Virtual Reality Technologies Supporting Screening Oculomotor Problems

Subjects: Others

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Oculomotor dysfunctions (OMDs) are problems relating to coordination and accuracy of eye movements for processing visual information. Eye-tracking (ET) technologies show great promise in the identification of OMDs. Virtual Reality (VR) and ET technologies emerged in the field of vision science, integrating built-in eye trackers into head-mounted displays (HMDs). Therefore, today, VR has the potential to be an effective tool in complementing the treatment of a variety of vision disorders requiring ET technologies for identification or treatment, e.g., treating amblyopia and convergence insufficiency.

eye-tracking | head-mounted display | oculomotor dysfunction | funtional vision problems

1. Introduction

Eye disorders are reasonably frequent among the population. Many common problems can be identified by visiting clinical experts, e.g., ophthalmologists, orthoptists, or some clinical specialists in vision, and corrected with eyeglasses or surgery. However, vision problems can occur even if the eyes seem normal, and the results from the usual vision tests (e.g., visual acuity assessment, refraction for eyeglass prescription, or examination of the anterior and posterior segments of the eye) do not show vision disorders [1][2]. Some people may have problems processing visual information, addressed in this paper as functional vision problems (FVPs). These problems, also called functional visual disorders or functional vision impairment, refer to disturbances that cannot be explained by structural or physiological abnormalities of the eyes. Many of these conditions are characterized by a mismatch between the diagnosed eye health and the visual problems experienced by the individual. These sight disturbances hinder one from clear vision and problems, e.g., for reading, experiencing blurry vision, correctly estimating distances, headache, or balance problems. FVPs are common, especially in stroke patients (up to 92%) [3][4][5] or in adults suffering from brain injury (60–85%) [6]. Not diagnosing FVPs can have negative consequences, especially for children who do not necessarily realize and report their problems and are not given the usual vision testing at the ages of 5–7 [7].

Oculomotor dysfunction (OMD) is an FVP related to problematic coordination between the left and right eye. Approximately 17–30% of children with vision problems have such problems [8], which can lead to more severe vision disorders if not treated correctly [8] and can be considered a societal problem that cannot be solved with current resources due to the limited number and capacity of vision professionals [7][9].

Utilizing eye-tracking (ET) technologies shows great promise in the identification of OMD [10]. These ETs are integrated or attached to laptop systems and, based on recording a person's eye movements, separately for both eyes for a period of time, help professionals assess if the person has or does not have OMD-related vision problems. Due to the limited screen size and the inability to measure depth accurately, essential issues for a complete vision screening, these solutions have inherited limitations. Measuring basic eye movements helps professionals understand how a person can focus on objects (measuring fixations), follow objects with their eyes (measuring smooth pursuits), or how their eyes jump from one object to another. Since the movements from both eyes can be measured separately, and process information on visual stimuli can also be measured, this can provide an effective solution for examining FVPs related to eye coordination. There are already validated solutions on the market offering ET and laptop-based measures to professionals engaged in screening FVPs [11]. Supporting screening via technology is essential since vision screening should be based on objective measures and take less time. A complete vision screening, including screening for OMDs, takes more than one hour [11], and only a few professionals are educated to perform this.

Immersive VR technologies, e.g., HMDs, Hololenses, and VR rooms, allow users to interact directly with surrounding computer-generated 3D graphics, with the possibility of achieving higher user experiences and increased presence [12][13]. Medical VR applications take advantage of the technology's ability to elicit emotional responses and convey spatial information [14][15]. Since VR equipment allows experiencing a larger field of view (FOV) and depth, the hypothesis behind this work is that VR can add to future vision screening batteries. Until now, people are not aware of research or practice utilizing VR equipment for vision screening. This may be evident due to the main limitations of VR to exactly measure ocular movements and positions, e.g., handling "binocular disparity is a critical stimulus to vergence, which is a critical depth cue" making sure the eyes "are always focused on a single depth", which implicates loss of focusing and is accommodated in a current review [16] considering ET in VR.

2. VR Technologies Supporting Screening Oculomotor Problems

VR provides a surrounding experience by simulating a real-world environment with the help of technologies and users can be surrounded by 3D projection in a room. For example, in a head-mounted display (HMD), when the user is wearing special glasses, allowing them to see 3D projections around themselves [17]. Immersion, as defined in the literature, refers to the characteristics of technology that allow experiencing this 3D environment in space, not only on a 2D surface. Accordingly, an HMD is an immersive technology and a laptop is not. Presence refers to experiencing being physically present in a computer-generated application, and the interaction in it can be as believable as the interaction in the non-mediated conditions [12].

Immersive VR has gained significant attention from researchers due to allowing a larger field of view than a laptop, enabling more natural interaction, for example, with the hand, head, or body tracker with a computer-generated environment and built-in eye tracker for gaze recording. For enabling high presence or distracting users from painful or boring situations, VR is appreciated in various fields, from experiencing new architecture (e.g., [18]), training for emergency (e.g., [19]), or education (e.g., [20]). Medicine utilizes VR technologies to train to be prepared for surgery (e.g., [21]), pain management (e.g., [22]), anatomical education (e.g., [23]), or the treatment of psychiatric disorders (e.g., [24]). A current review examining the production of studies focusing on immersive VR in medicine questioned and enhanced this popularity by the large number (2700) of published studies, only in the last year in PubMed [14].

In recent years, VR has integrated ET technologies and emerged in the field of vision science, integrating built-in eye trackers into HMDs [16]. Therefore, today, VR has the potential to be an effective tool in complementing the treatment of a variety of vision disorders requiring ET technologies for identification or treatment, e.g., treating amblyopia [25] and convergence insufficiency [26]. VR and augmented reality (AR) are used for treating strabismus [27], amblyopia, and retinal diseases [28].

One of the most important eye problems to identify is amblyopia, or lazy eye, caused by three main factors: unequal refractive powers in both eyes (anisometropia), misalignment of the eyes (strabismus), and visual axis obstruction (deprivation) [29]. These factors lead to reduced vision in one eye due to the brain favoring the other eye or receiving insufficient visual input. Black et al. [30] performed a clinical test to measure amblyopia using virtual reality glasses where the amblyopic eye is exposed to stimuli with high contrast, while the stimuli shown to the non-amblyopic eye have varying contrast levels. Patients engage in a signal/noise task, enabling precise evaluation of excitatory binocular interactions.

Several research studies have investigated the use of VR with eye trackers to detect ocular deviation angles in strabismus. This approach offers advantages over traditional methods used for measuring ocular deviation, including the Krimsky test, the alternative prism cover test (APCT), and the simultaneous prism cover test [31]. Economides et al. [32] investigated the use of VR and ET in strabismus patients with ocular deviations ranging from 4.4° to 22.4°. Strabismus severity is determined by the magnitude of ocular deviation, which can be quantified using numerical values. These numerical measures serve to express the extent of misalignment in strabismic individuals [33]. The findings from this research showed that the fixating eye of patients with strabismus exhibited greater variability in position compared to the fixating eye of individuals without strabismus.

Laptop technologies, in general, and for a longer time, showed promise in complementing the treatment of amblyopia, strabismus, binocular vision disorders, and visual field deficits [34][35]. However, although developing associated algorithms and analyzing gaze measurements from ET data for fixations and saccades are available, more exact measurements are needed for better confidence in the results both for laptops and VR [10].

VR systems do not aim to reproduce an experience as realistic as in films or fiction; the experience and presence in the environment, and knowing how to react to the events, are important. Working with the technology, where the technology itself is hidden and goes away for the good of the application, is significant for increased user engagement, motivation, and enjoyment [17]. Since experiencing presence can be considered an added value for VR technologies, many tests aim to collect measurements about presence. These tests can be performed by addressing user opinions, e.g., by observations, questionnaires, or interviews, but also by trying to make sense of a user's action in the environments, e.g., by sensing technologies such as ETs or EEGs and finding more objective measures for presence.

Given the high prevalence of vision problems in the general population, functional vision screening is important for early detection and timely treatment, which can significantly improve visual outcomes and quality of life [7][36][37]. The literature also shows that using serious games increases motivation for learning or performing tedious, repeated, or painful activities, for example [38][39].

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