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Effects of virtual distant viewing technology on preventing nearwork-induced ocular parameter changes

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Abstract

Purpose: This study investigates whether virtual distant viewing technology can prevent nearwork-induced ocular parameter changes.

Methods: Twenty-six volunteers read a textbook on one day and the same content on a virtual distant viewing display on another day based on a randomization sequence, with both reading sessions at 33 cm for 4 hours. Visual acuity, diopter, ocular biology, visual fatigue, and accommodative function before and after the nearwork, as well as the number of pages read, were recorded.

Results: After 4 hours of nearwork in the textbook group, the spherical equivalent refraction decreased from -3.13 ± 2.65 D to -3.32 ± 2.70 D ($P < 0.001$), corneal thickness decreased from 531.6 ± 33.5 μm to 528.9 ± 33.0 μm ($P = 0.015$), anterior chamber depth decreased from 3.65 ± 0.35 mm to 3.60 ± 0.30 mm ($P = 0.002$), accommodative facility increased from 15.1 ± 3.5 to 16.4 ± 3.9 ($P = 0.018$), and subjective visual fatigue increased from 14.0 ± 9.2 to 19.3 ± 7.6 ($P = 0.002$); no significant changes were seen in the other parameters. In the virtual distant viewing group, the spherical equivalent refraction (from -3.17 ± 2.60 D to -3.11 ± 2.73 D, $P = 0.427$), corneal thickness (from 531.9 ± 32.8 μm to 529.7 ± 33.2 μm, $P = 0.054$), and anterior chamber depth (from 3.67 ± 0.35 mm to 3.69 ± 0.32 mm, $P = 0.331$) did not show significant changes, whereas accommodative facility increased from 14.7 ± 5.8 to 15.9 ± 5.5 ($P = 0.042$) and subjective visual fatigue increased from 13.5 ± 8.4 to 18.9 ± 8.6 ($P = 0.002$). In addition, choroidal thickness (from 217.7 ± 76.0 μm to 243.0 ± 85.0 μm, $P = 0.043$), positive relative accommodation (from -2.32 ± 1.07 D to -2.85 ± 0.89 D, $P = 0.007$), and amplitude of accommodation (from 7.26 ± 1.41 D to 7.89 ± 1.69 D, $P = 0.022$) also significantly increased in the virtual distant viewing group. The textbook group and the virtual distant viewing group read 176.0 ± 133.1 pages and 188.0 ± 102.0 pages, respectively, and there was no significant difference between the two groups ($P = 0.708$).

Conclusion: Virtual distant viewing technology can prevent the increase in myopia degree due to nearwork and improve accommodation function without increasing visual fatigue.

Keywords

Virtual reality, myopia, digital eye strain, prevention, nearwork

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Key summary points

- As a result of the COVID-19 pandemic, the development of online learning has further increased the duration of nearwork undertaken by children, and the prevalence of myopia has shown explosive growth in some regions.
- A distant-image screen display that can simulate the long-distance viewing of a blackboard on a narrow space on a child's study table was developed.
- The display can prevent ocular parameter changes induced by long periods of nearwork without increasing visual fatigue or decreasing reading speed in adults.

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- Future research should determine the efficacy for delaying myopia progression in schoolchildren.

Introduction

In the past 20 years, the incidence of myopia has increased in the <30-year-old population.[1,2] In China, the incidence of myopia in senior high school students is more than 80%.[1,2] Nearwork is the most important cause of myopia development and progression,[3,4] and possible mechanisms include increased accommodation during nearwork and increased peripheral hyperopic defocus.[5,6] Several hours of nearwork can increase diopter, increase ocular axial length, decrease choroidal thickness, and decrease accommodative function. To reduce accommodation and slow the progress of myopia, this study proposes a simple new design of a system to extend viewing distance; while an object is still placed at a near distance, a virtual image is located farther in front of the eye, resulting in accommodative relaxation (Figure 1). This device is based on the coaxial refractive freeform VR optics protocol in which a real image at 0.33 m is changed into a virtual image at 5

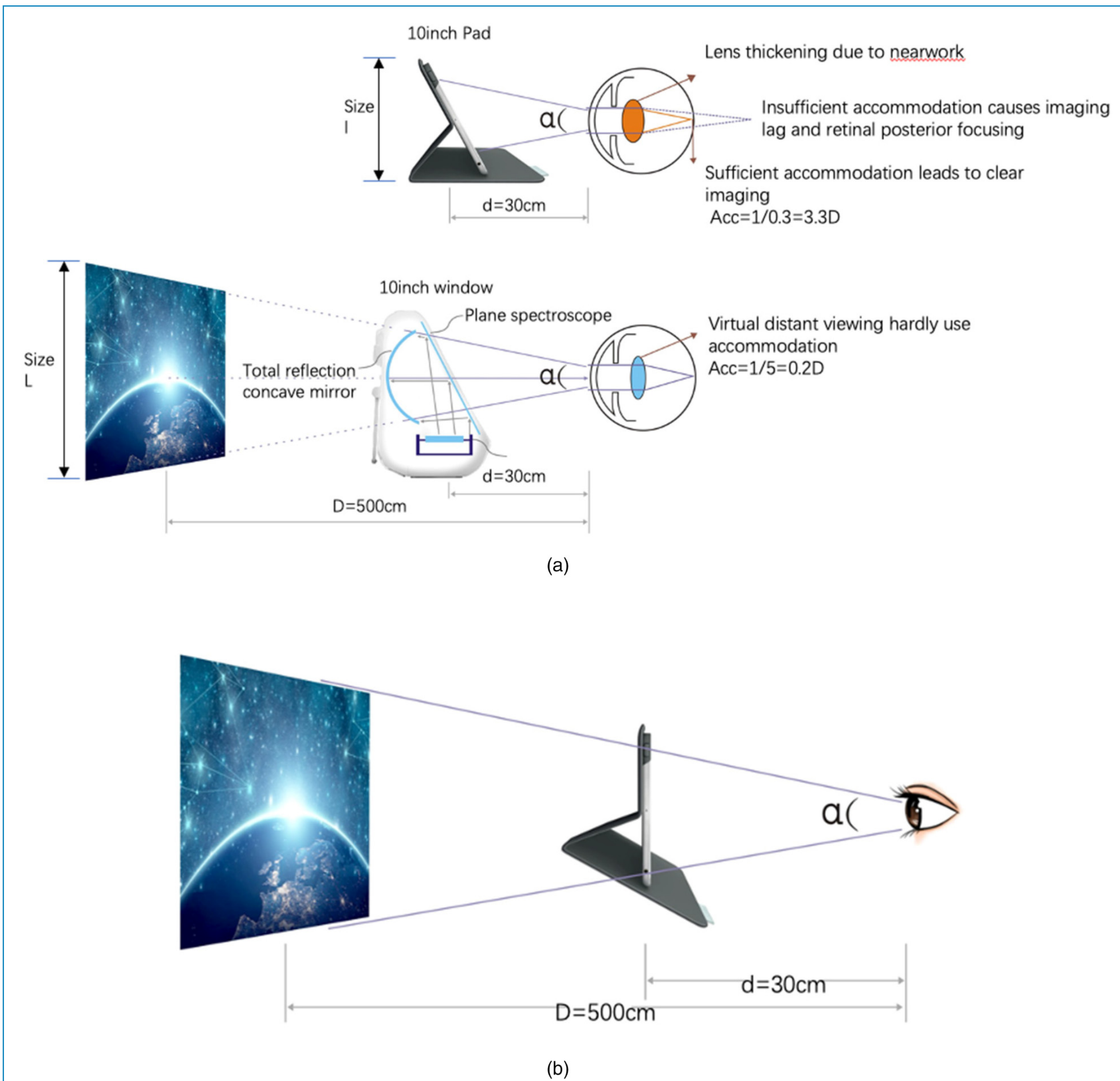

Figure 1. (a) Explanation of the effect of virtual distance viewing and close reading on eye accommodation. (b) Explanation of the equivalent visual angle during virtual distant viewing and close reading. The viewing angle can remain unchanged when L/D = l/d. For example, viewing a 10-inch pad from a 30 cm distance is equivalent to viewing a 100-inch virtual image from a 300 cm distance.

m. The results of previous studies showed that this equipment can decrease the accommodation requirements for nearwork. This study further assessed whether this equipment could prevent long periods of nearwork-induced ocular parameter changes.

Methods

Design of the virtual distant viewing system

This study used an optical electronic system based on the birdbath principle, which extends a close viewing scene to long-distance viewing to improve the accommodation. The optical imaging part of the system includes a semitransparent and semireflective plane spectroscope, an AR total reflection free-form surface concave mirror, and a 5.5-inch LCD electronic screen. The content of the LCD screen is reflected by the plane spectroscope and the free-form surface mirror, and then the optical path turns back and twice passes through the transmission of the semitransparent plane spectroscope into the viewer's eyes, presenting a virtual image with a distance of 5 m and a size of 100 inches on the retina. The resolution of the LCD is 1920×1080, the distance between the eyes and the ideal viewing distance of the device is within 30 cm, and the viewing angle of the magnified virtual image is close to 30° (Figure 1).

Research process for measuring ocular parameter changes

Twenty-six participants with normal vision (17 females and 9 males, mean age 26.4, range = 21–29 years) were recruited for the study. The mean spherical equivalent refraction of the cohort was −3.15 D, ranging from +0.75D to −6.50 D. All the participants had a refractive cylinder of ≤0.75 D. The best corrected visual acuity was at least 20/20. Exclusion criteria included the following: a history of severe dry eye, a history of strabismus and/or amblyopia, any systemic or infectious conditions or allergies that might interfere with participation, the use of systemic or ocular medications known to interfere with vision and/or accommodation, previous ocular surgery or orthokeratology, current myopia control therapy, or currently pregnant or lactating. Written informed consent was obtained from all participants before enrollment, and the study adhered to the tenets of the Declaration of Helsinki. The research was approved by the Human Studies Committee at Beijing Tongren Hospital (Beijing, China) in accordance with the Code of Ethics of the World Medical Association (registration number: ChiCTR2100047059). Participants signed a statement of informed consent prior to their participation in the study.

Before evaluation, the participants were reminded to be well rested for the day of the experiment, as it required their full attention. They were advised to not have any caffeinated or sugary drinks and avoid vigorous exercise during the evening preceding the morning study sessions. The reading sessions started approximately 2 hours after their waking time. All test sessions started at approximately 8:30 a.m. to avoid the impact of diurnal rhythm on objective measurement parameters such as refractive power and choroidal thickness. All participants were instructed to avoid reading, using mobile phones, and other nearwork before the experiment started at 8:30. The illuminance of the room was kept at normal photopic levels (around 300 lux), measured with the MAVOLUX 5032B/C photometer. SPSS software is used to generate random numbers and sort cases, and then participants are randomly assigned to the group 1 and the group 2 based on the magnitude of the random numbers. Group 1 reads the printed novel on the first day and reads the novel using the virtual remote monitor on the second day, while group 2 does the opposite. The reading distance for both methods is 33 cm and they were separated from their handheld devices, such as phones and smart watches, to maintain focus on reading.

The evaluation included two steps. The first step was an examination of basic visual function, where each participant received an initial examination of their visual acuity (Lighthouse modified ETDRS chart, Lighthouse International, New York, NY), accommodative function, and subjective and objective evaluation of eye strain. The second step was to measure the participant's refractive status (Grand Seiko Co., Ltd, Hiroshima, Japan) and ocular biometry. Figure 2 illustrates the timeline of the examination procedure. Visual acuity, accommodative function, and subjective and objective evaluation of eye strain were measured once before and after near work.

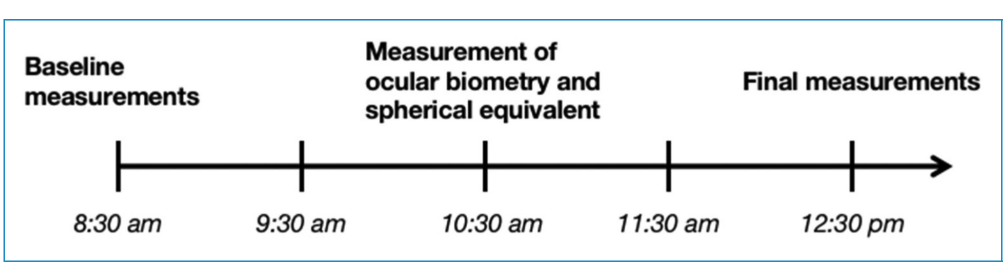

Figure 2. Schematic representation of the measurement procedure milestones.

The measurement of refractive status and ocular biometry was carried out five times in total.

Experimental section

Accommodative facility test. The test was conducted monocularly using a lens flipper (+2.00 D/−2.00 D lens combination). The participants were asked to focus on a 20/30 letter placed at 40 cm and were instructed as follows: "Try to keep the letter in focus. I will put a lens in front of your eye, which will blur the letter, but the image will become clear again in a short time. You should tap the table as soon as the image is sharp again, and we will repeat this process over a 1-minute period." The number of completed flipping cycles within 1 minutes was measured.

Monocular accommodation amplitude (MAA). The target was a 20/30 letter test line at 40 cm, and amplitude was measured using the minus-lens method. Participants were instructed to keep the central letter clear and report the first blur. The working distance adjustment used was maintained at 2.50 D to compensate for minification.

Negative and positive relative accommodation. A target of a 20/30 letter test line was placed at 40 cm. Spherical lenses were introduced in 0.25 D steps binocularly until participants reported the first persistent blur for stimulation of negative relative accommodation (NRA) or positive accommodation (PRA).

Accommodative lag. Participants were asked to view a 20/30 letter test line, with positive or negative lenses (motion or against the motion) interposed in front of one eye at a time, until the neutralization of the reflex was found in the horizontal meridian. A positive value represented a lag of accommodation, while a negative value represented a lead of accommodation.

AC/A ratio. The ratio was calculated using the values of far horizontal phoria (PF), near horizontal phoria (PN), and pupil distance (PD). The following formula was applied: $AC/A = PD + (PN - PF)/2.5$. PD was measured in centimeters, while fixation distance and reading distance were measured in meters (0.4 m, corresponding to a 2.5 D accommodation).

Objective eye strain evaluation. The critical flicker–fusion frequency (CFF) was used to evaluate the eye strain objectively. The CFF examination began with a calibration phase, where the frequency of the flashes was set to a beginning value (based on the mean CFF from 4 points at 10° eccentricity and increased by 12 Hz). Then it decreased with a step of 4 Hz up to 3 Hz. Participants were instructed to click a button when they noticed a flickering. The lights were presented for 3 seconds or until the participant reacted.

Subjective eye strain evaluation. We evaluated subjective symptoms related to eye strain with a 15-item questionnaire (Appendix A), adapted from a previous study.[7] Participants reported their responses on a Likert scale (0, never; 1, rarely; 2, cannot say either way; 3, a little; 4, very much) and were permitted to respond with nonintegral responses. We calculated the difference between the pre- and post-task responses, such that a positive change in score corresponded to an increase in eye strain, while a negative change in score corresponded to a decrease in eye strain.

Ocular biometry. For each eye was obtained with an optical biometer (Moptim Colombo IOL). We used the automated acquisition mode of the optical biometer (Moptim Colombo IOL) for all the participants, which minimized any operator-related biases. The ocular biometry was based on the optical low-coherence principle. With a 20k scanning speed, it provides up to a 3-mm OCT image of both the cornea and retina in real time, which allows the operator to perform a real-time fixation check to reduce the fixation-related biases. Fifteen B-scans were performed on the same position, and a HD OCT image of retina was averaged from 15 images, which enabled observation of the retina and choroid. We used the automated acquisition mode for all the participants, which minimized any operator-related biases. The program first asked the annotators the biometrics of an individual participant's eyes to account for the longitudinal magnification with respect to a standard schematic eye. The internal limiting membrane (ILM) and Bruch's membrane (BM) segmentation boundaries were then directly extracted from the data, and the choroid segmentation boundaries were extracted from the data based on the gradient change. Several points were extracted below the BM segmentation boundaries, and then some points were retained for curve fitting after deleting the error points.

Data analysis

Before study initiation, we calculated the necessary sample size to ensure feasibility. We recruited 10 volunteers to compare the NITM induced by two types of display equipment. The mean spherical equivalent change of the tablet and DIS was 0.20 ± 0.23 D and 0.02 ± 0.21 D, respectively. The test level was 0.05, and the test power was 0.90. Based on the difference in the mean between the two groups, 16 volunteers were needed based on the sample size calculation formula. Considering a dropout rate of 10%, at least 18 volunteers were needed.

Because there was a significant correlation between the diopter of the left and right eyes ($r = 0.969$, $P < 0.001$), one eye was randomly selected for statistical analysis. For the statistical analysis, the change of ocular parameters was determined by comparing the measurements taken at the end of reading and those taken at baseline. The means and standard error of mean (SEM) were used to describe the distributions. Paired *t*-tests were used to determine whether participants were significantly different before and after viewing the video, and a factorial analysis of variance was used to determine whether participants differed significantly between the two devices. Data were analyzed using SPSS (version 26.0, IBM, Armonk, NY, USA); GraphPad Prism 8 (GraphPad software, San Diego, CA, USA) was used to perform the analysis and prepare the figures. Trend analysis was also performed with Prism 8 software, and linear fits were obtained to explain the changes seen in control and test eyes. Bonferroni's correction was applied whenever applicable, and a corrected value of $P < 0.05$ was considered for statistical significance.

Results

Effect of reading with textbook on ocular parameter

After 4 hours of reading in the textbook group, the degree of myopia increased from −3.13 ± 2.65 D to −3.32 ± 2.70 D ($P < 0.001$), corneal thickness decreased from 531.6 ± 33.5 µm to 528.9 ± 33.0 µm ($P = 0.015$), anterior chamber depth decreased from 3.65 ± 0.35 mm to 3.60 ± 0.30 mm ($P = 0.002$), accommodative facility increased from 15.1 ± 3.5 to 16.4 ± 3.9 ($P = 0.018$), and subjective visual fatigue increased from 14.0 ± 9.2 to 19.3 ± 7.6 ($P = 0.002$); no significant changes were seen in the other parameters (Table 1).

Effect of reading with the virtual distant viewing system on ocular parameters

After 4 hours of reading in the virtual distant viewing group, the degree of myopia (from −3.17 ± 2.60 D to −3.11 ± 2.73 D, $P = 0.427$), corneal thickness (from531.9 ± 32.8 µm to 529.7 ± 33.2 µm, $P = 0.054$), and anterior chamber depth (from 3.67 ± 0.35 mm to 3.69 ± 0.32 mm, $P = 0.331$) did not show significant changes, whereas accommodative facility increased from 14.7 ± 5.8 to 15.9 ± 5.5 ($P = 0.042$) and subjective visual fatigue increased

Table 1. The ocular parameters of the textbook group before and after reading.

	Before reading	After reading	*t*	*P* value
Vision acuity (LogMar)	−0.10 ± 0.08	−0.09 ± 0.09	−0.732	0.471
Spherical equivalent refraction, D	−3.36 ± 2.96	−3.55 ± 2.96	4.253	<0.001***
Central corneal thickness, µm	531.6 ± 33.5	528.9 ± 32.9	2.600	0.015*
Anterior chamber depth, mm	3.65 ± 0.35	3.60 ± 0.35	3.495	0.002**
Lens thickness, mm	3.70 ± 0.41	3.63 ± 0.31	1.164	0.256
Axial length, mm	24.27 ± 1.39	24.26 ± 1.40	0.321	0.751
Choroidal thickness, µm	230.6 ± 78.9	221.6 ± 76.4	1.267	0.217
Blink frequency, times/min	21.2 ± 12.5	20.9 ± 8.4	0.160	0.874
Critical flicker-fusion frequency, Hz	32.3 ± 3.9	32.8 ± 2.9	−0.793	0.435
Subjective symptoms related to eye strain	14.0 ± 9.2	19.3 ± 7.6	−3.526	0.002**
AC/A ratio	6.3 ± 2.1	6.1 ± 1.8	0.613	0.545
Accommodative lag, D	−0.04 ± 0.44	−0.02 ± 0.29	−0.267	0.791
Negative relative accommodation, D	2.08 ± 0.42	2.07 ± 0.47	0.099	0.992
Positive relative accommodation, D	−2.83 ± 1.22	−2.59 ± 0.91	−1.395	0.175
Monocular accommodation amplitude, D	7.51 ± 1.26	7.69 ± 1.46	−0.712	0.483
Accommodative facility, cycles/min	15.1 ± 2.5	16.4 ± 3.9	−2.538	0.018*

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

from 13.5 ± 8.4 to 18.9 ± 8.6 ($P = 0.002$). In addition, choroidal thickness (from 217.7 ± 76.0 μm to 243.0 ± 85.0 μm, $P = 0.043$), positive relative accommodation (from −2.32 ± 1.07 D to −2.85 ± 0.89 D, $P = 0.007$), and amplitude of accommodation (from 7.26 ± 1.41 D to 7.89 ± 1.69 D, $P = 0.022$) also significantly increased in the virtual distant viewing group (Table 2).

Effects of virtual distant viewing on preventing nearwork-induced ocular parameter changes

Table 3 shows the baseline ocular parameter data of the textbook group and the virtual distant viewing group before reading; there were no significant differences between the two groups. Table 4 compares the ocular parameter changes before and after reading of the textbook group and virtual distant viewing group. After 4 hours of reading, diopter decreased by −0.19 ± 0.23 D in the textbook group and increased by 0.06 ± 0.19 D in the virtual distant viewing group (t = −3.018, $P = 0.004$); anterior chamber depth decreased by 0.05 ± 0.07 mm in the textbook group and increased by 0.02 ± 0.12 mm in the virtual distant viewing group (t = −2.623, $P = 0.012$); choroidal thickness decreased by 9.0 ± 36.2 μm in the textbook group and increased by 25.4 ± 60.8 μm in the virtual distant viewing group (t = −2.479, $P = 0.017$); positive relative accommodation decreased by 0.24 ± 0.88 D in the textbook group and increased by 0.63 ± 1.32 D in the virtual distant viewing group (t = 3.078, $P = 0.003$). There were no significant differences in other ocular parameter changes between the two groups. The textbook group and the virtual distant viewing group read 176.0 ± 133.1 pages and 188.0 ± 102.0 pages, respectively, within 4 hours, and there was no significant difference between the two groups (t = −0.377, $P = 0.708$).

Figure 3 shows the variation curves of diopter and choroidal thickness after 4 hours of reading. In the textbook group, diopter showed a decreasing trend as reading duration increased, while diopter showed a slight increase

Table 2. The ocular parameters of the virtual distant viewing group before and after reading.

	Before reading	After reading	*t*	*P* value
Vision acuity (LogMar)	−0.09 ± 0.07	−0.09 ± 0.09	−0.575	0.571
Spherical equivalent refraction, D	−3.40 ± 2.95	−3.34 ± 3.07	−0.807	0.427
Central corneal thickness, μm	531.9 ± 32.8	529.7 ± 33.2	2.021	0.054
Anterior chamber depth, mm	3.67 ± 0.35	3.69 ± 0.32	−0.992	0.331
Lens thickness, mm	3.65 ± 0.29	3.61 ± 0.24	0.732	0.471
Axial length, mm	24.26 ± 1.39	24.25 ± 1.40	0.359	0.722
Choroidal thickness, μm	217.7 ± 76.0	243.0 ± 84.5	−2.131	0.043*
Blink frequency, times/min	19.0 ± 9.4	21.8 ± 12.6	−1.251	0.223
Critical flicker-fusion frequency, Hz	32.4 ± 2.8	32.5 ± 2.77	−0.212	0.834
Subjective symptoms related to eye strain	13.4 ± 8.4	18.9 ± 8.6	−4.765	<0.001***
AC/A ratio	6.1 ± 1.8	6.5 ± 1.8	−1.303	0.204
Accommodative lag, D	0.00 ± 0.28	−0.26 ± 1.0	1.292	0.208
Negative relative accommodation, D	2.01 ± 0.90	2.12 ± 0.38	−0.647	0.524
Positive relative accommodation, D	−2.32 ± 1.07	−2.85 ± 0.89	2.922	0.007**
Monocular accommodation amplitude, D	7.26 ± 1.41	7.89 ± 1.69	−2.435	0.022*
Accommodative facility, cycles/min	14.7 ± 5.8	15.9 ± 5.5	−2.143	0.042*

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

Table 3. The baseline ocular parameter data before reading.

	Textbook group	Virtual distant viewing group	t	P value
Vision acuity (LogMar)	-0.10 ± 0.08	-0.09 ± 0.07	−0.074	0.941
Spherical equivalent refraction, D	-3.36 ± 2.96	-3.40 ± 2.95	0.053	0.958
Central corneal thickness, µm	531.6 ± 33.5	531.9 ± 32.8	−0.028	0.978
Anterior chamber depth, mm	3.65 ± 0.35	3.67 ± 0.35	−0.147	0.884
Lens thickness, mm	3.70 ± 0.41	3.65 ± 0.29	0.507	0.614
Axial length, mm	24.27 ± 1.39	24.26 ± 1.39	0.009	0.993
Choroidal thickness, µm	230.6 ± 78.9	217.7 ± 76.0	0.604	0.549
Blink frequency, times/min	21.2 ± 12.5	19.0 ± 9.4	0.711	0.480
Critical flicker-fusion frequency, Hz	32.3 ± 3.9	32.4 ± 2.8	−0.112	0.911
Subjective symptoms related to eye strain	14.0 ± 9.2	13.4 ± 8.4	0.283	0.778
AC/A ratio	6.3 ± 2.1	6.1 ± 1.8	0.381	0.705
Accommodative lag, D	-0.04 ± 0.44	0.00 ± 0.28	−0.471	0.640
Negative relative accommodation, D	2.08 ± 0.42	2.01 ± 0.90	0.346	0.730
Positive relative accommodation, D	-2.83 ± 1.22	-2.32 ± 1.07	−1.602	0.115
Monocular accommodation amplitude, D	7.51 ± 1.26	7.26 ± 1.41	0.673	0.504
Accommodative facility, cycles/min	15.1 ± 2.5	14.7 ± 5.8	0.303	0.763

with reading duration in the virtual distant viewing group. In the textbook group, choroidal thickness showed a decreasing trend as reading duration increased, while diopter showed an increasing trend with reading duration in the virtual distant viewing group.

Discussion

An increase in nearwork is a main contributing factor to increased myopia incidence, and a causal relationship is present between nearwork intensity and duration and myopia prevalence and severity.[8–10] French[11] and Lin[12] found that nearwork is not only an independent risk factor for myopia but also a predictor of myopia progression.[13] Pärssinen et al.[14] found that myopia progression is directly proportional to nearwork duration, and >42 hours of nearwork every week will significantly increase myopia incidence.[15] The results of a meta-analysis showed that the OR of nearwork in inducing myopia was 1.14 (CI: 1.08–1.20), and every increase in 1 D/hour of nearwork burden per week increased the risk of myopia by 2%.[16] Long duration and overly short distance will increase the risk of myopia 1.5–2.5-fold,[17] and >5 hours of nearwork every day increases the prevalence of myopia from 28.6% to 43.1%.[18] However, the increase in nearwork duration in students is mostly because students hope to increase their education level to improve their career prospects and quality of life, and increasing outdoor activities often conflicts with this dream. The equipment designed in this study employs virtual distant viewing to solve the conflict between decreasing nearwork duration and ensuring adequate learning time.

With the advancements in science and technology, people have changed their habits of receiving information and acquiring knowledge in unprecedented ways. The frequent use of electronic digital devices for reading books, newspapers, and magazines has led to an increase in the frequency and time of nearwork.[19] A study by Demir et al.[20] showed that 128 schoolchildren aged 12 ± 2.4 years old had an average of 5.3 ± 3.1 hours of daily nearwork activity and an average of 2.6 ± 2.2 hours of daily outdoor activities and found that the time used for nearwork activities

Table 4. The ocular parameter changes before and after Reading of the textbook group and virtual distant viewing group.

	Textbook group	Virtual distant viewing group	*t*	*P* value
Vision acuity (LogMar)	0.01 ± 0.04	0.01 ± 0.05	0.041	0.968
Spherical equivalent refraction, D	−0.19 ± 0.23	0.06 ± 0.35	−3.018	0.004**
Central corneal thickness, μm	−2.7 ± 5.36	−2.2 ± 5.5	−0.376	0.708
Anterior chamber depth, mm	−0.05 ± 0.07	0.02 ± 0.12	−2.623	0.012*
Lens thickness, mm	−0.07 ± 0.33	−0.04 ± 0.27	−0.436	0.665
Axial length, mm	0.00 ± 0.04	0.00 ± 0.04	0.037	0.971
Choroidal thickness, μm	−9.0 ± 36.2	25.4 ± 60.8	−2.479	0.017*
Blink frequency, times/min	−0.4 ± 11.9	2.7 ± 11.1	−0.973	0.335
Critical flicker-fusion frequency, Hz	0.5 ± 3.3	0.1 ± 1.9	0.572	0.570
Subjective symptoms related to eye strain	5.2 ± 7.5	5.6 ± 6.0	−0.194	0.847
AC/A ratio	−0.3 ± 2.1	0.4 ± 1.6	−1.284	0.205
Accommodative lag, D	0.02 ± 0.37	−0.27 ± 1.06	1.308	0.197
Negative relative accommodation, D	−0.01 ± 0.50	0.11 ± 0.83	−0.606	0.547
Positive relative accommodation, D	0.24 ± 0.88	−0.53 ± 0.92	3.078	0.003**
Monocular accommodation amplitude, D	0.18 ± 1.3	0.63 ± 1.32	−1.235	0.222
Accommodative facility, cycles/min	1.28 ± 2.56	1.15 ± 2.75	0.167	0.868
Number of pages read	176.0 ± 133.1	188.4 ± 102.0	−0.377	0.708

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

approximately doubled the time spent engaging in outdoor activities.

During near-vision accommodation in humans, the ciliary body will move forward and inward, and mechanical traction causes the choroid to become thinner and ocular axial length to increase.[21,22] During accommodation, excitation of the autonomic nervous system will cause choroidal nonvascular smooth muscle (CNVSM) contraction and cause the choroid to become thinner. This change is more significant in the myopia population.[23,24] Mallen et al.[25] found that during accommodation, equatorial diameter decreases and intraocular contents are redistributed, which causes the anterior chamber to become shallower and ocular axial length to increase. The sclera in myopic eyes is usually thinner than that in normal people and tends to become deformed under the same force.[26,27] Woodman et al.[28] found that the anterior sclera becomes thinner in 3D and 6D accommodation in adult myopic patients, but there was no significant change in emmetropic people. Hughes et al.[6] observed changes in ophthalmologic parameters in children under different viewing distances. The results showed that near-vision 3D accommodation causes anterior chamber depth to decrease by 0.10 mm and ocular axial length to increase by 0.01 mm, and ocular parameter changes become more significant as accommodation increases. The results of this study showed that anterior chamber depth decreased, and choroidal thickness showed significant changes after nearwork. The intensity of the abovementioned changes is highly correlated with the occurrence and progression of myopia.[29,30]

Nearwork-induced transient myopia (NITM) refers to the small and transient myopic shift in the refractive state of the eye at far induced by a period of sustained nearwork.[11] NITM reflects an inability of the crystalline lens to reduce its power appropriately and rapidly. Its magnitude is also related to the risk of myopia progression.[12,31] Our

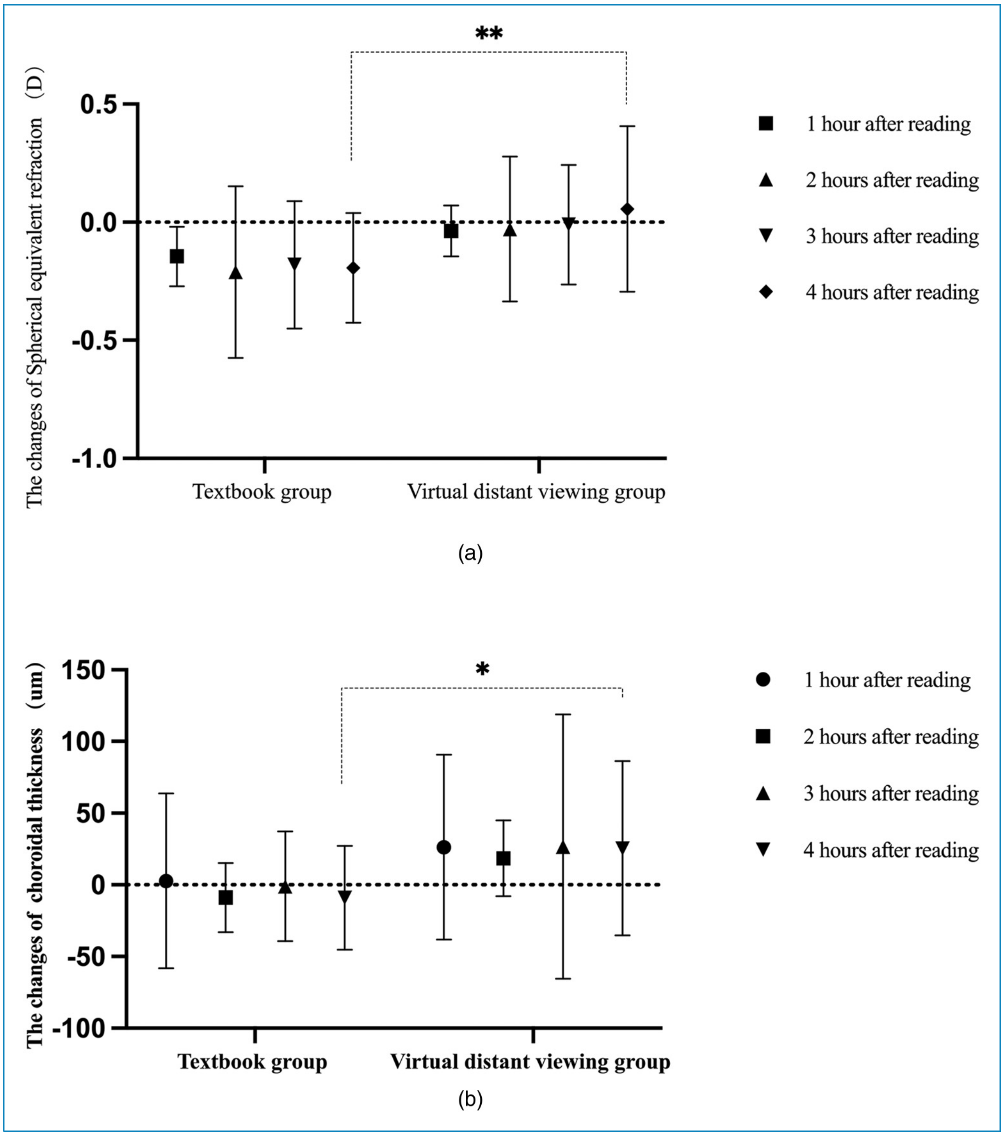

Figure 3. (a) Diopter variations after 4 hours of reading. (b) Variations in choroidal thickness after 4 hours of reading.

results showed that the degree of myopia increased by 0.19 ± 0.23 D after 4 hours of reading in the textbook group, which was close to the results of Sivaraman et al. (0.26 ± 0.12 D).[32] The main factor contributing to NITM is indeed fatigue in the accommodation system caused by prolonged nearwork. However, the decreased elasticity of lens fibers (and/or lens capsule) due to aging may also affect the natural crystalline lens's ability to rapidly change its shape and accommodation power.[33] This reduction in elasticity can potentially impact the lens's accommodative ability, which is its capacity to alter its shape to focus on objects at different distances. Consequently, when considering NITM the age-related decrease in lens elasticity is a significant factor that cannot be ignored. The decline in lens elasticity may affect an individual's ability to adapt to close-up work, increasing the risk of NITM and other vision problems.

Increasing the duration of outdoor activities can decrease myopia prevalence and progression and may be related to a reduction in nearwork duration and stimulation of dopamine release.[34,35] A study-based intervention trial showed that increasing daily outdoor activity duration by 40 minutes significantly decreases the incidence of myopia.[36] During the experiment, the reading distance in the textbook group was 33 mm, and the accommodation requirement was 3 D. The total nearwork burden of the experiment was 13.2 D hours. Although the distance from the eyes to the screen in the virtual distant viewing group was also 33 cm, the virtual image position was 5 m behind the screen in the equipment. Therefore, the actual accommodation requirement was 0.19 D. During the experiment, the total nearwork burden was 0.76 D hours, which was decreased by 91.3% compared with the textbook group.

The results showed no significant differences in spherical equivalent, choroidal thickness, and anterior chamber depth changes before and after reading in the virtual distant viewing group compared with the textbook group, and there was no tendency toward myopia. The text displayed in virtual distant viewing was far away, while amplification processing was carried out at the same time to ensure that the visual angle of text imaging in the human eye remained unchanged. There were no significant differences in changes in subjective and objective visual fatigue parameters or the number of pages read after usage between the groups, showing that the new equipment did not induce new visual fatigue or decrease reading speed, demonstrating its feasibility as a textbook replacement as a learning tool for adolescents.

There are three shortcomings in this study. Firstly, all the participants were adult volunteers. In the future, we will recruit schoolchildren to observe whether learning using virtual distant viewing technology will delay myopia development and progression. Secondly, previous studies have shown that the parameter changes in myopia after close-up work are greater than those in emmetropia.[37] In this study, no restrictions were imposed on spherical prescriptions during enrollment, resulting in only 20% of the enrolled volunteers being emmetropic. Consequently, a direct comparison between the effects of the product on emmetropic and myopic volunteers is not feasible. In subsequent research, we plan to conduct stratified comparisons to observe differences among hyperopic, emmetropic, and myopic volunteers, aiming to obtain more comprehensive results. Thirdly, previous studies have shown that the impact of 4 hours of near work on refraction disappears in about 20 minutes.[38] Therefore, in this study, the time interval between two reading sessions was set to 24 hours. In subsequent research, the interval can be further extended to ensure more complete washout.

Conclusion

This study compared the changes in subjective/objective parameters before and after nearwork to demonstrate that nearwork performed using virtual distant viewing technology allows for the same reading speed as textbooks, does not increase additional visual fatigue, and can prevent changes in ocular parameters related to myopia development and progression. Therefore, a distant-image screen display can prevent myopia occurrence and progression by decreasing nearwork time.

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APPENDIX A

1. My eyes feel tired.
2. When doing work at my computer or at my desk, I find it hard to focus my eyesight.
3. I see written or computer text as blurry.
4. My computer monitor looks too bright.
5. I feel tired when doing work at my desk or on my computer.
6. My eyes feel dry from time to time.

7. I feel as if there is something in my eye.
8. My neck, shoulders, back, and lower back hurt.
9. My finger(s) hurt.
10. I feel mentally stressed.
11. I feel pain around or inside my eyes.
12. The sun's glare affects my eyes when outdoors.
13. I find fluorescent office lighting to be bothersome to my eyes.
14. My eyes feel heavy.
15. My eyes feel itchy.