virtual Reality (FDVR) was realized in 2022 but it is a dream technology in our world. The brain is sometimes expressed as a black box since it has many unknown mechanisms and functions, and it is difficult to investigate the real human brain in vivo. However, various technologies for neuroscience are being developed rapidly, for example, related software or hardware which enable to analyze brain activities with device to realize FDVR. At the same time, the applications of virtual reality (VR) have been highly expected not only in the entertainment world but also in the medical field. Although VR use for surgical treating has already become popular with robotics, we must much more innovate medical applications for treatments and safety. This study demonstrates the possibilities of VR and FDVR. First, I will investigate the development in VR and the feasibility of VR application in pediatrics and then elucidate FDVR possibility and difficulty, with which I would like to grapple for future trials.

Introduction

Full Dive Virtual Reality (FDVR) is from a Japanese light novel and Anime series, Sword Art Online (SAO) written by Rekik Kawahara in 2009 (TV Animation, n.d.). It is a futuristic technology designed to create a Virtual Reality Massive Multiplayer Online Role-Playing Game (VRMMORPG). You can go through an immersive virtual reality with a wearable device, like a helmet, receiving external signals for user interaction between the brain and a computer. It looks like scuba diving; we jump into the sea world with all of our senses. This concept is very attractive for gamers as well as developers, but it is still a dream. The expansion of the application is highly expected, especially in the medical field.

FDVR is akin to virtual reality (VR), but the system is entirely different. FDVR needs more advanced technology which enables not only to understand electroencephalograms precisely but also to make sensory feedback to the brain. Some of the Brain-Computer-Interfaces (BCI) have been developed to perceive brain activities. Though these BCI developments are on the way, conventional VR is also revamped for its quality challenges for medical use. First, I will investigate the feasibility of the application of VR in the medical field and then elucidate FDVR's possibility and difficulty for future trials, which I would like to challenge.

Methodology

The use of VR in the medical field, primarily pediatric, electroencephalogram (EEG) and the potential use for the sensory disorder, and the possibilities of obtaining FDVR are investigated and discussed. The searches were done by using Google Scholar through Google search engine in English and Japanese. The searched terms are listed in Table 1, which includes some related words with VR, FDVR in medicine.

TABLE 1: Search terms

	English Terms	Japanese Terms
1	Full Dive Virtual Reality	フルダイブ技術
2	Sword Art Online, NerveGear	ソードアートオンライン、ナーヴギア
3	Sword Art Online Full Dive system	ソードアートオンライン、フルダイブ技術
4	Virtual Reality and Medical use	バーチャルリアリティと医療応用
5	Pediatric and Virtual Reality	小児科とVR
6	Pediatric Pain	
7	VR and Pediatric Mental Health	VRと小児患者のメンタルヘルス
8	Brain-Computer Interface	
9	VR and Psychology	VRと
10	VR and Pain	VRと痛み
11	Pediatric Mental Health	小児科とメンタルヘルス
12	Sensory disorders	感覚器障害
13	Cochlear implant	人工内耳
14	Visual impairment and treatment	視覚障害と治療法

TABLE 2: Number of references used by category. The number in parentheses is for Japanese.

	Paper	Article (blog)	Video (YouTube)	Total number
Full Dive	0 (0)	6 (5)	0 (0)	6 (5)
Electroencephalogram	1 (0)	7 (5)	3 (0)	11 (5)
VR and Pediatric	7 (1)	1 (1)	0 (0)	8 (3)
VR technology	3 (0)	2(0)	1 (0)	6(0)
Pediatric Patients	2 (2)	0 (0)	0 (0)	2 (2)
Sensory Disorder	7 (4)	0 (0)	0 (0)	7 (4)
Total number	**20 (7)**	**16 (11)**	**4 (0)**	**40 (19)**

The references collected for this study were arranged according to the following genres: Full Dive Virtual Reality, Electroencephalogram, VR and Pediatric, VR technology, Mental Health, and Pediatric Patients, Sensory disorders. The order makes it easy to correlate the facts between different things. In each reference, the information is distinguished by how relevant and irrelevant. (e.g., it excludes the cause of sensory disorder but includes the treatment).

All searches were done with the keyword listed in Table 2. Though there are not so many, it is thought to be enough coverage for this study. However, much improvement remains for the following study.

Results

This part is divided into four parts, (1) Virtual Reality, (2) Virtual Reality and Pediatric Treatment, (3) Full Dive Virtual Reality and Electroencephalogram, and (4) Sensory Disorder and treatment.

(1) Virtual Reality

Virtual Reality (VR) is defined as "the computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors" (Lexico Dictionaries, n.d.). The user gets through VR using output and input devices such as a headset, headphones, and controllers. The restriction of the user's movement decreases the quality of immersion feelings of VR. TESLASUIT (Teslasuit, 2020; Full body haptic feedback & motion capture tracking VR suit, 2021) is a full-body haptic suit and training solution for physical VR experiences (Figure 1). The haptic sensation is requisite for enhancing the immersion. The suit generates feedback to any part of the body area from gentle touch to feelings of physical exertion and temperature. It outputs haptic feedback from VR (touch feedback is similar to an abdominal muscle pad) which can be used for training or

FIGURE 1: TESLASUIT is a full body haptic suit and training solution for physical VR experience. Author's own figure created in reference to TESLASUIT (2021).

learning how to use their body efficiently. It is incredible technology because touch feedback makes it easier to control and demonstrate sensitive movements. If you do not have sensitive haptic feedback, you will not be able to move normally. Fig. 2 shows an example of the importance of feedback when grabbing a cupcake. In Fig. 2a, a person getting feedback about the distance between the hand to the cupcake can approach it in the proper position. Still, in Fig. 2b, the hand could not reach it without the visual information because the brain could not calculate the correct distance for the approach. Figs. 2c and 2d demonstrate shockingly different results without the proper haptic feedback. The person must grab the cupcake with the correct amount of force. Otherwise, exerting too much energy when grabbing makes the cupcake compact, as seen in Fig. 2c. The meticulous feedback cycles with fine tactile signals from your hands fulfill your brain's will to make you happy with the cake to eat.

Besides sensory, we need body ownership in VR for a high-quality immersive experience, i.e., positional information about our body parts. In the study (Kondo et al., 2018; Yin, 2018; Urushih, 2018), humans can feel body ownership for a virtual body at least when they see their arms and legs, but still, it is weak. They feel real pain to the virtual body that the person feels ownership of, but it only happens when they experience something so hard or impressive, like a knifed imaginary body. In another study (Kanaya et al., n.d.), a person felt stimulation, including illusory thermal sensations for their prosthetic hand made of rubber when the person observes hot water poured on the rubber hand, called rubber hand illusion (RHI). It is a crucial term for developing VR.

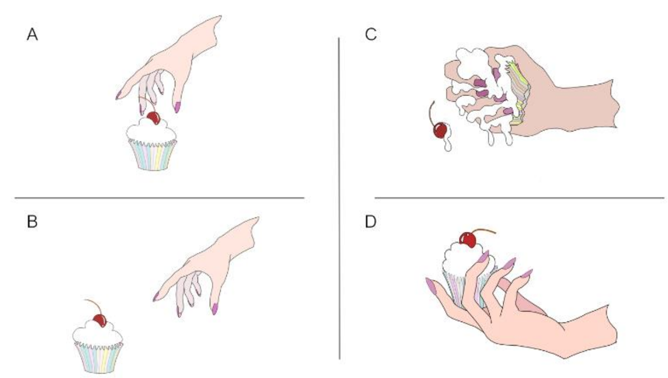

FIGURE 2:
a. A hand in the right approach to pick up the cake
b. A hand in the wrong place resulting in failing to touch the cake
c. A hand in the right place without touch feedback culminating crashing the cake
d. A hand in right approach and place with proper visual and tactile feedback to succeed in holding the cake

(2) Virtual Reality and Pediatric Treatment

Some papers indicate the effectiveness of reducing pain during the treatment or chronic pain. Also, it could be applied to mental diseases. The study (Won et al., 2017) reviews recent literature in pediatric virtual reality in procedural and anxiety, acute and chronic pain, and some rehabilitation applications. Participating in the virtual environment featuring a wintery scenario, called "SnowWorld" during painful repetitive dressing changes in patients with burn wounds reduced 27-44% for acute and procedural pain. It also shows success in lessening procedural pain and distress related to intravenous (IV) placement and other needle-related procedures (note: it was not immersive VR). In chronic pain, it demonstrated a significant change in complex regional pain syndrome (CRPS) and phantom limb pain (PLP), which indicates the effectiveness for adults. In addition, it revealed the benefits of the neurorehabilitation application of VR.

Another study (Eijlers et al., 2019) demonstrated that VR significantly impacts pediatric pain and anxiety during medical procedures, especially for younger children. It is hardly effective for adults for the quality of VR used. Furthermore, it can be used to reduce anxiety before the operation (Ahmadpour et al., 2020; Gold et al., 2021) for example, "Doc McStuffins: Doctor for a Day" (it is a VR experience program done before the operation for children to introduce operation room and tools).

To exhibit higher quality experience and effectiveness, we need to think about the best content for children's treatment. There are many types of VR content to have real-life-like experiences (also includes fighting games) (Nuhei, 2003).

Examples of VR applications:

- Let's go to the zoo
- VR school (joining the class from the hospital bed)
- VR miniature garden (creating a miniature garden with pictures of humans, animals, plants, etc.)
- VR cast (talk with characters in the VR in real-time).

These terms show that the emotion will change with the detail of VR.

Long-term treatment like childhood cancer provides numerous challenges and sources of stress for patients and it removes children from their everyday social environment and previously enjoyed activities. Therefore, VR can be used for mental health care (Tennant et al., 2020), such contents listed above.

(3) Full Dive Virtual Reality and Electroencephalogram

FDVR is stated that electronic equipment (e.g., brain-computer interfaces) reads EEG and gives feedbacks (e.g., sensory feedback also emotional) to the brain; it would be done without using any parts of the body, excluding our brain. It is forwards compatible with VR but remains the state of dream technologies (Eisenberg, 2021). In FDVR, there are two types, invasive type and noninvasive type, which is to put the electrode directly into the brain or not (Kawakatsu, 2021; Editorial, 2019).

EEG is a wave-like signal in which electrical activities in the brain are recorded by electroencephalography called brain-computer interfaces (BCIs) (National Science Foundation, 2015; What is an electroencephalogram?, n.d.; Wikimedia Foundation, 2021). There are some examples of practical use of reading EEG (Directly decipher sentences from the brain activity of people who cannot speak, 2021; Birbaumer & Cohen, 2007; Kubota, 2021).

Example 1: the examiner is a 36 years old man who had a stroke at the age of 20, got articulation disorder, and cannot move the head, neck, arms, and legs from its sequelae. In this examination, he conversed for the first time over 15 years. He usually talks with the stick on his baseball cap to point out the alphabet on the paper (US Scan Francisco (UCSF), 2021). First of all, BCIs and artificial intelligence (AI) made it possible to read EEG and generate it into the words at a maximum of 18 words per minute, an average accuracy of 75%. It was an invasive type that stings electrodes directly into the brain. Before making it possible, they took a few months to record the electric signal into the computer to educate AI.

Example 2: A car demonstrated that it could be controlled by visualizing cubic movements in its head (Emotiv's new neuro-headset, 2014). It means you cannot move a car when you visualize the car moving or recite to move; it moves only when you visualize the cube moving for now. It works by scanning your brain for signals using the Emotiv EEG device on your head.

If the technologies in the two examples are used practically, more things are possible to control with our brain without the presence of physical forces.

(4) Sensory Disorder and treatment

The research was primarily done about hearing and sight impairment. First, an artificial cochlear implant is a device that duplicates the inner ear cochlear with engineering technology and complements patients' hearing by putting it within the inner ear cochlear (Kaneko, 2016) (Fig. 3).

This device is a bypass information processing system that decomposes sound information into frequencies and transmits it as an electrical stimulus to the cochlear nerve. The patients do not hear the same as the original human hearing system, so they need special training. Thus, the implant is a great way to deal with hearing impairments, but it is still difficult to hear naturally. Also, surgical implantation sometimes causes infection complications, so some patients were forced to remove it (Brkic et al., 2018).

Cochlear implanted children's levels of hindrance are different so that corresponding individual treatments are needed. For example, talking with one person is possible, but it is not easy to talk with more than one person or listen to someone talking in the crowd, which estimates that each cochlear implanted child needs long-term rehabilitation with doctors, speech-language-hearing therapists, and teachers (Moroto & Naito, 2021). Moreover, the teachers want to have a training session to learn about involvement, the ways to communicate children with disability (National Institute of Special Needs Education, 2021).

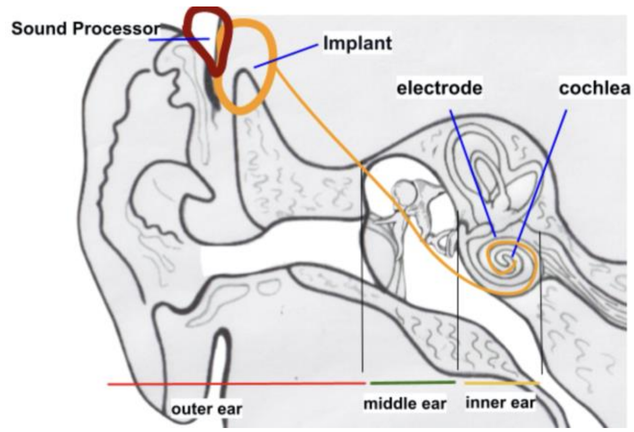

FIGURE 3. Anatomical demonstration of artificial cochlea implant in the ear

Second, an alternative device for the treatment of eye impairment. The system comprises custom-designed headgear with a camera and wireless transmitter, a vision processor unit and software, and a set of 9x9 mm tiles that are implanted into the brain (Opening eyes to a frontier in vision restoration, 2020). The small tile embeds into the brain receives the information from a camera and stimulates the brain, and it helps improve or resurrect the sight.

Discussion

This study shows what we can do now and the limit to realize practical use of VR/FDVR with existing techniques.

VR has pros and cons; one of the pros is that we can exercise our bodies for real and go to the VR world simultaneously with corresponding feedbacks, but it may become a con. When the person cannot give a signal to the VR system (what they want, controlling an avatar in the video game) or cannot receive the feedback, the sense of presence becomes poor because VR's feedback depends on the sense of sight and hearing a lot. Also in real experience, we usually obtain full-scale body information against the environment as feedback as five-senses. Furthermore, to perceive touch feedback, you need to wear a device (Full body haptic feedback motion capture tracking VR Suit, 2021; Charlton, 2021). Most of the quality of experiences is compensated by audio-visual responses to use's action. Those haptic feedbacks make it possible to do detailed and vivid sensation for humans.

This research encourages the use of VR within the treatments for pediatric patients. In the investigation, VR is effective for reducing pain, stress (anxiety), and the amount of medicine. Nevertheless, examinations are not enough to prove that VR is a reliable treatment for those users.

To actualize FDVR, both input and output have to work well at the same time; input is the sense of touch, sight, hear, smell, tastes (the last two have not been mentioned in any references and the result), and output is expressing (including face, conversion, etc.) and moving body in avatar. For that sake, we need to develop plenty of devices. At this moment, we could have wireless electronic implants input to the sight from the camera (Liu et al., n.d.). In the device development process, the developer needs aiming to monitor each nerve cell level and analyze its change. Thus, I came up with the idea of computed neural circuit encephalogram (CNCE) using the similar technology of computed tomography (CT); its technology can be used to detect much more specific activities of the neural networks by calculating based on the stored AI processed algorithm.

Also, skills to remove the noise of electromyogram (EMG) from CNCE is necessary; that is why we collect the noisy data of EMG while moving the body. In addition, we need to send information directly into the brain; the cochlear implant is close to that, i.e., sends the electric signal into the cochlear nerve but not directly into the brain. Even though we cannot convey the stimulus to the brain directly, the sounds implanted-patients hear might be electric-like sounds, entirely different from what we hear. To be used to or understand that sounds need much rehabilitation with a special therapist. If the rehabilitation can be done in FDVR, it will be possible to deploy high-quality-language treatment to everyone who needs it.

Requirements for the effective FDVR:

- No pain to use, no blood (noninvasive FDVR system)
- Lightweight
- No risk of infection
- Everyone can use it for treatment (universal style and low-priced)
- High-speed connection to the Internet
- High quality sensor
- Seemingly real and intriguing content for the users

These requirements would make FDVR more useful to provide a high-quality experience.

I suggest that if FDVR can access the brain directly, it helps to accelerate brain plasticity to improve human life. It means it could rebuild neural circuits with FDVR system; in other words, it may create new memories in FDVR world to replace the bad memories with happy ones. FDVR needs output signals from our brain to control the avatar and input signals to the brain for better output as a feedback system. At the same time, it intentionally enables us to cut or add the signals by creating the same environment as the patients feel. It could provide opportunities to experience how difficult the patients feel and check how much they improve with the treatment.

There were some limitations for this investigation; the lack of information on FDVR and VR use in pediatrics, but it shows the benefit of utilizing it as an additional treatment in the medical field. It would also work for adults if its quality of reality and contents increases.

To conclude, there is enormous room for improvement and development in VR/FDVR. They could expand what we can do in this world, especially in the medical field.

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