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Implementation of Virtual Reality Technology in Strabismus

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Abstract:

As virtual reality technology continues to fundamentally change the way we experience the world, it has been applied to numerous domains. To date, an abundance of research has been conducted on using virtual reality (VR) in strabismus. This is a review paper that analyses the relevant research in the areas of VR application in strabismus teaching, screening, and diagnosis, therapy, and surgery training. Multiple pieces of research have shown that users would benefit from the implementation of VR in strabismus.

Keywords*: Virtual reality technology, Strabismus, Teaching, Screening, Diagnosis, Vision Therapy, Surgery Training*

I. INTRODUCTION

Strabismus is a frequent ocular disorder in which the eyes don't properly align with each other which can be regarded as a binocular vision dysfunction. Based on the relative position of the eyes, strabismus can be divided into the flowing groups: exotropia (where one eye turns in towards the nose), esotropia (where one eye turns outwards), hypertropia and hypotropia (where one eye is higher or lower than the fellow eye). It is one of the most common eye conditions in children. The estimated pooled prevalence (95% CI) of any strabismus, exotropia, and esotropia was 1.93% (1.64-2.21) [1], Amblyopia caused by strabismus would lead to severe vision loss. The understanding, detecting, diagnosing, and managing of strabismus can be tough, considering the low emphasis on strabismus teaching in ophthalmology curricula. There are numerous studies have specifically assessed the effectiveness of VR in Ophthalmology such as VR and ophthalmologic teaching [2, 3], VR and eye disorders screening [4-7], VR and surgery [8-11], etc. VR as an innovative tool has been used in nearly all aspects related to strabismus, but the literature on the use of VR in strabismus is rarely seen. However, there is a lack of detailed review to focus on VR application in strabismus, the paper aims to combine the VR technology and strabismus to further discuss recent research related to this area.

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II. MATERIALS AND METHODS

Literature searches were performed mainly in PubMed, Embase, and Google scholar from January 1, 2007 through April 2022 without publication restriction, the key words used as search terms were: "Virtual reality", "simulation", "strabismus"," amblyopia", "ophthalmology", "ophthalmic", "eye", "3D", "teaching"," learning", "screening", "detection", "diagnosis", "vision therapy", "vision training", "surgery" and etc. Endnote20 (2022; Clarivate Analytics) was used to all identified publications and remove duplicates.

2.1 Virtual Reality Technology

Virtual reality technology is a computer-generated environment that appears to be real to the experiencer, it gives users the perception of being in an immersive, interactive, present, relatively safe, and simulated environment that is otherwise impossible or difficult to experience in the real world. Virtual reality software is combined with hardware to build immersive 3D environments, it relies on the use of headsets and controllers to enable interaction with the virtual world. Virtual reality plays an important role in all fields of medicine, in a variety of applications like medical education, surgical training, physical therapy, rehabilitation, overcoming psychological problems, etc.

2.2 VR Application in Strabismus Teaching

The eye is one of the most complex organs of the human body. The anatomy of extraocular muscles is the basis of strabismus teaching, cadaver dissection and prosection is perceived as the "gold standard" in anatomy teaching, the benefits of cadaveric dissection could be limited due to the small size of the eyeball. Otherwise, the use of cadavers in anatomy teaching of the eyeball has very limited application because of the problems of preservation, cost, and ethics, Therefore, the traditional sources of extraocular muscles anatomy mainly rely on graph or plastic models. it is not surprising that various extraocular muscles with their functions confused the majority of students, and most of them are trapped by this subject without active learning tools [12]. To date, Virtual Reality offers a new to hyper-accelerate teaching in a way never before imagined by man. It enhances anatomy teaching in a simulated 3D environment which allows students to explore the human anatomy at their own pace, reviewing and reinforcing complex spatial relationships of anatomical structures like muscles, bones, nerves, arteries, veins, and organs [13]. At present, there are a few high-cost products of virtual reality educational tools for anatomy which is popular on the market such as the anatomy of the eye on EON-XR produced by Eye sim, EON Reality Inc. Chinese researchers such as our group have developed a toolset of VR teaching software including extraocular anatomy on our own (Fig 1)

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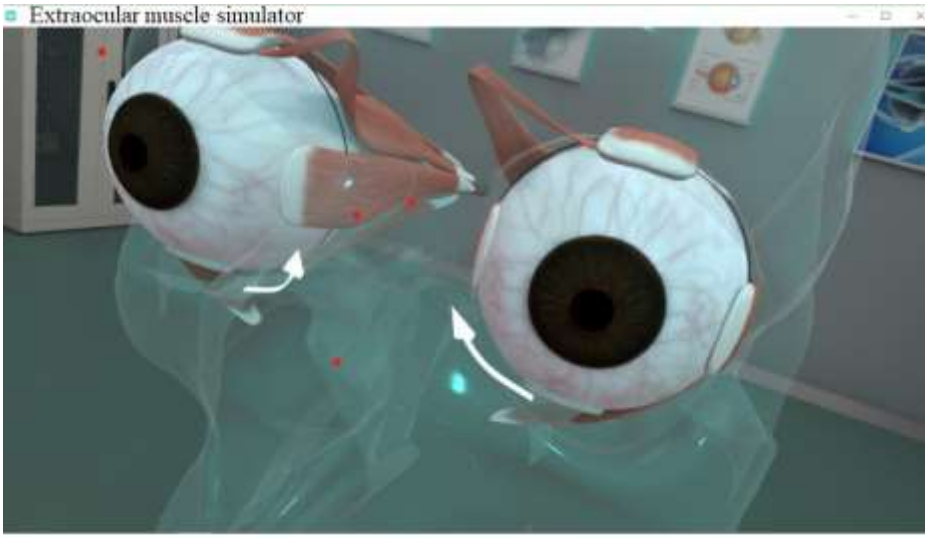

Fig 1: VR software interface of extraocular muscle anatomy

With the innovative learning tool, Students could not only gain a better understanding of vivid, realistic scenes of subtle structures but also may rotate, zoom in(out), and pull in(out) the simulated 3D model of the eyeball to visualize any inner structure (Fig 2).

Fig 2: Extraocular muscle VR-based system operation

Multiple papers estimated that compared to the traditional tool, the effectiveness of VR teaching in the anatomy teaching area is satisfactory [12-14].

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2.3 VR application in Strabismus Screening and Diagnosis

Amblyopia from strabismus occurs when vision loss happens during childhood because the eyes are not aligned. Most kids with strabismus are diagnosed when they're under 6 years old [15]. The earlier diagnosis and intervention are extremely significant for improving vision outcomes and psychosocial health of the patient with strabismus, however, require prompt screening and skilled detection. The strabismus screening and diagnosis can be inherently challenging, considering complex theory or a lot of skills deeply rooted within strabismus, not to mention the cooperation problems of children [16]. For improving diagnostic and prognostic accuracy in strabismus, one research [17] emphasizes the usefulness of virtual reality-based training for ophthalmology residents. The study recruited 14 ophthalmology residents to accept VR training in diagnosing strabismus. The participants could perform cover-uncover, alternated cover, and prism cover tests to detect virtual patients with all kinds of strabismus under simulated environments. By comparing the accuracy score and performance score before and after virtual reality-based training, it concluded that VR-based training would be beneficial to improving physicians' diagnostic skills for strabismus.

Some research aimed to explore the efficiency of VR technologies in detecting strabismus misalignment directly [18-23]. Although the VR techniques, comparison techniques, and investigated measures are various, all the researches mentioned in Table I. This shows that VR-based technology may be promising in the evaluation of ocular alignment. Especially, it should be noted that HTC VIVE Pro Eye (Taiwan) with integrated eye tracker adopted in the three recent studies [20] [21, 23], may disclose the great potential of HTC VIVE Pro Eye (Taiwan) in the application of strabismus screening even other ophthalmic screenings.

TABLE I. VR detection for strabismus

Subjects	VR technique	Comparison technique	Investigated measure	Conclusions	Year
40 healthy subjects	A hemispherical visual display system named CyberDome	Major amblyoscope	The subjective angle of strabismus; motor fusion amplitude; stereopsis	A good correlation($P<0.0001$) was manifested between CyberDome and major amblyoscope	2009[22]
3 patients with ocular misalignment	Oculus Rift (commercial version, 2016) virtual reality headset	Traditional Lees screen test	Horizontal and vertical deviation	The misalignment results obtained using the VR test showed agreement with that obtained from Lees's screen across a range of common pathologies.	2017[19]

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17 patients	FOVE VR device	prism cover test by doctors	Ocular deviation	The test results from the VR device were agreeable with the results from doctors' measurements. (mean difference less than 0.7°)	2020[18]
14 healthy participants	HTC VIVE headset	Nine lines of sight	Ocular deviation; Panum's Fusion area	The mean absolute error of the system demonstrates similar results for left and right eyes, strabismus measurement is possible within the extent of Panum's Fusion area	2020[23]
38 patients with strabismus	Vive Pro Eye with an eye-tracking system	Alternative prism cover test (APCT) conducted by physicians	Ocular deviation	An intraclass correlation coefficient of ocular deviation angle is 0.897, Thus, a VR-based device could provide measurements with near excellent correlation with the APCT.	2021[20]
38 strabismus patients	HTC VIVE Pro Eye with an integrated eye tracker	Monitor-based Hess screen test	Ocular deviation from Hess Screen Test	Compared to the monitor-based methods, the results from VR-based methods showed significantly higher measured deviations.	2021[21]

Besides, strabismus is relevant to binocular vision function loss [24], meanwhile, some patients with strabismus occur amblyopia[25], To our knowledge, there are three pieces of research with VR applications related to those fields[26, 27]. One study applied a new VR-based method to quantify the extent of suppression during dichoptic image recognition tasks [26], and the other study introduced a laptop computer connected to a pair of virtual reality goggles to measure suppression in amblyopia [27]. The third study [28] manifested that a binocular imbalance test in a virtual reality headset is feasible and reliable. All the studies above showed the great potential of VR-based technology in binocular functional tests that it may offer the diagnosis of the existence of binocular function loss but also the extent of binocular function loss.

2.4 VR Application in Strabismus Treatment with Vision Therapy

The conventional treatments of strabismus may include optical prescription (glasses or prisms), eye muscle surgery, and occlusion. Recently, more and more researchers are fascinated by the clinical role of vision therapy in strabismus [29]. Compared to irreversible surgery, unsustainable occlusion, as a non-invasive method, vision therapy brings hope to parents who have a child with strabismus. Some

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researchers claim that Vision therapy for strabismus treatment helps reduce or correct eye misalignment and trains the brain to simultaneously use both eyes to merge the images seen by each eye into a single 3D piece of information. Conventionally, Vision therapy consists of personalized exercises that make use of lenses, prisms, filters, etc. multiple tools. Nowadays, vision therapy has stepped into the VR era [30], and most VR-based vision therapies are designed by serious games [31]. Five representative studies were chosen to show the implementation of VR-based vision therapy in strabismus with or without amblyopia (Table II). We could easily find out that: All the studies gain positive results with using VR-based vision therapy in strabismus. However, the number of subjects involved in relative studies is small; VR systems and comparison techniques used in these studies are various; the investigated measures are different during these researches; few studies conduct a comparison of VR-based vison therapy and conventional therapy. It reminds researchers that the study of VR-based vision therapy in strabismus may need further standardization in some ways, or we could hardly gain a reliable conclusion about the efficacy and usefulness of VR-based vision therapy in strabismus.

Table II. VR-based vision therapy in strabismus

Subjects	**VR technique**	**Specific treatment**	**Comparison technique**	**Investigated measure**	**Conclusions**	**Year**
6 patients (3-7years old) with anisometropia or(and) strabismus	Interactive Binocular Treatment system	Watching video clips and playing interactive games	Vision acuity comparison between Pre-treatment and post-treatment	Vision improvement	Initial vision in the amblyopic eye ranged from 6/12 to 6/120 and post-treatment 6/7.5 to 6/24-1	2006[32]
22 strabismus patients (8-35 years old)	Google Cardboard	games	Not mentioned	Efficacy equals strabismus and amblyopia didn't return after treatment	95.5% was effective	2018[33]
25 patients with intermittent exotropia (5-39 years old)	Dichoptic visual neuroplasticity training based on a VR platform	Computer-controlled perceptual examination evaluation	Eye position and stereopsis comparison between	stereopsis and eye position improvement	The horizontal perceptual eye position was much lower than those pretraining	2018[34]

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			Pre-treatment and post-treatment		(P=0.018)	
45 students (17-28years old)	Conventional visual therapy based on a VR platform	Brock cord; approach technique; convergence and divergence	Not mentioned	User experience questionnaire	VR application has a minimum score of "Good", and in 67% of the categories, a score of "Excellent" was achieved.	2019[35]
A 21-year-old man	the VR system (RemmedVR Sp. z o.o., Poland)	Intensive anti-suppression and stimulating stereopsis train ing	Cover test; worth 4 dots; NPC; vergence range; stereopsis results were compared before and after VR system training	Improvement of stereopsis	contour stereopsis – Wirt circles (60") compared to that of the pre-training (contour stereopsis – Wirt circles (400"))	2021[36]

Because amblyopia is one of the main consequences of strabismus, it is reasonable to pay attention to the studies about amblyopia therapy based on virtual reality. There is a huge number of researches investigated the use of visual rehabilitation with the potential of using serious games combing perceptual learning and dichoptic stimulation [37-42], visual acuity improvement is manifest in each paper, still, there are few studies to explore the efficacy between the innovative technology and conventional vision therapies. Furthermore, some children may fail to complete VR dichoptic treatment due to their young age should be highly noted [43].

2.5 VR Applications in Strabismus Surgery Training

Residents were always demanded to accept optimal surgical skill enhancement during the stipulated time in ophthalmologic training programs so that they could better adapt to their routine work. Due to easy access, surgical simulation has often been emphasized in animal eyes always. However, surgical skill enhancement on animal eyes in strabismus is rarely discussed, it is not only because of the complex anatomy of extraocular muscles but also because the routine harvesting of animal eyes for ophthalmic

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surgeries usually does not includes the extraocular muscles. Surprisingly, more and more ophthalmic surgery simulators were adopted in physician training. The EyeSi Surgical Simulator (VR magic, Mann-Heim, Germany) is the predominant simulator applied for ophthalmic surgery training. There was an abundance of studies that have shown the efficiency of training with Eyesi Surgery compared with conventional training. The Eyesi platform can be equipped with interfaces for cataract and vitreoretinal surgery but strabismus surgery relevant to extraocular muscles. Only one research introduced a virtual surgery of extraocular muscles based on gesture interaction, This study showed mapping five kinds of gestures into the performing surgery on the virtual surgery platform of extraocular muscles in the laboratory, The application possibility of the extraocular muscle virtual surgery system into the real situation of surgery was hinted during the research.

Heads-up surgeries involving 3D cameras with the 3D display were broadly used in other surgical fields, most users preferred heads-up surgery to conventional surgery. Unfortunately, there is little research on utilizing VR programs for strabismus surgical guidance directly.

2.6 Challenges of VR Application in Strabismus

From current research, we could find out that the VR application in strabismus is at the starting point. The number of relevant researches isn't vast, the subjects in VR application research are small, the VR technology platforms are various, nearly no paper about the comparison of VR technology and conventional technology, so the evidence is obscure to support the efficiency or usefulness of VR application in strabismus practice. Even the VR application in vision training relevant to strabismus which involves the most evidence needs for additional high-quality comparative studies. In general, the VR application in strabismus needs to be further explored within all related fields due to the lack of evidence.

In addition, there are adverse effects of VR application which is called "cybersickness", which evolves in subjective symptoms such as dizziness, headache, motion sickness, and objective influence in accommodation, convergence, refractive errors, and tear films. Some evidence suggests that 60–95% of participants experience some level of CS during exposure to a virtual environment. The exact mechanism of cybersickness is uncertain, the main theories to explain that include Sensory conflict, eye movement, postural instability, and differences in virtual and physical head pose theories. As strabismus mainly occurs in children aged 6 to 72 months [25], Considering the potential risks brought by VR application to people(especially to children), some researchers suggested that more long-term standardized research is needed to ascertain if these adverse effects will significantly affect the efficacy and usefulness of strabismus application.

Furthermore, the cost of VR technology application in strabismus will also be a major concern for extended unity. The complexity and cost of VR have made it difficult for numerous potential users to emerge. Luckily, technological advancement in computer science almost always results in the reduction of expense over time, and so one can predict that high price isn't likely a long-term concern.

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III. CONCLUSION

This paper presented a literature review on the implementation of virtual reality technology in strabismus. We highlighted the potential use of VR application in teaching, clinical examination, screening and diagnosis, vision therapy, and surgery related to strabismus, meanwhile, we exemplified those 3 main barriers of VR application in strabismus that need to be addressed: lack of high-quality evidences, cybersickness, and cost issue. Although there are limitations in present VR technology, we are optimistic that as reality technologies improve in hardware and software, strabismus will eventually gain benefit from the widespread adoption of this technology in practice.

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