Usefulness of Virtual Reality-Based Training to Diagnose Strabismus

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Abstract

Purpose: To study the usefulness of virtual reality (VR) based training for diagnosing strabismus

Methods: Fourteen ophthalmology residents performed at least 30 VR training sessions to diagnose esotropia and exotropia. Examinations of real patients with esotropia or exotropia before and after the VR training were video-recorded and presented to a strabismus expert to assess accuracy and performance scores for measuring the deviation angle and diagnosing strabismus with anonymization. A feedback survey regarding the usefulness and ease of use of the VR application was conducted for participants.

Results: The mean age of 14 ophthalmology residents, including 10 men and 4 women, was 29.7 years. Before VR training, participants showed a mean accuracy score of 14.50 ± 5.45 and performance score of 9.64 ± 4.67 for measuring the deviation angle and diagnosing strabismus in real patients with strabismus. After VR training, they showed a significantly improved accuracy score of 22.14 ± 4.37 ($p = 0.012$) and performance score of 15.50 ± 1.99 ($p = 0.011$). According to the survey, most participants agreed on the usefulness of VR application.

Conclusions: This study suggests that VR based training improves ophthalmology residents' clinical diagnostic skills for strabismus in a short period.

Introduction

The deviation angle measurement and accurate diagnosis of strabismus require extensive experience. The incidence of strabismus is high among children; therefore, appropriate diagnosis and treatment are necessary to prevent worsening of strabismus and subsequent sequelae such as amblyopia.

However, children cannot easily concentrate during strabismus examination, and physicians may be unable to cannot easily measure the deviation angle or determine the type of strabismus or fusional ability. Additionally, children and their parents may complain of discomfort related to the educational clinical practice of students or residents, thereby adversely affecting the doctor-patient relationship.[1] Parents often want the consultation of specialists for strabismus. Therefore, the opportunity to examine and diagnose strabismus has been decreasing for ophthalmology residents and remains minimal.[1,2] Further, the coronavirus disease 2019 (COVID-19) pandemic has significantly impacted residents' practical training, underscoring the need to promptly include new technology-based training tools, such as web-based teaching, virtual surgical simulators, and telementoring in resident education.[3–6]

To date, methods such as practice-based learning, problem-based learning, team-based learning, and e-learning have been used to train medical specialists. In recent years, virtual reality (VR) and augmented reality (AR) simulation training have also been utilized, focusing on various medical fields. Advancements in VR represent some of the newest modalities being integrated into ophthalmologic practice and resident education, and the importance of incorporating simulation in resident education and skills assessment is increasingly emphasized.[7] The VR technology has also been actively used in the field of ophthalmologic surgical training. The VR simulator has been developed for cataract and vitreous surgery training, and many studies have reported its efficacy.[8–11] In the fields of strabismus and pediatric ophthalmology, a few studies using VR technology have been reported. VR programs could improve the visual acuities of children and adults with amblyopia and reduce the deviation angle in patients with intermittent exotropia.[12–14] However, VR applications have not been developed to train residents for diagnosing strabismus.

We developed a VR application for diagnostic training of strabismus that could measure the deviation angle and diagnose strabismus using the head-mounted display (HMD) and VR technology. This study was aimed at investigating the usefulness of VR application as a training tool for ophthalmology trainees in the clinical strabismus field.

Methods

VR application for diagnostic training of strabismus

The VR application was created based on the Oculus Rift (Oculus VR, LLC, Irvine, USA), the VR HMD, Oculus Touch (Oculus VR, LLC, Irvine, USA), wireless haptic controllers, and a computer running Windows 10 (Microsoft Corporation, Redmond, WA, USA).

The Oculus Rift HMD device was equipped with a liquid-crystal display (5,7" diagonal, resolution of 1,280 × 1,440 pixels per eye), with a 110° field of view, mounted with an accelerometer, a gyroscope, and a magnetometer sensor for the positional tracking system. Oculus Touch controllers were peripheral accessories of the Oculus Rift and were employed to track the user’s hand position and orientation in a 3-dimensional space. The HMD device and controllers were connected to a PC system.

A simple user manual has been prepared to help using this VR application, and tutorials are also included in the application (Fig. 1). Users could use controllers to select and set the desired type of strabismus in the virtual environment. Thus, they could perform clinical tests and observe ocular motility in various strabismus types, such as horizontal, vertical, paralytic, and specific strabismus.

In a VR environment, similar to an outpatient clinic, the strabismus patient is sitting looking at a distant object, and the user is facing the patient from the right side. Furthermore, a virtual occluder and prisms with a spacing of 5 prism diopters are placed step by step on a virtually implemented table. The users could use the controllers to operate the virtual instrument. We also implemented cover-uncover, alternate cover, and prism cover tests to allow users to measure the patient's deviation angle (Fig. 2). In virtual patients with exotropia and esotropia, the non-dominant eye moves for fixation when the dominant eye is covered. In contrast, the dominant eye does not move when the non-dominant eye is covered. In the alternate cover test, an ocular movement is made such that the type of strabismus could be distinguished. Furthermore, when the users perform the prism cover test, strabismus decreases but persists when a smaller prism than the patient’s deviation angle is applied. In contrast, when a prism larger than the virtual patient's deviation angle is applied, the eye moved in the opposite direction. And then, when using a prism matching the patient's deviation angle, no ocular movement is ascertained use (see **Supplementary Video S1** online).

Study design, setting and participant

All participants provided written informed consent. The study complied with the tenets of the Declaration of Helsinki. The Institutional Review Board of the Chonnam National University Hospital approved the study protocol. This study followed the Standards for Quality Improvement Reporting Excellence Strengthening the Reporting (SQUIRE) guidelines for pre-post quality improvement study.

A total of 14 ophthalmology residents volunteered in this study from the Chonnam national university hospital of South Korea between March 30, 2020, and July 31, 2020. Exclusion criteria were strabismus, previous ocular surgery, and ocular media's opacification, including cataract and active ocular disease. The same person (H.S.M.) instructed participants with a brief standardized instruction on using this VR application, including a manual, tutorials of each module, and information about controlling the virtual occluder and prisms.

Participants carried out examinations on 3 real patients with esotropia or exotropia before and after 30 sessions of VR training. The interval between examinations on real patients and VR training was limited to a maximum of 2 weeks. Each session of VR training lasted at least 5 minutes, and participants were recommended to perform 30 sessions in 2 weeks. In each session, they performed at least one ocular motility examination, cover-uncover test, alternate cover test, and prism cover test on virtual patients. The virtual patient's strabismus settings were limited to esotropia and exotropia between 20–40 prism diopter.

Evaluation

Procedures were video-recorded and anonymized. After completing the process, videos were presented to the strabismus specialist (H.H.) in random order. The primary outcome measure was participants' accuracy and performance scores, measured by a predetermined scoring standard, which comprises specific procedures. Assessments of accuracy and performance scores included 4 procedures. A deviation angle and diagnosis report of the participant were included only in the accuracy score (Table 1). The performance score was evaluated on a scale of 1 to 5, where 1 meant "Poorly performed" and 5 meant "Performed well" (Table 2). Subsequently, participants completed a feedback survey on the usefulness and ease of use of the VR application. Participants were asked to quantitatively rate their perceptions of the VR application on a scale of 1 to 5, where "1" meant "Disagree" and "5" meant "Agree" (Table 3).[15]

Table 1
Accuracy score rating standard of the diagnostic procedure for strabismus

Procedures	Items to check	Score
Ocular motility examination	Using the instrument (1) Specifying the target (2) Checking the oblique muscles (2)	5
Cover–uncover test	Occlusion skill (5)	5
Alternate cover test	Occlusion skill (5)	5
Prism cover test	Prism-applying skill (3) Occlusion skill (2)	5
Diagnosis report	Accuracy of identifying the dominant and non-dominant eye/direction of deviation (3) Measured deviation angle (3) Strabismus diagnosis (4)	10
Total score		30

Table 2
Performance score rating standard of the diagnostic procedure for strabismus

Procedures	Grade				
	Poorly performed		**Performed with some errors or hesitation**		**Performed well**
Ocular motility examination	1	2	3	4	5
Cover–uncover test	1	2	3	4	5
Alternate cover test	1	2	3	4	5
Prism cover test	1	2	3	4	5
Total score					20

The performance score was evaluated on a scale of 1 to 5, where 1 meant “Poorly performed” and 5 meant “Performed well”.

Table 3
Results of virtual reality application experience survey from participants

Questions	Mean value
Perceived usefulness	
The application improves my understanding of the processes involved in the diagnosis of strabismus.	4.43 ± 0.49
The application improves my strabismus inspection ability.	3.86 ± 0.64
The application made it easier to observe the anomalies related to ocular position and movement.	4.14 ± 0.35
The application will give me the confidence to perform this task on a person in the future.	3.86 ± 0.64
Average mean score	4.07
Perceived ease of use	
Learning to use the application would be easy for me.	3.57 ± 1.18
I find it easy to control virtual examination tools.	3.71 ± 0.70
Average mean score	3.64
Participants' perception of virtual reality applications was quantitatively evaluated on a scale of 1 to 5, where 1 meant “Disagree” and 5 meant “Agree”.	
Data are expressed as mean ± standard deviation unless otherwise indicated.	

Statistical analysis

Statistical analysis was performed using SPSS Statistics for Windows version 18.0 (IBM Corp., Armonk, NY, USA). Data are presented as mean ± standard deviation. The paired *t*-test was used to compare changes in accuracy and performance scores before and after the VR application training. A p-value < 0.05 was considered to be statistically significant.

Results

A total of 14 ophthalmology residents, including 10 men and 4 women, with a mean age of 29.7 years (range, 26–34 years), were enrolled in this study. No participants were excluded. The mean corrected visual acuity of participants was 0.00 LogMAR, and the mean stereoacuity with the Titmus Stereo test (Stereo Optical Co., Inc., Chicago, IL, USA) was 40 seconds of arc. When examining three real patients with strabismus before VR training, participants had a mean accuracy score of 14.50 ± 5.45 and performance score of 9.64 ± 4.67. After 30 sessions of VR training for 2 weeks, participants again examined three real patients with strabismus and showed an accuracy score improved by 53% to 22.14 ± 4.37 ($p = 0.012$) and a performance score improved by 61% to 15.50 ± 1.99 ($p = 0.011$) (Fig. 3).

On a 5-point rating scale, the overall score was 4.07 for the usefulness of the VR application and 3.64 for the ease of using the device and VR application (Table 3). Most participants agreed on the usefulness of the VR application, while some participants had a neutral opinion.

Discussion

VR application for diagnostic training for strabismus could improve the accuracy and performance of residents' skills to diagnose strabismus after performing only 30 sessions for 2 weeks. The analysis of the recording of participants' examination on real patients with strabismus revealed that the participants' skills of holding prisms, placing the occluder, and performing cover-uncover and alternating occlusion improved after VR training. Furthermore, the time required to measure the deviation angle was lesser compared to that in previous VR training. Participants trained by applying a virtual occluder and prism to virtual patients, such as in the cover-uncover, alternate cover, and prism cover tests, which are essential tests to diagnose strabismus. Thus, users could determine both the type of strabismus and the angle of deviation. Although our VR application includes other vertical, incomitant, or specific strabismus, our study was limited for participants to perform VR training with virtual patients with exotropia and esotropia, which were implemented with various angles of deviation to assess the accuracy of the measured angle.

Studies regarding VR simulators and programs related to ophthalmic examination, treatment, and education have been reported. Tsapakis et al.[16] developed a VR-based visual field (VF) test and reported that the results significantly correlated with the previous Humphrey VF examination results for glaucoma patients. Unlike previous studies, Nakanishi et al.[17] developed a VF test device measuring a multifocal steady-state visual-evoked potential by combining an electroencephalogram and electrooculogram with a VR device. As for the treatment, Sayed et al.[18] reported the expansion of peripheral VF with VR spectacles by a customized algorithm to relocate and resize unseen peripheral targets within the remaining VF. Studies on the HMD technology for low-vision rehabilitation and vision enhancement have been conducted.[19] Additionally, studies on the treatment of amblyopia and binocular vision using VR technology have also been carried out, particularly to treat adolescents and adults, considering stability related to the weight and wearing of the device. Žiak et al.[12] reported that the mean best-corrected visual acuity of adult patients with amblyopia improved with dichoptic training. Li et al.[14] reported that the degree of strabismus and stereopsis improved with dichoptic visual training using a VR platform in patients with intermittent exotropia. Nesaratnam et al.[20] reported the first use of a VR headset in assessing ocular misalignment and demonstrated its feasibility as the dissociative test for strabismus. We have developed a system using HMD combining the eye-tracking technology and VR to measure the angle of strabismus with the principle of cover-uncover and alternate cover tests. We found that this system could identify ocular deviation with high accuracy and efficiency.[21]

Most reports on education using the VR technology were of cataract surgery training using VR simulators of Eyesi® (VRmagic, Mannheim, Germany), a representative cataract training simulator. Thomsen et al.[10] conducted cataract surgical training for surgeons with different levels of experience and reported that clinically relevant cataract surgical skills could improve with proficiency-based training using a VR simulator, particularly for novices and intermediate-level surgeons. McCannel et al.[22] suggested that VR surgical simulation training with the capsulorhexis intensive training curriculum on Eyesi® reduces the rate of errant capsulorhexis. Ng et al.[23] reported that residents who had completed the Eyesi® simulation training had greater confidence in performing tasks perceived to be the most difficult during phacoemulsification. In addition to surgical training, VR technology was used for training to perform other ophthalmic examination procedures. Wilson et al. developed the VR ophthalmoscope and reported that it could successfully simulate the processes involved in performing eye examinations.[15]

To our knowledge, this is the first study to apply VR for strabismus education for examination and diagnosis, not in the field of surgery, such as cataract surgery, which has been attracting attention in the field of ophthalmology. Resident training has not been easy or straightforward in the strabismus field, consistent with other fields. The process of accurately diagnosing strabismus is complicated and requires specialized skills. Opportunities have been poor for residents to examine patients with strabismus directly. Parents wanted the examination and treatment of their child to be performed only by skilled professionals, and in some cases, they refused the participation of residents in their child's surgery.[1] In such situations, this VR application, as in other aforementioned educational programs, could play a role in allowing residents to train their skills free from the burdens of space and time limitations and parents' rejection. Additionally, residents developed the confidence to examine and diagnose children with strabismus. Although the VR application in this study was aimed at ophthalmology residents, it could be beneficial for trained ophthalmologists to maintain or practice their skills.

An advantage of the VR application in our study was that the virtual patient's eyes could react to different virtual prism powers. When a prism larger than the virtual patient's deviation angle was applied, the eye moved in the direction opposite to that of the strabismus. Further, when using a prism matching with the patient's deviation angle, it was set that there was no ocular movement. This virtual patient's reaction could be applied to objective structured clinical examination or clinical performance examination for medical student education. An additional advantage was being able to train on the VR program without a simulator, such as for cataract surgery training, and only requiring an Oculus VR headset and wireless haptic controllers. Thus, learners could train without time and space constraints.

These VR applications could be a necessary alternative to traditional medical and surgical education during the current COVID-19 pandemic. The pandemic has profoundly influenced medical education, including that of ophthalmology residents, leading to changes in the long-term educational curriculum while upholding social distancing. Recent researches have demonstrated that the demand for new technical educational tools for web-based teaching, telementoring telemedicine, self-directed learning, and in-person clinical encounters, including VR simulators, has increased and so has its use in practice.[3–6]

A limitation of our study was the lack of a control group. It was not possible to conduct a randomized controlled trial because of the small sample size. It would have been optimal to randomize one group of residents to VR training while another one to no training or examine real patients with strabismus. It was challenging to control regular educational schedules for residents, and every resident could not examine 30 real patients with strabismus because many of them were children whose parents were reluctant to allow residents to examine their children. The lack of a control group leads to the risk of confounding and bias. To address this risk, we applied the generalizability theory to the before and after study design. The natural learning curve for regular education schedules for residents could affect the results as a confounding factor. We let them conduct VR training only for 2 weeks to remove this element. Additional limitations were the small number of participants and the inclusion of horizontal strabismus alone. Including more participants and various types of strabismus would have enabled multiple regression analysis, with the experience level and complexity of strabismus as variables. Currently, the virtual patient model is being improved through a continuous update of the application and VR environment to determine various strabismus types in addition to the disease entity. Moreover, a real-time evaluation mode should be developed within the VR environment in order to create a proficiency-based education program beyond repetitive and time-based education.

In conclusion, the results of our study suggest that the VR application for diagnostic training for strabismus could improve the accuracy and performance of examination skills of ophthalmology residents in the short term.

Declarations

Data Availability

The datasets generated during the current study are available from the corresponding author on reasonable request.

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Author Contributions Statement

HSM: study design and conception, data acquisition, data analysis and interpretation, writing manuscript, manuscript revision, final approval and agreement to be accountable. HJY: study design and conception.

SWP: study design and conception, manuscript revision. CYK, MSJ, SML, JHR: Administrative, technical, or material support. HH: study design and conception, data analysis and interpretation, writing manuscript, manuscript revision, final approval and agreement to be accountable. All authors reviewed the manuscript.

Additional information

The authors declare no conflicts of interest regarding any material discussed in this article.

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Figures

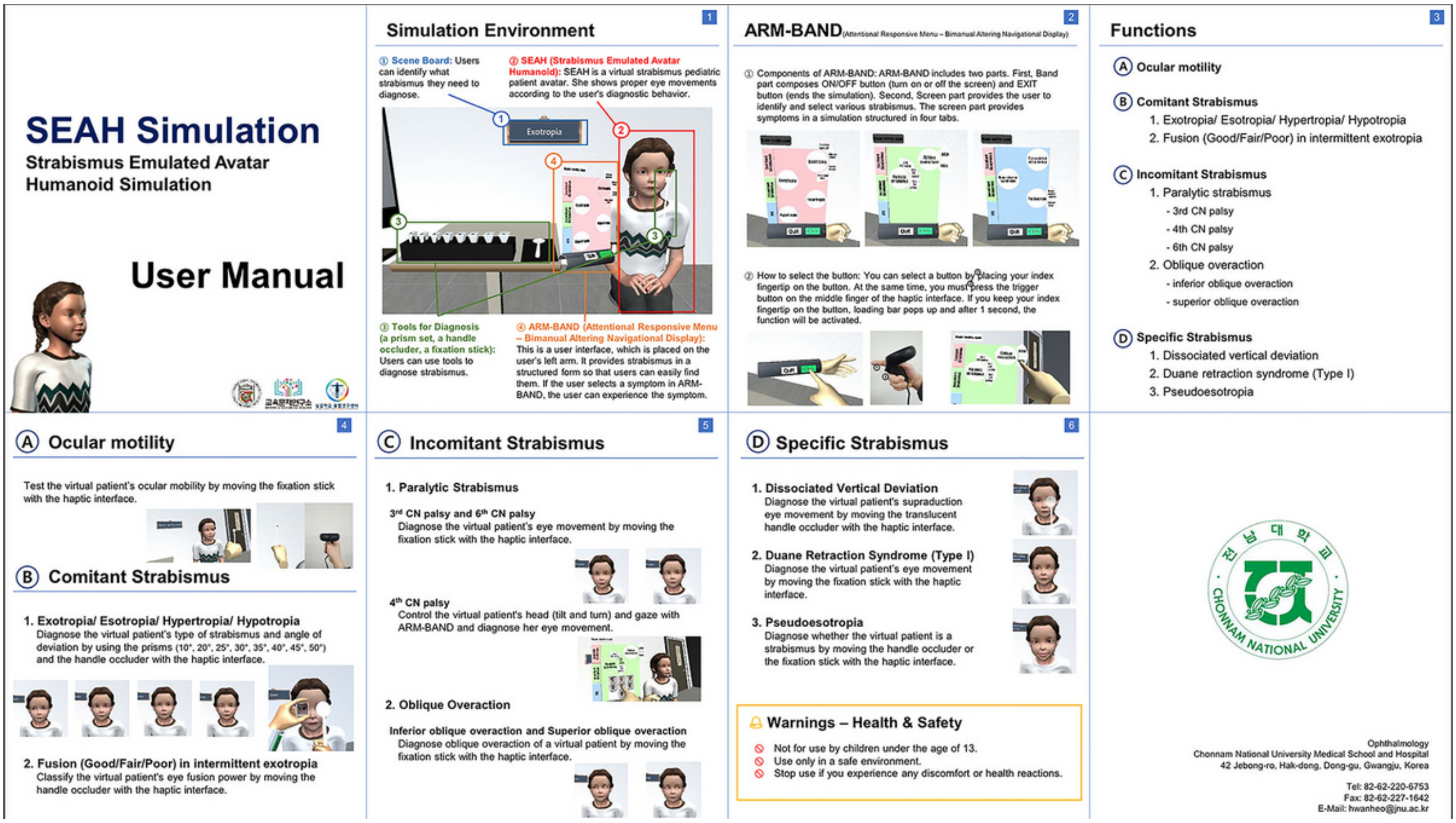

Figure 1

The user manual of the virtual reality application for diagnostic training of strabismus. The manual, which contains 8 pages, describes the simulation environment and the user interface implemented on the left wrist. The user interface provides lists of examinations that can be performed through simulation and how to carry them out.

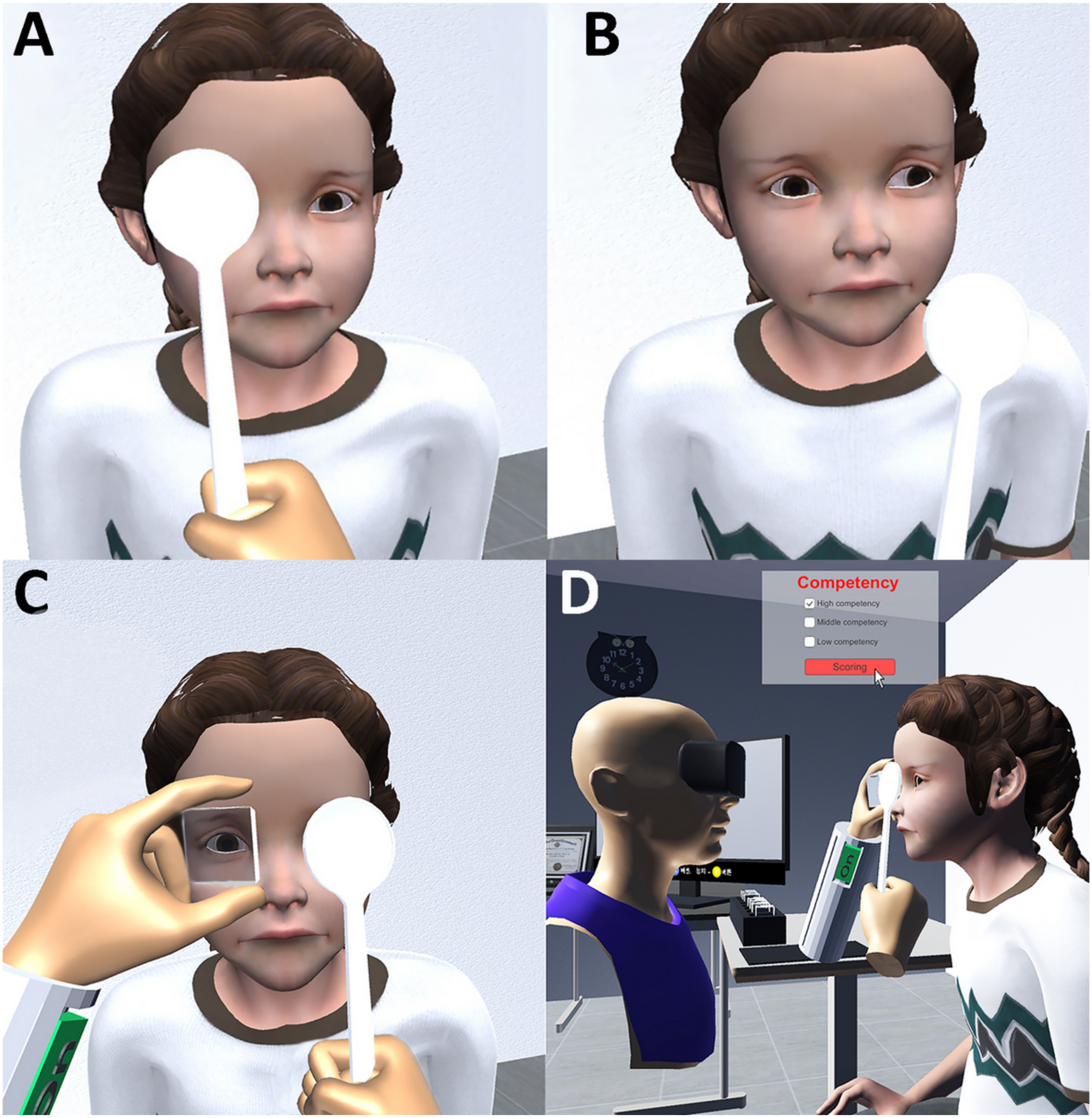

Figure 2

The virtual examination of virtual patients using an occluder and prisms implemented in virtual reality. (A, B) The cover-uncover test in a patient with left exotropia. (C) The prism cover test. (D) A user and a patient from the perspective of a third party.

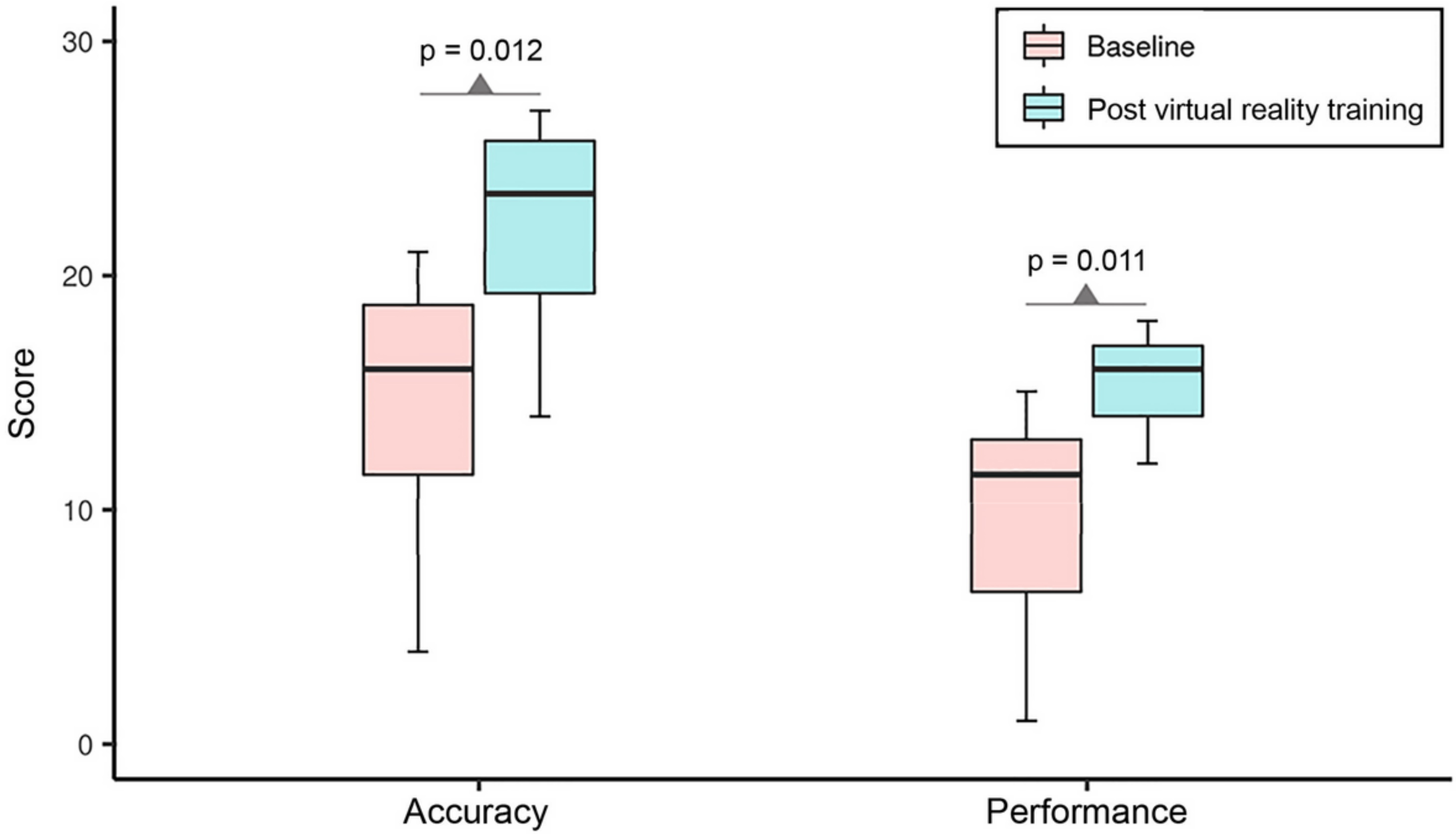

Figure 3

Comparisons of accuracy and performance scores before and after virtual reality training. After 30 sessions of virtual reality training for 2 weeks, participants' accuracy and performance scores significantly improved. (Total accuracy and performance scores are 30 and 20 points, respectively; The paired t-test was used to compare changes in scores).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryVideoS1.docx
- SupplementaryVideoS19.mov