

Virtual reality training improves accommodative facility and accommodative range

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Abstract

● **AIM:** To evaluate the effects of virtual reality (VR) training on different parameters of vision.

● **METHODS:** Sixty individuals ranged 18-60 years old with asthenopia were randomly divided into short-term ($n=40$) and long-term ($n=20$) treatment groups. They were given a specially designed VR training device only once for 15min or 3-4 times a day for 15min each time for 1mo. The visual acuity, spherical equivalent, accommodative range, accommodative facility, pupil size, and visual fatigue were evaluated before (control) and after VR training.

● **RESULTS:** The visual acuity, accommodative range, and accommodative facility increased in subjects of the short-term treatment group, whereas their pupil size contracted significantly. No significant changes in spherical equivalent and visual fatigue were observed. The changes in distant vision and corrected visual acuity were positively correlated with those in pupil size, but not with spherical equivalent. The accommodative range and accommodative facility improved significantly in subjects of the long-term treatment group. No significant changes in visual acuity, spherical equivalent, pupil size, and visual fatigue were noted.

● **CONCLUSION:** VR training can improve the accommodative range and accommodative facility of human eyes. Although short-term VR training can transiently improve vision, which probably due to bright light adaptation, there is no evidence that it can improve myopia.

● **KEYWORDS:** virtual reality; visual function; myopia; visual fatigue; accommodation

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INTRODUCTION

Virtual reality (VR) refers to the user's interactive experience with the virtual three-dimensional (3D) world through head-mounted displays and wearable devices. The technology has been widely used in the fields of education, entertainment, medicine, industrial engineering, and commerce, as well as in various civil fields^[1-2].

In China, more than 600 million people have myopia, with an epidemiological survey indicating that approximately 80% of primary and secondary school students suffer from the condition^[3]; while in Asia, the incidence rate reaches 60%^[4]. Meanwhile, it has been predicted that without any intervention, the myopia prevalence among Chinese students in primary schools, junior schools, and high schools can reach 45.6%, 81.3%, and 90.5%, respectively by 2030^[5]. Moreover, myopia can induce a series of complications including glaucoma, cataract, retinal detachment blindness^[6], and even mental health complications, such as depression and lower cognitive function^[7]. Therefore, devices that can control or prevent myopia are likely to have a broad market in China. Several investigators have reported that VR devices can ideally simulate outdoor light^[8], train ciliary muscle, relieve ciliary spasms to release visual fatigue^[9], and slow down the development of myopia. Furthermore, Shibata *et al*^[10] revealed that visual acuity increased after viewing stereoscopic 3D images on developed displays, which subsequently prompted Zhao *et al*^[11] to hypothesize that specially designed VR devices may help to prevent myopia. However, multiple studies have reported inconsistencies between accommodation and convergence when viewing 3D videos, which may be due to functional eye conditions such as visual fatigue, dry eyes, transient accommodative strabismus, phorias, amblyopia, and video terminal syndrome^[12-14]. Interestingly, Kim *et al*^[15]

reported that watching 3D videos can lead to transient myopia. Currently, the effects of VR device use on vision are not clear, and it is unknown if a specially designed VR training device can eliminate visual fatigue or improve myopia.

The aim of this study was to evaluate the visual acuity, diopter, pupil size, accommodative range, accommodative facility, and visual fatigue symptoms, as well as correlations among these parameters, before and after use of a VR training device specially designed for accommodation training. We also determined the effects of the VR training device on accommodation and convergence.

SUBJECTS AND METHODS

Ethical Approval The study protocol was approved by the University Research Ethics Committee, and this clinical trial has been registered in the Chinese Clinical Trial Registry (ChiCTR2000029793).

Sixty subjects ranged 18 to 60 years old admitted to the First Affiliated Hospital of Zhejiang University or Shulan Hospital from November 2018 to July 2019, who were willing to participate in this clinical trial, were enrolled, and all of them were capable of cooperating with all procedures. The inclusion criteria were a corrected visual acuity in both eyes of >0.8 , binocular stereopsis, $-6.00\text{ D} \leq$ spherical equivalent $\leq 6.00\text{ D}$, $-3.00\text{ D} \leq$ astigmatism $\leq +3.00\text{ D}$, and no evidence of anisometry. Subjects had no history of organic ophthalmic diseases, ophthalmic surgeries, or serious systemic diseases, and they had normal cognitive ability.

Parameters of VR Training The VR training device used in this study was produced by Hangzhou Look Technology Co., Ltd. The main body of the device was comprised of a VR headset and a mobile phone (Figure 1). The VR headset lens was constructed with optical polymethyl methacrylate (PMMA) materials. The single field of view angle was 110° (55° for half field of view), and the distance of the virtual image displayed on the mobile phone screen from human eyes was 25 cm. The LeTV Max 2 mobile phone ($1440 \times 1280\text{ p}$) was used. The brightness of the mobile phone screen was set to automatic mode before the test.

VR video was produced by Hangzhou Look Technology Co., Ltd. The device used “depth of field synchronization” and “focus follow-up” to produce videos and real-time binocular images, which simulated the subtle differences in the angle, path, and light intensity of the incident glasses in distant and nearby views. In the video, the subject moved back-and-forth and turned around. In the long-range view (*i.e.*, infinity), the subject had an infinite convergence angle of 0° . In the short-range view, the convergence angle was 30° , which was approximately 11.6 cm away from the human eyes (calculated using a pupil distance of 62 mm, which is slightly different in individuals with different pupil distances). The subject was



Figure 1 VR training device used in this clinical study.

located in front of the eyes and turned around three times with a half viewing angle of 30° . The total length of the video was 15min, and the frame rate was 60 frames per second. One cycle consisted of one forward and backward motion each at low speed, as well as one forward and backward motion each at high speed, with the subject turning around three times. Each cycle lasted approximately 30s (Online supplementary, Video 1).

Treatments The short-term treatment group consisted of 40 randomly assigned subjects (11 males and 29 females) with an average age of $33.5 \pm 13.4\text{y}$. Baseline data were measured after a short shut-eye rest for approximately 5min when subjects were involved. The subjects wore the VR device for 15min, during which they gazed at the moving object in the video. Then, they closed their eyes and rested for 5min. Last, the subjects underwent the 6 main observation indexes tests.

The long-term treatment group consisted of 20 randomly assigned subjects (7 males and 13 females) with an average age of $30.4 \pm 11.7\text{y}$. Following the baseline examinations, the subjects were asked to use the VR device 3-4 times a day for 15min each time. Each intervals between the training sessions were longer than 2h. The individuals were asked to visit the hospital 1mo later ($\pm 7\text{d}$) for the 6 main observation indexes tests. They were asked not to use the VR device or come to the hospital on the same day that baseline measurements were collected. All the tests were completed by professional technicians who were not involved in this research study.

Main Observation Indexes and Examination Methods

The 6 main observation indexes included: 1) naked distant vision; 2) best-corrected visual acuity; 3) diopter (using the ARK-1S automatic computer optometer, which recorded the spherical equivalent); 4) accommodative range (using the ARK-1S automatic computer optometer); 5) accommodative facility (performing with the flipper glasses, recording cycles per minute); 6) visual fatigue symptoms (*via* a questionnaire including 11 items: eye dryness, double vision, lacrimation, puffy eyes, photophobia, eye-strain, headache, dizziness,

Table 1 Changes in visual function after the use of the VR training device for 15min

Parameters	Pre-test data (mean±SD)	The use after 15min (95%CI)	P
Distant vision (logMAR)	0.46±0.48	-0.09 (-0.12 to -0.06)	<0.001
Corrected visual acuity (logMAR)	-0.02±0.11	-0.04 (-0.06 to -0.02)	<0.001
Spherical equivalent (D)	-1.93±2.17	0.05 (-0.04 to 0.13)	0.289
Accommodative range (D)	3.42±2.60	0.41 (0.11 to 0.71)	0.008
Accommodative facility (/min)	12.60±5.33	1.29 (0.84 to 1.74)	<0.001
Pupil size (mm)	5.46±0.65	-0.34 (-0.46 to -0.22)	<0.001
Visual fatigue	4.00 (1.00-9.00)	1.90	0.058

LogMAR: Logarithm of the minimum angle of resolution.

nausea, drowsiness, and difficulty concentrating; each parameter was divided according to the degree of subjective feeling, and scores of 0 to 5 corresponded to “completely no”, “uncertain”, “a little”, “feeling”, “stronger feelings”, and “very strong feelings”; the total score of all the items was the visual fatigue score).

Statistical Analysis SPSS 22.0 Software was used for data analysis. For the 6 main observation indexes, the Kolmogorov-Smirnov test was conducted to determine the normal distribution of the data. If the data conformed to normal distribution, the results were presented as means±SD, and paired sample *t*-test was performed to compare the differences before and after VR device use; otherwise, the results were presented as medians (P25-P75), and Wilcoxon sign rank sum test of paired samples was performed to compare the differences. For visual acuity, diopter, and pupil size, in-pair correlation tests were performed to examine the correlation between the two groups. If the data from both groups conformed to normal distribution, the Pearson’s test was used; otherwise, the Spearman’s test was used. $P<0.05$ were considered statistically significant.

RESULTS

The distant vision and corrected visual acuity of subjects in the short-term treatment group improved significantly by -0.09 (95%CI, -0.12 to -0.06, $P<0.001$) and -0.04 (95%CI, -0.06 to -0.02, $P<0.001$), respectively. In addition, the accommodative range and accommodative facility increased significantly by 0.41 (95%CI, 0.11 to 0.71, $P=0.008$) and 1.29 (95%CI, 0.84 to 1.74, $P<0.001$), respectively. The pupil contracted significantly by -0.34 (95%CI, -0.46 to -0.22, $P<0.001$). No changes were observed in spherical equivalent or visual fatigue (Table 1). Meanwhile, positive correlations were found between the changes in distant vision ($r=0.361$, $P<0.01$) and corrected visual acuity ($r=0.516$, $P<0.01$) after the test and the changes in pupil size, indicating that the improvements in distant vision and corrected visual acuity were related to the pupil size instead of the spherical equivalent ($P>0.05$; Table 2).

The accommodative range and accommodative facility of the subjects in the long-term treatment group increased

Table 2 Correlations between diopter, pupil size, distant vision, and corrected visual acuity

Parameters	Spherical equivalent	Pupil size
Distant vision	0.076	0.361 ^a
Corrected visual acuity	0.063	0.516 ^a

^a $P<0.01$. Pearson’s correlation test was adopted.

significantly by 0.69 (95%CI, 0.26 to 1.11, $P=0.002$) and 0.90 (95%CI, 0.45 to 1.35, $P<0.001$), respectively. No changes were observed in distant vision, corrected visual acuity, spherical equivalent, pupil size, or visual fatigue ($P>0.05$; Table 3).

DISCUSSION

This study examined the changes of visual acuity, diopter, accommodative function, pupil size, and visual fatigue as well as their correlations in subjects after use of a VR training device for 15min or 1mo. We found that naked distant vision and corrected visual acuity of the subjects improved significantly after using the VR training device for 15min compared with the control. However, no significant change was found in the diopter, and the correlation test showed no correlation between the spherical equivalent and visual changes, indicating that the improved visual acuity by using the VR training device was not related to changes in the diopter (*i.e.*, pseudo myopia). A strong positive correlation was observed between visual acuity and pupil size; we also found that the pupils of the subjects contracted significantly after using the VR device, revealing that the improved naked distant visual acuity and corrected visual acuity were attributed to pupil contraction after using the device. Emoto *et al*^[16] examined subjects who watched 3D television and reported significant pupil contraction after the test. They suggested that visual fatigue and accommodative spasms might have contributed to myosis^[16-17]. Meanwhile, VR has been reported to induce significant visual fatigue, even after 10min watching^[18]. However, we found that 15min use of the VR training device did not significantly increase visual fatigue based on the visual fatigue scale, indicating that visual fatigue did not induce myosis. To determine the cause of myosis, an illuminometer was used to detect the brightness of the VR training device and test environment. An average

Table 3 Changes in visual function after the use of the VR training device for 1mo

Parameters	Pre-test data (mean±SD)	The use after 1mo (95%CI)	P
Distant vision (logMAR)	0.55±0.44	-0.02 (-0.07 to 0.02)	0.248
Corrected visual acuity (logMAR)	-0.05±0.08	0.00 (-0.02 to 0.03)	0.734
Spherical equivalent (D)	-2.57±2.20	-0.08 (-0.17 to 0.02)	0.119
Accommodative range (D)	3.44±2.50	0.69 (0.26 to 1.11)	0.002
Accommodative facility (/min)	12.05±5.09	0.90 (0.45 to 1.35)	<0.001
Pupil size (mm)	5.48±0.68	-0.16 (-0.33 to 0.01)	0.058
Visual fatigue	0.50 (0-6.25)	-1.78	0.058

LogMAR: Logarithm of the minimum angle of resolution.

of 5 consecutive measurements revealed an illumination of 272.4 lx for the test environment while 80.2 lx for the VR training device, which was similar to watching a VR video in a relatively dark room. These findings were also consistent with most individuals' subjective feelings of external illumination immediately after taking off the VR headset. Therefore, only the subjects responsive to increased ambient brightness might have experienced myopia. This might be due to the fact that VR headsets enclosed both eyes by the nature of their design, and the effect of watching a VR video was similar to that of watching a movie in theatre. However, few studies have reported changes in diopter and pupil size, or the brightness of the device and environment; it is still unknown if VR devices can improve vision by training ciliary muscles or relaxing accommodative spasms.

According to our results from the long-term treatment group, after one-month continuous use of the VR device, no significant changes were found in naked distant vision, corrected visual acuity, diopter, pupil size, or visual fatigue. In a previous study involving individuals (32 subjects aged 20±1y and 12 subjects aged 46.6±3.5y) exposed to 6min use of a VR device for 11 consecutive days, it was reported that the distant vision improved in both the young and the old groups after 5d, with the myopic diopter decreasing in the young group^[9]. However, the authors failed to provide details about the VR device, the number of training sessions per day, and the other specific endpoints. Therefore, it was difficult to conduct in-depth comparative analyses. Based on our results in this study, we assumed that the visual acuity measurements were taken immediately after the VR training, and speculated that the improvement in distant vision was caused by light adaptation to myopia instead of myopia relief.

Furthermore, we found that the accommodative range and accommodative facility were significantly increased after using the VR device for 15min, as well as after one-month continuous use of the device, which is consistent with the results of Zhang *et al*^[19]. These findings indicate that VR device can improve eyes' ability to accommodate the lens and delay the development of presbyopia to a certain extent. Due to the unchanged display position in VR devices, stereoscopic

images were produced based on the parallax principle, while the real impact of VR device on the accommodative function of the subjects remains controversial^[20-21]. Shibata *et al*^[16] have combined 3D displays with optometric instruments to measure the real-time changes in diopter when subjects were watching 3D films. Although the position of the actual display was not changed, the results showed that the diopter of human eyes accommodated to the distance of the virtual image, suggesting that VR training might play a role in accommodation^[10,22]. It should be noted that VR training for more than 30min significantly increased visual fatigue while decreased accommodative range and accommodative facility.

The pathogenesis of myopia is complex, as a result of the interactions between genetic and environmental factors^[23]. It is believed that a low degree of hyperopic defocus of the peripheral retina can be the key factor leading to myopia^[13,24-25], while the role of accommodative function in the development of myopia is still unknown^[26-28]. Screenivasan *et al*^[29] examined 25 children with emmetropia and 27 children with myopia, and reported that poor accommodative facility and stability were the risk factors for myopia. We found that the accommodative facility of the subjects after using the VR device was significantly higher than that before use. Although the use of the VR device may delay the development of myopia in theory, the unchanged diopter after VR training might be related to the limited number of subjects and insufficient follow-up time length. Therefore, further studies are needed to confirm the effects of VR training on the development of myopia in juveniles.

This clinical trial is one of the studies that comprehensively evaluated the impact of VR training on vision and explored the relationship among various influential indicators. Unlike other studies, this trial introduced the parameters of the VR training device, which can aid in subsequent analyses. However, multiple limitations are involved in this study. First, this trial did not include juveniles younger than 18 years old due to ethical constraints. Given that ciliary muscle accommodation was improved in adults, and no cases of pseudomyopia or other disorders were found, the conclusion that VR training has no effect on the diopter of human eyes might not be applicable

to juveniles. Second, the follow-up was short due to time constraints. Further clinical trials with an observation time of not less than half a year are necessary. Last, the population size was small and subgroup analyses were not performed, which might serve as one of the future directions of further studies.

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