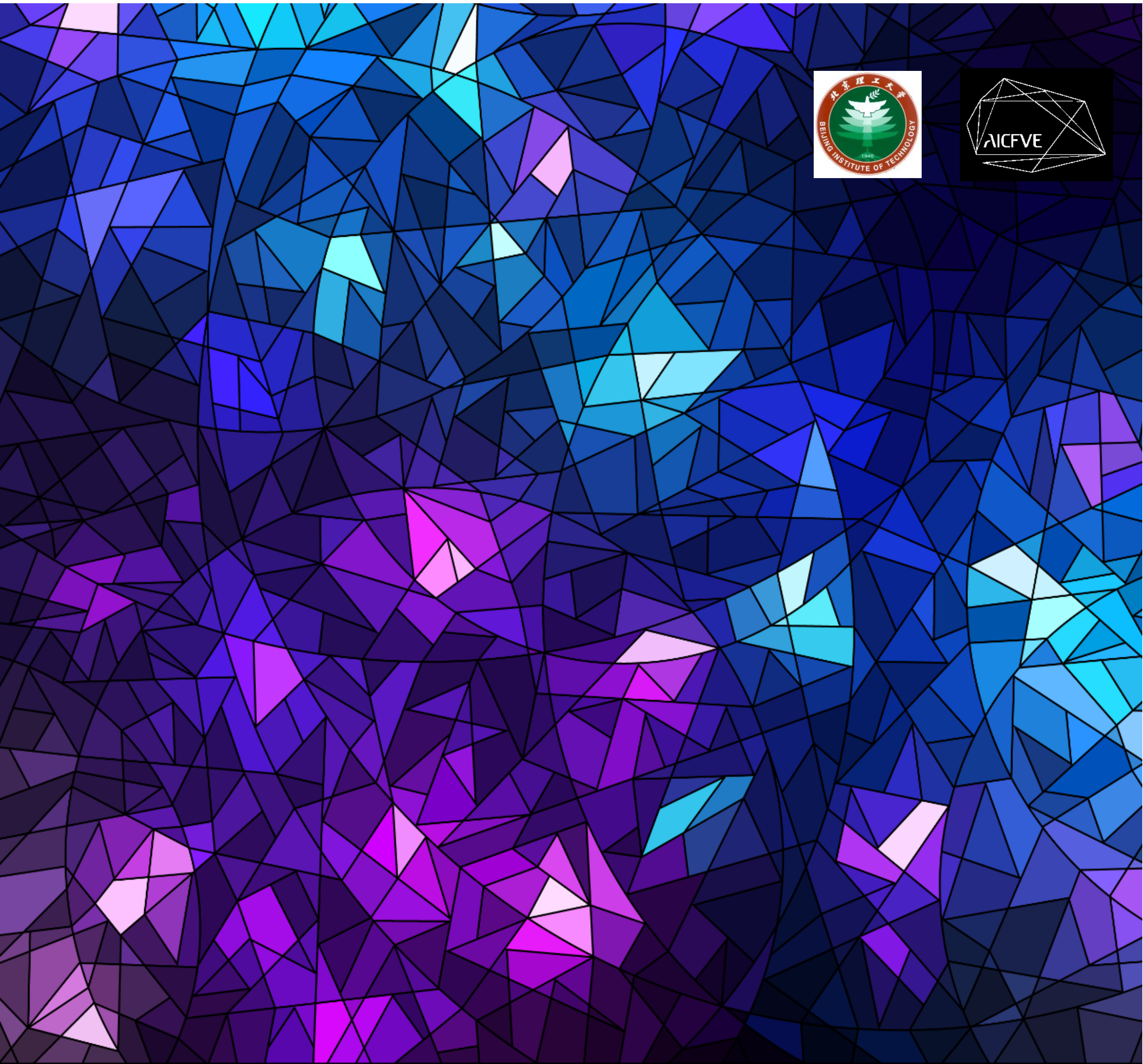


Experiment Report on the Impact of Long-Term Use of Virtual Reality (VR) Head-Mounted Displays on the Vision of Pre-teen Users

•Participating Organizations

Advanced Innovation Center for Future Visual Entertainment in Beijing

Beijing Institute of Technology

Beijing Blue Focus E-Commerce Co., Ltd.

CONTENTS

Abbreviations and Terminology

Abbreviation or Terminology	Description
VR	Virtual reality
HMD	Head-mounted display
Subject	Subject under experiment or test
Pre-teens	Young people between age 9 and age 12

1 Background

As virtual reality (VR) technology advances rapidly, VR devices have become part of everyday life. At present, most VR HMD designs often contain a single focal plane for both eyes. The design is structurally simple and widely user-friendly. Compared with traditional VRs intended for specialized and short-term use scenarios, the current VR technologies are expected to be used in general, long-term use scenarios. However, the users constantly focus their eyes at a fixed distance when using HMDs, which raises concerns of severe eye fatigue or even potential harm caused by VR HMDs. As VR technologies have brought dramatic changes and ground-breaking innovations to various industries, these concerns bring uncertainty to the development of the industry.

For this reason, Beijing Advanced Innovation Center for Future Visual Entertainment joined forces with Beijing Institute of Technology and other units and designed the experiment to explore the impact of long-time VR HMD use on pre-teen users' vision.

Organizations that participated in this experiment include:

Organization Name	Contents of Participation
Advanced Innovation Center for Future Visual Entertainment in Beijing	Experiment design, data analysis
Beijing Institute of Technology	Experiment implementation, data analysis
Beijing Blue Focus E-Commerce Co., Ltd.	Experiment implementation, field organization

Also, to ensure the validity of the experiment, various organizations are invited to contribute to data collection and analysis and to supervise the experiment process.

The list of organizations invited is as follows.

Organization Name	Contributions
Vive Immersive Media Lab	Suggestions on HMD setup and test

	environment
Beijing Sweet Technology Co., Ltd.	Suggestions on experiment design and implementation arrangement

2 Experiment Objectives

The experiment aims to explore the impacts of long-time VR HMD use on pre-teen users' vision. The experiment conducted comparative tests on tablets and VR HMD devices and arranged for the subject to take an hour-long test in pre-defined similar conditions. Meanwhile, to further analyze the impacts of VR HMDs on pre-teen users' vision. The experiment collects data from subjects before, after and during using VR HMDs through both subjective and objective measurement.

3 Participants

Main participants of the experiment are listed as follows.

Name	Organization	Title/ Position	Contents of Participation
Bao Yihua	Advanced Innovation Center for Future Visual Entertainment in Beijing	Research Executive	Experiment coordination, experiment design
Weng Dongdong	Beijing Institute of Technology	Associate researcher	Experiment design
Yu Xingyao	Beijing Institute of Technology	Master degree candidate	Experiment design, data analysis
Guo Jie	Beijing Institute of Technology	Doctoral candidate	Subjective measurement scale design
Liu Jun	———————	Certified optometrist	Objective test equipment use
Su Haixin	Beijing Blue Focus E-Commerce Co., Ltd.	Senior Manager	Experiment coordination

4 Experiment Process

4.1 Selection of Subjects

Subjects of the experiment are participants in an on-campus VR experience event. Project group records the whole process of how subjects participated in the event, organizes and analyzes the record to compile the experiment report.

The age range of subjects in the experiment: 9 to 12. Special requirements: exclude participants who have undergone myopia corrective surgery or who have eye problems (including acute myopia, hyperopia, achromatopsia, dyschromatopsia, and acute astigmatism) and participants whose eyes were fatigued prior to the experiment. Fifty eligible subjects participated in the experiment, including 26 males and 24 females.

Subjects of the experiment are divided into two groups by age: fourth-grade and sixth-grade group.

The actual condition is shown in Table 4-1:

Table 4- 1 Number of Subjects in Each Group

Sixth-grade	VR	25
	Tablet (control group)	13
Fourth-grade	VR	25
	Tablet (control group)	13

In the experiment, there are 50 subjects in total, 25 subjects for each group (11 females and 14 males in the sixth-grade group; 13 females and 12 males in the fourth-grade group). All subjects finished the VR experiment. To ensure the reliability of the experiment, 13 subjects from each group participated in the tablet (control group) test the following day.

4.2 Selection of VR Contents in the Experiment

In the experiment, the subjects use smart tablets or VR HMDs for a long time. Thus, some specific VR contents are required.

Criteria for selecting VR contents include:

(1) The contents should be vivid and interesting, educational while entertaining, and can be used by the subjects for a long time;

(2) Overall, the picture should be bright, and the luminance should remain steady throughout the experience;

(3) In the picture, there should be abundant objects;

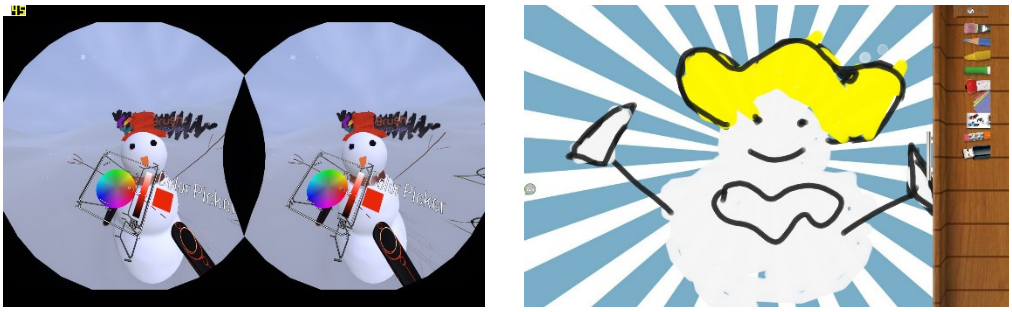
(4) A large amount of fast-moving objects and other elements that may cause motion sickness shall be avoided in the experiment;

(5) Contents in VR games and tablet games are highly consistent.

The experiment selected VR contents shown in Table 4-2. The picture is shown in Fig. 4-1.

Table 4-2 Contents of Experiment

Content Selection	Manufacturer	Group	Length of Use
Tilt Brush (with snowfield background)	Google	VR Group	1 Hour
Painting Pad	Murtha Design Inc.	Tablet Group	1 Hour



(a)Tilt Brush (b) Painting Pad

Fig. 4-1 VR contents in the experiment

4.3 Experiment Equipment

Main equipment in the experiment includes computers for constructing VR environments, HMDs, interaction tracking systems, and related test equipment.

The detailed list is shown in Table 4-3.

Table 4-3 List of experiment equipment

Equipment Name	Brand/Model/Parameter	Quantity	Application
HMDs and interaction tracking system	HTC Vive	4	Displaying VR contents Tracking interaction
High-performance workstation	Video card: NVIDIA GeForce GTX 970, AMD Radeon R9 290, or above	4	Rendering VR contents
Tablets	iPad	2	Tablet experiment as control group
	Samsung/Android	1	
	Nokia/Android	1	
Phoropter	NIDEK Multi-functional Computer Phoropter	1	Verifying changes in eye parameters before and after using device and before and after recovery
Visual acuity chart box	NIDEK visual acuity box	1	Verifying changes in vision before and after using device

4.4 Measurement Methods of Experiment

The experiment adopts both subjective and objective measurement. Subjective measurement uses visual fatigue scale. Objective measurement uses a visual acuity chart box to measure changes in the vision of subjects and uses a phoropter to measure changes in vision parameters of subjects before and after the experiment. Measurement items of the experiment are shown in Table 4-4.

Table 4-4 Measurement Items and Measurement Methods

Measurement Items	Equipment	Measurement Methods
diopters	Phoropter	Measuring the diopters of the left and right eyes for

		assessing vision decline within a short time. Main measurable parameters are: Diopters of spherical power of left eye (L/OS) and right eye (R/OD) (Sphere, S, positive diopter (+) or negative diopter (-)· diopter of cylindrical power (Cylinder, C, positive (+) or negative (-) degree of astigmatism; Types of astigmatism (CYL, positive (+), negative (-) or mix) Astigmatic axis direction (Axis, A, degree); Pupillary distance (PD/mm); Spherical equivalent power, S.E. VD on optometry prescription is a parameter set by a computer system and does not vary by individual. Eye accommodation;
Vision	Visual acuity chart box	Subjects' line of sight shall be parallel with the row for 1.0. The distance between the visual acuity chart box and subjects shall be fixed at 1.1 meters. Before the examination, subjects' eyes shall be covered for a few moments. Then subjects shall identify the opening direction of the character "E". Record the last line where they can still identify opening directions of all characters. Normal vision shall be 1.0 or above.
Vision Fatigue	Subjective test scale for visual fatigue	The subjective test scale for visual fatigue adopts James E. Sheedy's scale, which lists various factors with potential impacts to visual fatigue and considers diverse conditions that lead to symptoms of visual fatigue. The scale includes 9 items corresponding to 9 symptoms of visual fatigue. The highest score for each item is 100. The higher the score, the more severe the symptom.

Need to emphasize is Sheedy visual fatigue scale. In a normal situation items in the scale shall be graded by the subjects themselves. Since the subjects are relatively young, they are lack of understanding to the scale shall and perception is not clear about their symptoms. Therefore in this experiment, the scale shall be divided into 5 grades: 0 for "no symptom at all", 25 points for "mild symptom", 50 points for "moderate symptom", 75 points for "severe symptom", and 100 points for "very severe symptom”. The subjects respond with one of the five options above after the researchers orally ask them about the severity of their symptoms. Refer to Appendix I to see the nine questions.

Fig. 4-2 Equipment for objective measurement phoropter (left) visual acuity chart box (right)

4.5 Experiment Procedure

The experiment process contains three stages: preparation stage, testing stage, and vision recovery stage.

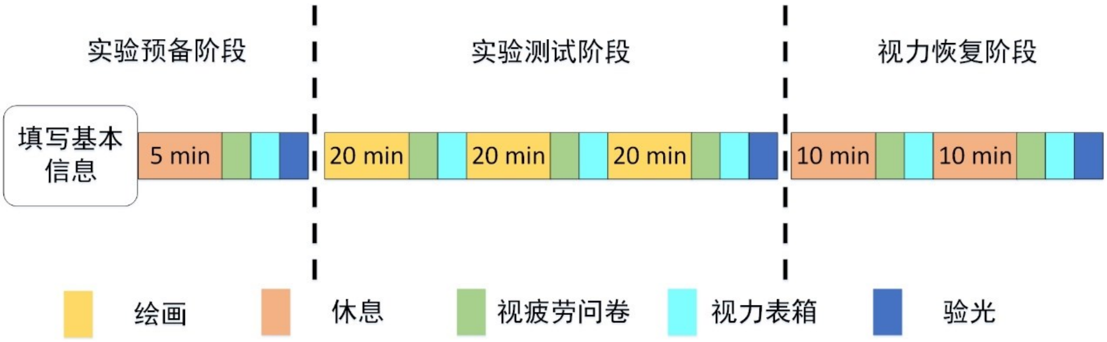


Fig. 4-3 Experiment procedure

Note:
实验预备阶段 Preparation phase
实验测试阶段 Testing phase
视力恢复阶段 Recovery phase
填写基本信息 Fill in basic info
绘画 Painting
休息 Rest time
视疲劳问卷 Visual fatigue scale
视力表箱 Visual acuity chart
验光 Optometry exam

4.5.1 Preparation Stage (5 Minutes)

Before the experiment, after relaxing the eyes for 5 minutes, subjects fill out the visual fatigue scale and complete an optometry and vision test. The experiment setup is shown in Fig 4-4.

Fig. 4-4 Photo of experiment setup

4.5.2 Testing Stage (60+ Minutes)

In the testing stage, subjects in the tablet group paint with painting pads under normal indoor lighting. Subjects in VR group wear HMDs and paint with the software Tilt Brush.

Testing for each subject lasts for 60 minutes, 20 minutes per section and three sections in total. At each stage, subjects must finish their painting tasks within the testing time, and painting contents for the two groups are roughly identical for each section. At the end of each section, subjects shall complete the visual fatigue scale, and their visual acuity chart data are collected; the time for such checks does not count toward the 20 minutes of each section. Each test lasts for no more than 2.5 minutes.

After the 60-minute process ends, subjects are required to take one more optometry exam. The experiment setup is shown in Fig 4-5.

Fig. 4-5 Photo of experiment setup

4.5.3 Vision Recovery Stage (20+ minutes)

After the experiment, all subjects are required to relax their eyes for 20 minutes, 10 minutes for each section. In the sections, subjects are prohibited from watching any electronic screens as to allow their vision to recover. At the end of each 10-minute section, subjects shall complete a visual fatigue scale, and their visual acuity chart data are collected. After the 20-minute stage ends, subjects are required to take one more optometry exam.

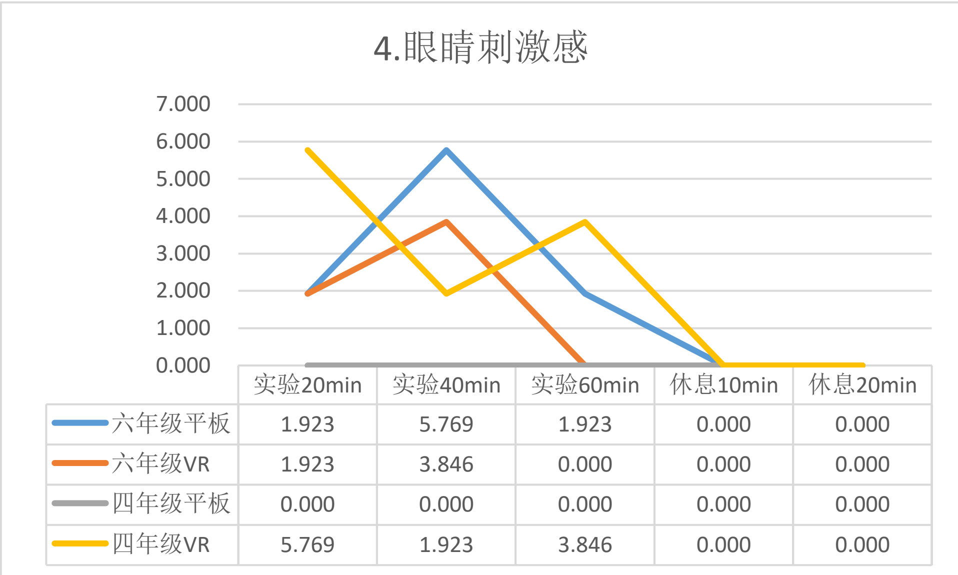
5 Experimental Results

5.1 Subjective Measurement： Visual Fatigue Scale

The visual fatigue scale results are shown in Fig. 5-1. The data showed the difference values of fatigue between the 2nd, the 3rd, the 4th, the 5th, and the 6th experiment and the initial measurement values respectively, indicating the impact of the relevant experimental phase on the result, i.e.

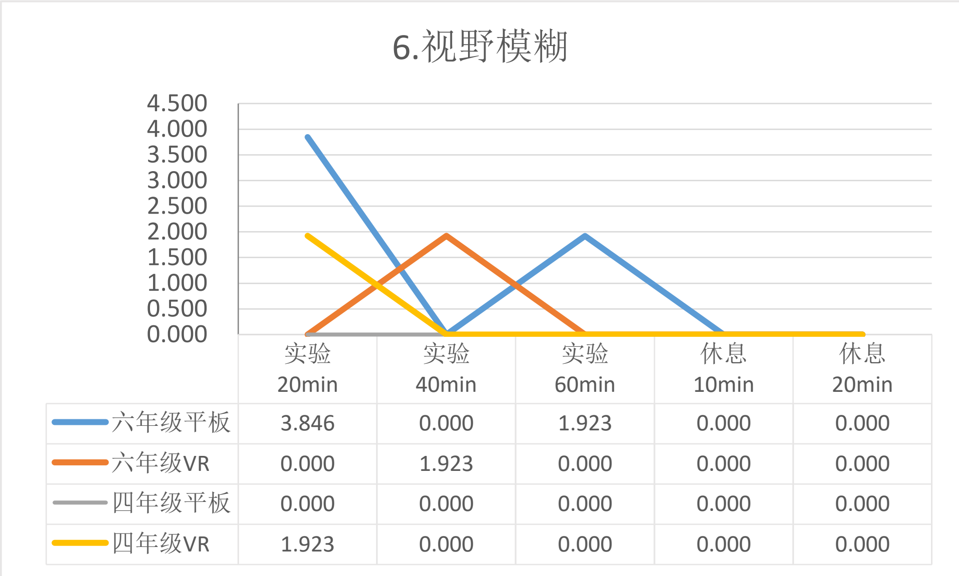
the number 0 represents the data is the same as the level prior to the experiment.

From the visual fatigue scale results, we can observe the changes in the VR subjects and the tablet subjects' subjective fatigue levels in various fatigue symptoms. In a few symptoms, the fatigue levels of the tablet subjects are higher than the VR subjects, such as the fourth symptom (eye stimulation) and the sixth symptom (blurry vision) in Fig. 5-1 (a) (b). In some other symptoms, the fatigue levels of the tablet subjects are slightly lower than the VR subjects, such as the eighth symptom (dry eye) and the ninth symptom (headache) in Fig. 5-1 (c) (d).

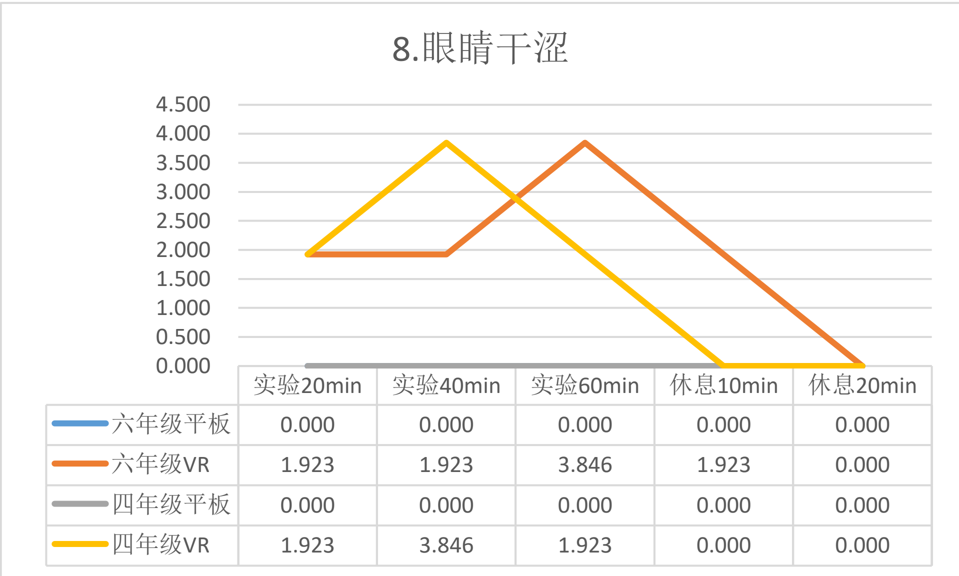


	实验20min	实验40min	实验60min	休息10min	休息20min
六年级平板	1.923	5.769	1.923	0.000	0.000
六年级VR	1.923	3.846	0.000	0.000	0.000
四年级平板	0.000	0.000	0.000	0.000	0.000
四年级VR	5.769	1.923	3.846	0.000	0.000

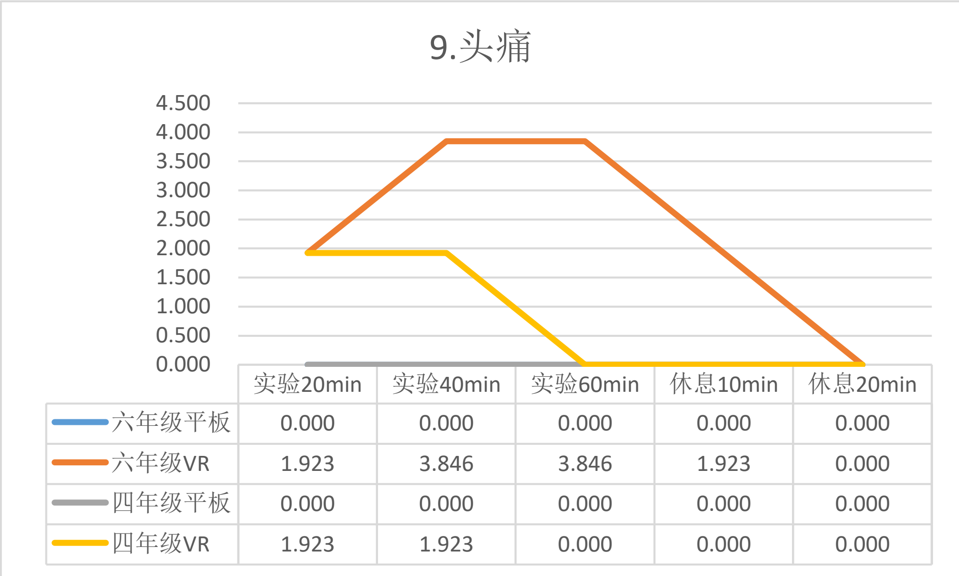
(a)


6.视野模糊
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
实验 20min | 实验 40min | 实验 60min | 休息 10min | 休息 20min
六年级平板 3.846 0.000 1.923 0.000 0.000
六年级VR 0.000 1.923 0.000 0.000 0.000
四年级平板 0.000 0.000 0.000 0.000 0.000
四年级VR 1.923 0.000 0.000 0.000 0.000

(b)


8.眼睛干涩
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
实验20min | 实验40min | 实验60min | 休息10min | 休息20min
六年级平板 0.000 0.000 0.000 0.000 0.000
六年级VR 1.923 1.923 3.846 1.923 0.000
四年级平板 0.000 0.000 0.000 0.000 0.000
四年级VR 1.923 3.846 1.923 0.000 0.000

(c)



(d)

Fig. 5-1 Changes of Visual Fatigue

Note:

眼睛刺激感 Eye stimulation

视野模糊 Blurry vision

眼睛干涩 Dry eyes

头痛 Headache

实验 Test

休息 Rest time

六年级平板 Sixth-grade tablet

六年级 VR Sixth-grade VR

四年级平板 Fourth-grade tablet

四年级 VR Fourth-grade VR

In addition, the four figures above indicate that the both VR and tablet subjects can gradually recover from the visual fatigue caused by the experiment by resting. In other words, visual fatigue of the VR and the tablet subjects in the experiments will completely disappear after a short rest.

For the symptoms of VR subjects, one possible reason is that the HTC VIVE used in this experiment has an adjustable minimum pupillary distance of 60 mm; by contrast, the average pupillary distance of sixth-grade subjects in this experiment is 60 mm, while the minimum distance is 56 mm, and the fourth-grade subjects have a pupillary distance of 57 mm on average with a minimum value of 52 mm. Slight difference in pupillary distance may influence fatigue level to some extent. Moreover, the VR experience requires more physical activities, and a few fourth-grade subjects report that the HMD is a little heavy. These may be important reasons for some fatigue symptoms in the VR group. Further investigation into this phenomenon and its cause are needed.

5.2 Objective Measurement Results: Vision Changes

Due to the pre-teen group's better vision and visual accommodation, there are more subjects with binocular vision of 1.5 on the standard visual acuity chart. Considering the chart’s upper limit is 1.5 with no room for growth, samples are categorized based on the 1.5-binocular-vision-standard will be analyzed independently before the first measurement, as shown in Table 5-1.

Table 5-1 Categorization

Initial Binocular vision	Total Samples	Initial Vision =1.5	Initial Vision <1.5
Sixth-grade VR	25	13	12
Fourth-grade VR	25	17	8
Tablet Device (sixth-grade)	13	7	6
Fourth-grade Tablet	13	10	3

Besides, since the adjacent classes are not entirely equidistant from 0.2 to 1.5 in the chart (i.e., the higher level of 1.0 is not 1.1 but 1.2, whose upper level is 1.5), the results are converted into those in a five-division notation logarithmic visual acuity chart, so that we can calculate differences between the initial measurement and the 2nd, 3rd, 4th, 5th, and 6th. Please see appendix II for the chart.

5.2.1 Subjects with 1.5 Initial Vision

The subjects have experienced 6-phase tests. Among them, subjects at fourth-grade and sixth-grade with 1.5 initial vision (5.2 in the logarithmic visual acuity chart), whether they are VR group or tablet group, the absolute values of vision changes in the chart are all less than 0.1 and recover fast in the following phase.

Table 5-2 The average vision changes of subjects with 1.5 initial vision

	After 20min of Testing	**After 40min of Testing**	**After 60min of Testing**	**After 10min of Rest**	**After 20min of Rest**
Sixth-grade Tablet	0.000 SD=0.000	-0.014 SD=0.035	0.000 SD=0.000	0.000 SD=0.000	0.000 SD=0.000
Sixth-grade VR	-0.014 SD=0.047	-0.014 SD=0.047	-0.014 SD=0.047	-0.014 SD=0.047	-0.014 SD=0.047
Fourth-grade Tablet	-0.013 SD=0.033	0.000 SD=0.000	0.000 SD=0.000	0.000 SD=0.000	0.000 SD=0.000
Fourth-grade VR	-0.006 SD=0.023	0.000 SD=0.000	-0.006 SD=0.023	0.000 SD=0.000	0.000 SD=0.000

5.2.2 Subjects with Initial Vision of Less than 1.5

The details of subjects with initial vision of less than 1.5 are as follows:

Table 5-3 The average vision changes of subjects with initial vision of less than 1.5

	After 20min of Testing	After 40min of Testing	After 60min of Testing	After 10min of Rest	After 20min of Rest
Sixth-grade Tablet	0.050 SD=0.126	0.167 SD=0.340	0.050 SD=0.126	0.033 SD=0.149	0.000 SD=0.153
Sixth-grade VR	0.039 SD=0.095	0.035 SD=0.117	0.010 SD=0.104	0.007 SD=0.085	0.016 SD=0.083
Fourth-grade Tablet	-0.033 SD=0.047	0.033 SD=0.094	0.033 SD=0.094	0.000 SD=0.082	-0.033 SD=0.125
Fourth-grade VR	0.061 SD=0.047	0.031 SD=0.042	0.042 SD=0.057	0.048 SD=0.055	0.048 SD=0.055

According to the figure, in the first 20 minutes, the three groups other than the fourth-grade tablet group showed increased vision; at the end of the test (60 minutes after the experiment starts, namely, the value in the third phase), all groups showed vision improvement from before the test; and in the rest process, the vision of the tablet group gradually returned to previous levels and those of the VR group still showed upward trends.

Fig. 5-2 shows the visual changes of the non-1.5-vision subjects in the rest period. According to the figure, the vision of the tablet group in the rest period tended to decrease: the sixth-grade tablet group showed unchanged vision in the last test period compared to before the experiment, while the fourth-grade tablet group showed a slight vision decrease. In contrast, the average visual values of the VR subjects within the post-experimental 20-minute rest period returned to at least the pre-experimental level, or even higher. However, these data with a large standard deviation in Fig. 5-3 can only be used as a qualitative analysis, generally implying that the condition of the VR subjects is slightly better than that of the tablet subjects.

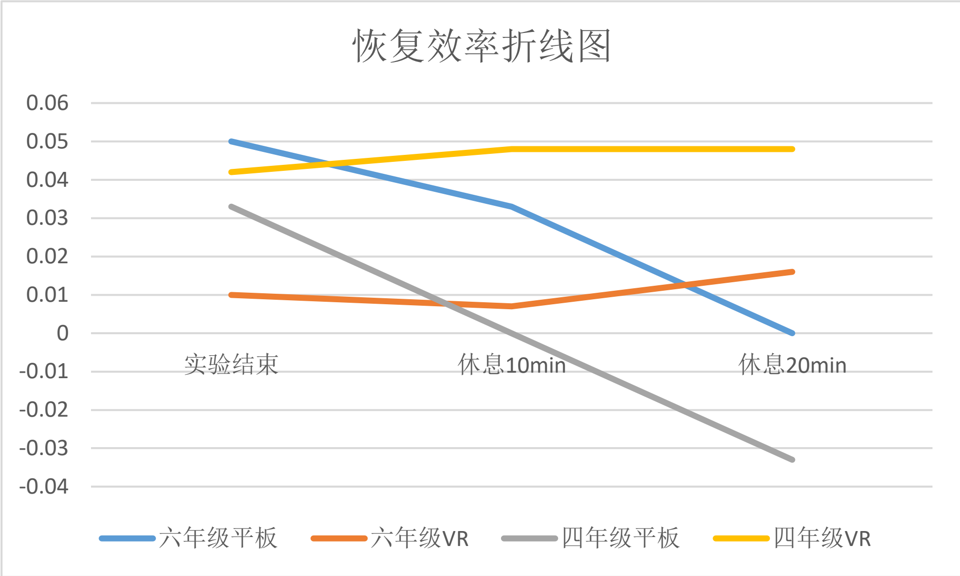


Fig. 5-2 Visual recovery during rest

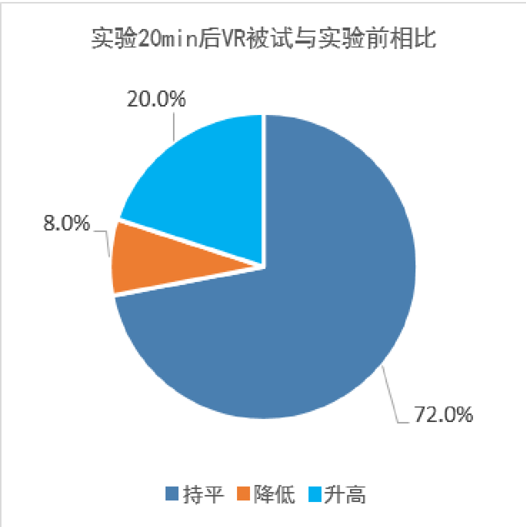
Note:
恢复效率折线图 Recovery progress line chart
实验结束 End of experiment
休息 Rest time
六年级平板 Sixth-grade tablet
六年级 VR Sixth-grade VR
四年级平板 Fourth-grade Tablet
四年级 VR Fourth-grade VR

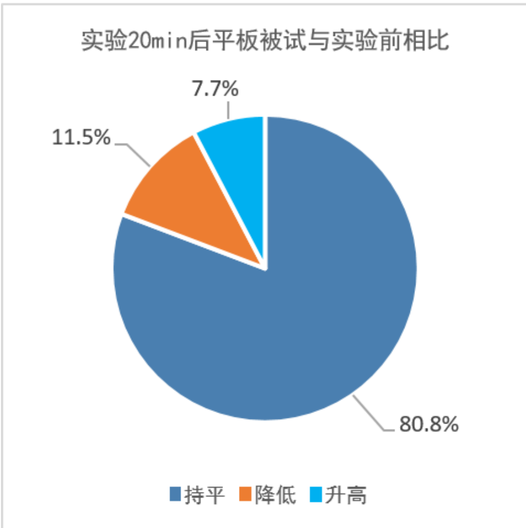
In addition, the experiment also compares pre-experimental vision with that of the first 20 minutes of the test, at the end of the test and after the rest period, with the results shown in Fig. 5-3. Based on the figure, in the overall experimental procedure, lasting more than 1 hour and 20 minutes, the percentage of the vision of VR subjects leveling off and even increasing is as high as 90%. The possible reason for the increase is the high probability of the pre-teen users' tendency to farsightedness.

The visual promotion reasons can attribute from the following two aspects:

A paper published from the Rochester University in 2007, the conclusion is for users often play video games, their average visual sharpness is higher than the users who don't play games with the same age. While the users who are not playing game usually, we can let them play video games regularly each day and increase their visual sharpness appropriately. In this experiment, because young users' vision did not finalize the design and more vulnerable to external influence, we speculate that during they use of HMD and flat subjects in 1 hour, they have influenced by the video games, so there is a brief visual improvement.

Another possible reason for the increase is the high probability of the pre-teen users' tendency to farsightedness with the effect thereof on the experiment discussed in 5.2.3.





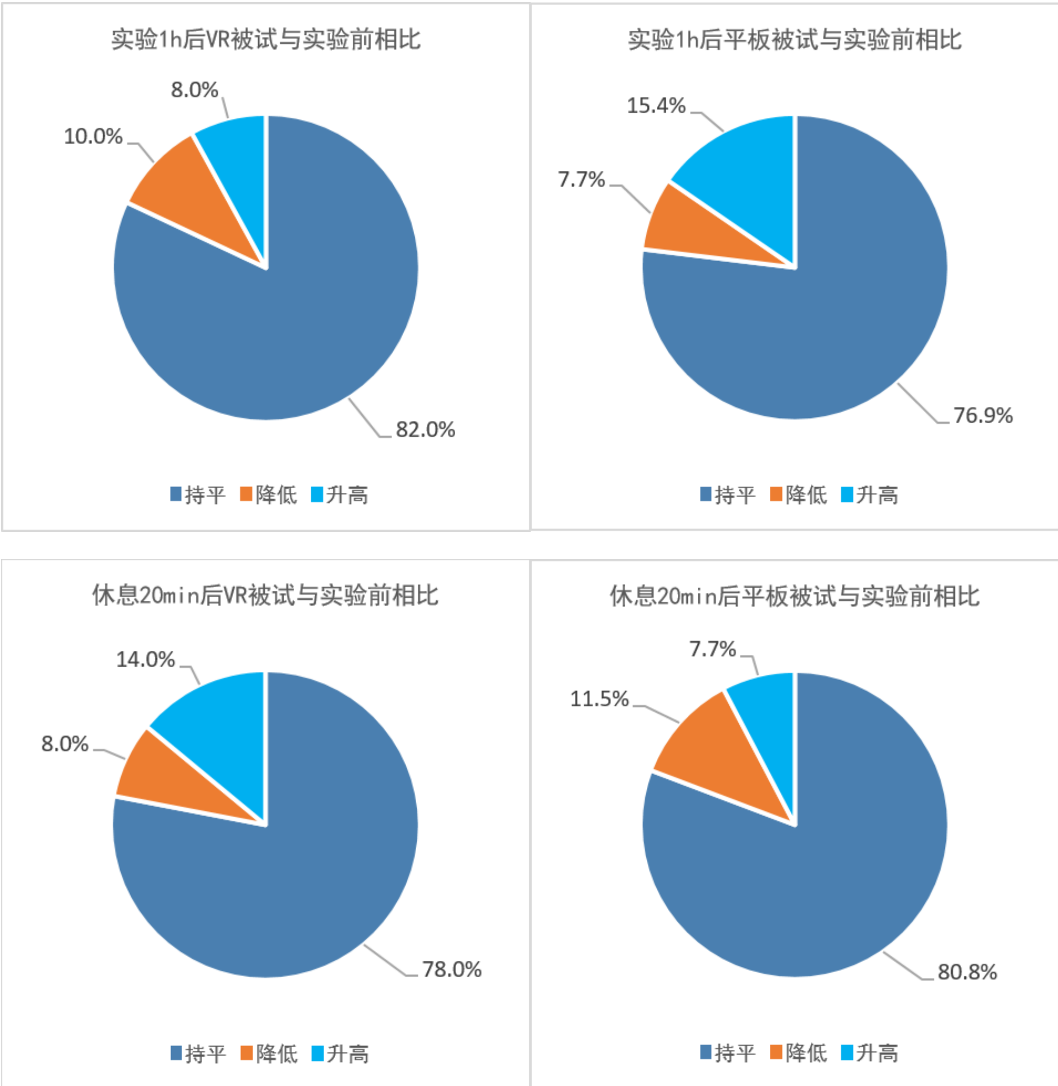


Fig. 5-3 Changes in Vision

Note:

实验 20min 后 VR 被试与实验前相比

VR Subjects 20 mins after the test compared to before the test

实验 20min 后平板被试与实验前相比

Tablet Subjects 20 mins after the test compared to before the test

实验 1h 后 VR 被试与实验前相比

VR Subjects 1h after the test compared to before the test

实验 1h 后平板被试与实验前相比

Tablet Subjects1h after the test compared to before the test

休息 20min 后 VR 被试与实验前相比

VR Subjects 20 mins after rest compared to before the test

休息 20min 后平板被试与实验前相比 Tablet Subjects 20 mins after rest compared to before the test 持平 Unchanged 降低 Decreased 升高 Improved

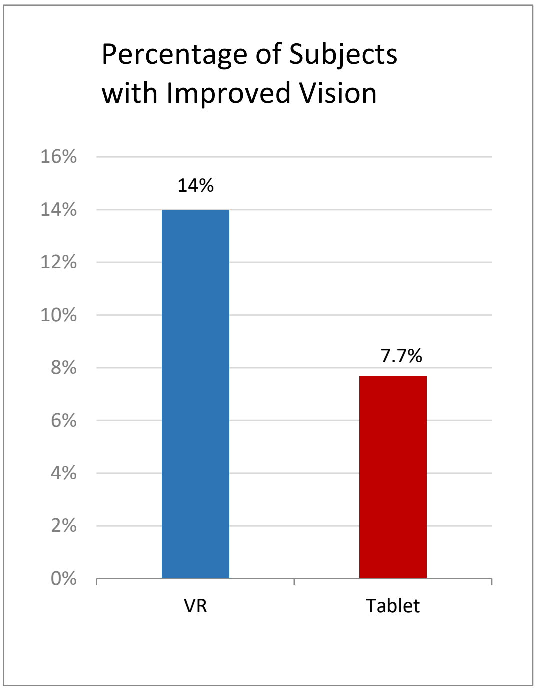


Fig. 5-4 Percentage of Subjects with Improved Vision

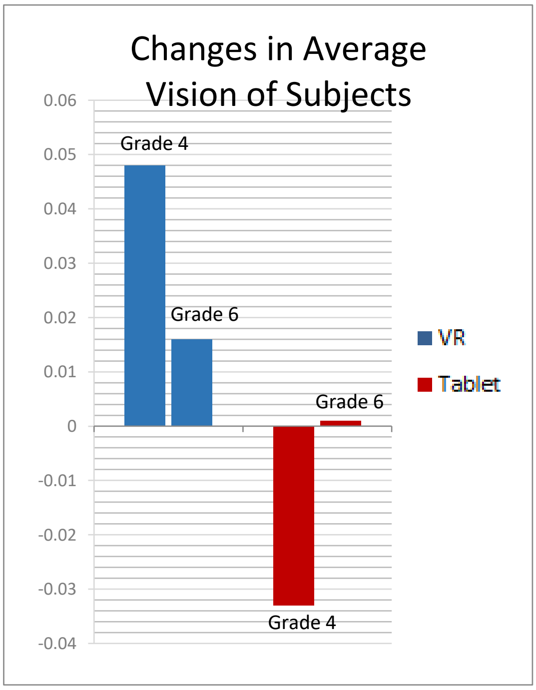


Fig. 5-5 Changes in Average Vision of Subjects

From Table 5-3 and Fig. 5-3, end results of vision change are deducted and shown in Fig. 5-4 and Fig. 5-5. Based on Fig. 5-4 Percentage of Subjects with Improved Vision, as many as 14% of the VR subjects showed improvement of vision while only 7.7% of tablet subjects showed improvement of vision after the experiment. The number of subjects with improved vision in the VR group is almost twice of that of the tablet group; in Fig.5.5 the distribution data of changes in average vision of subjects, the average change value in the vision of subjects in the VR group is ≥ 0, which means that the average vision of the VR group tends to improve; the average change value in vision of subjects in the tablet group is ≤ 0, which means that the average vision of the VR group tends to remain unchanged or even to drop. Based on the current initial empirical results, VR has a positive influence on students' vision, if the VR devices are worn properly and suitable VR contents are selected. If we consider tablets to be acceptable for students to use in classroom learning, then VR devices should be acceptable as well.

5.2.3 Impact of Hyperopia and Myopia on Experimental Results

Among the 50 VR subjects, optometry exams showed that 22 had at least one eye with a diopter higher than 0; while 12 out of the 26 tablet subjects had such a condition. Eyes with a diopter higher than 0 can be considered to have hyperopia tendencies; when such eyes watch objects they can clearly see placed fairly close to them for long periods of time, the lens will adjust, pulling closer the focal plane of the eye.

Among the 50 VR subjects, optometry exams showed that 32 had at least one eye with a diopter lower than 0; while 18 out of the 26 tablet subjects had such a condition. Eyes with a diopter lower than 0 can be considered to have myopia tendencies; when such eyes watch objects they can clearly see placed fairly close to them for long periods of time, the lens will adjust, pushing the focal plane out.

Meanwhile, the visual acuity of the left and right eyes are not completely identical, i.e., it is possible for one eye of the same person to have myopia tendency while the other is normal or even has hyperopia tendency. The myopia/ hyperopia tendencies of the 50 VR subjects are shown in Table 5-4:

Table 5-4 myopia/ hyperopia tendencies of both eyes of the VR subjects

R ight Left	**Myopia**	**Hyperopia**	**Normal**	**Total**
Myopia	21	1	0	22
Hyperopia	6	9	2	17
Normal	4	5	2	11
Total	31	15	4	50

Also, the subjects' vision before the experiment is further categorized based on the absolute difference|∆D| between the diopters (D) of the eyes. The strength of prescription is defined by the value of the diopter multiplied by 100. In the chart, 0.5 and 1 are used to divide the diopter difference: the diopter difference of the eyes is consider "Negligible" if the value is smaller than 0.5, "Minor" if the value is between 0.5 and 1, and "Notable" if the value is greater than 1.

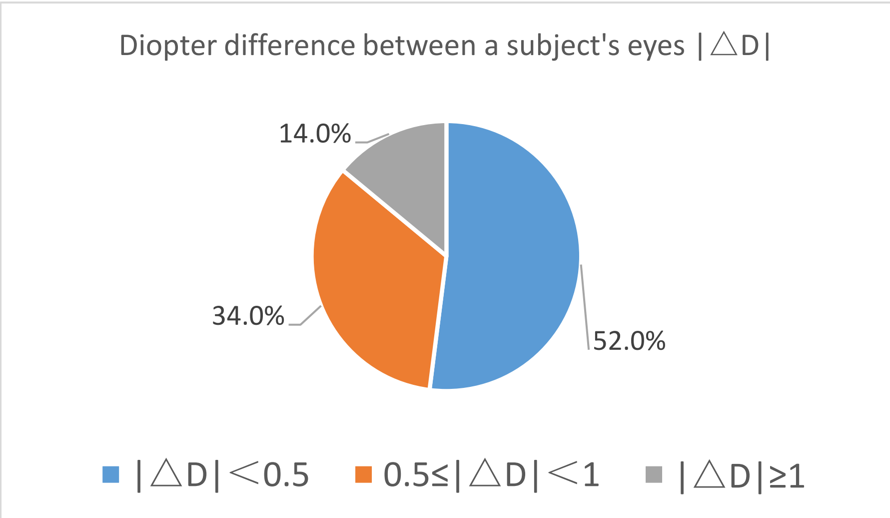


Fig.5-6 the D-value ratio chart of the diopter difference between a subject's eyes |△D|

According to the experimental data, the vision of pre-teen users' left and right eyes is notably different; there are even subjects whose eyes have both hyperopia and myopia tendencies. For example, Table 5-4 and Fig.5-6 show that 1 subject has myopia in the right eye and hyperopia in the left eye, and 6 subjects have hyperopia in their right eyes and myopia in their left eyes; 34% of the VR subjects have a diopter difference between 0.5 and 1, and 14% have a diopter difference higher than 1. Due to poor self-control, most children develop poor vision habits, which can cause a diopter difference between their eyes; this is common among pre-teen children.

To examine the vision changes of subjects with vision of less than 1.5 and myopia/hyperopia symptoms, the following table contains records of the VR/tablet subjects' vision 1 hour after using the VR/tablet:

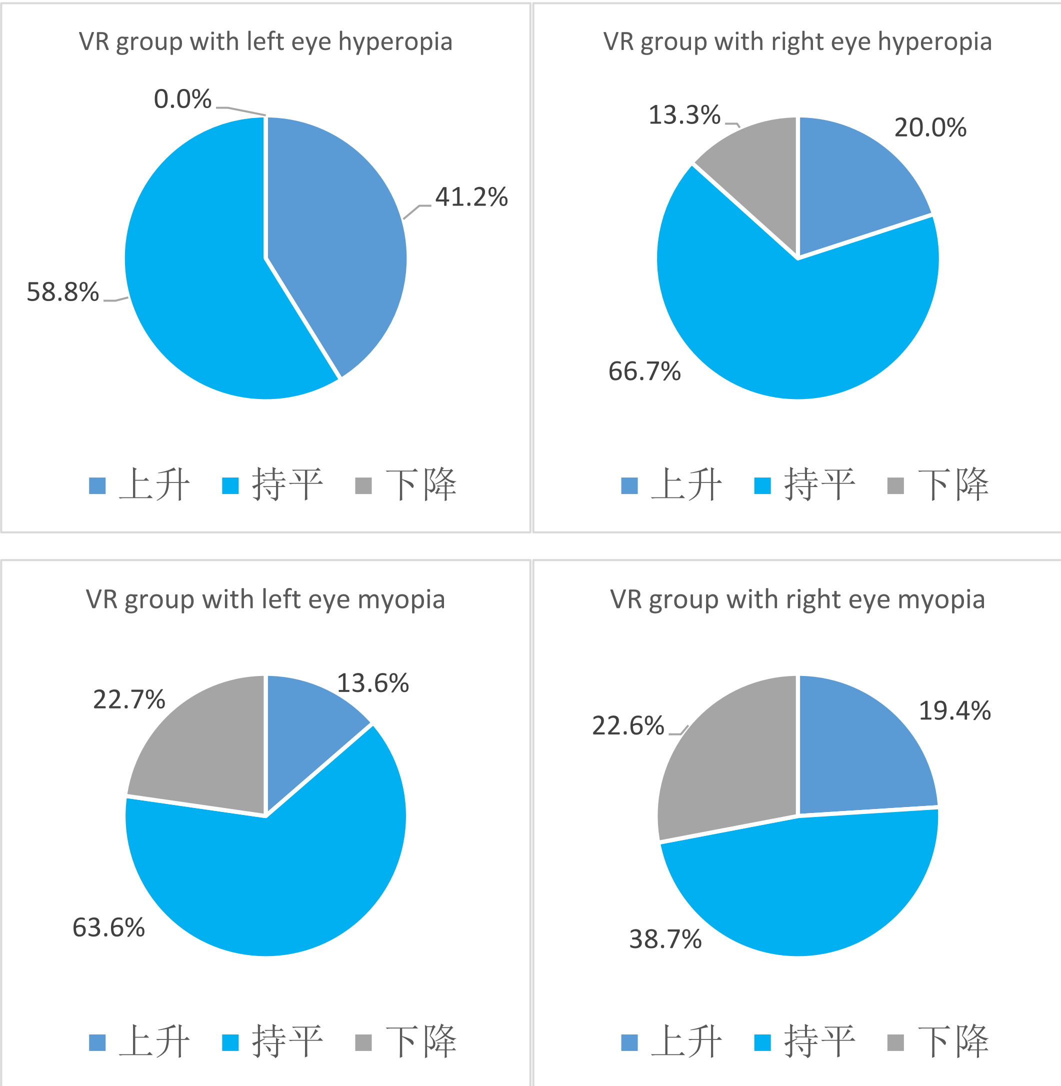
Table 5-5 Vision change of subjects with myopia/hyperopia problems

Group	**Vision problem**	**Eye**	**Total**	**Initial vision ＜ 1.5**	**Subjects with improved vision**	**Subjects with unchanged vision**	**Subjects with decreased vision**	**Percentage of subjects with decreased vision**
VR (50 subjects)	Hyperopia	Left eye	17	11	7	4	0	0.0 %
		Right eye	15	7	3	2	2	13.3 %
	Myopia	Left eye	22	14	3	6	5	22.7 %
		Right eye	31	19	6	6	7	22.6 %
Tablet (26 subjects)	Hyperopia	Left eye	8	3	1	2	0	0.0 %
		Right eye	6	1	1	0	0	0.0 %
	Myopia	Left eye	14	9	2	5	2	14.3 %
		Right eye	18	11	3	4	4	22.2 %

As shown in Table 5-5, among the 50 VR subjects, there are 15 with hyperopia in the right eye, of which 8 subjects had an initial vision of 1.5 (not listed in the Table), and 7 less than 1.5. One hour after the experiment, 3 of the 7 subjects with vision less than 1.5 reported improved vision, 2 had unchanged vision and 2 had decreased vision; the subjects with decreased vision account for 13.3% of the 15 subjects in total.

Therefore, VR HMD designs for pre-teen users should take the hyperopia/myopia cases into account and support independent adjustment for the focal distance of each eye.

The figure below (Fig. 5-7) lists the vision change of subjects with myopia/hyperopia after the experiment.



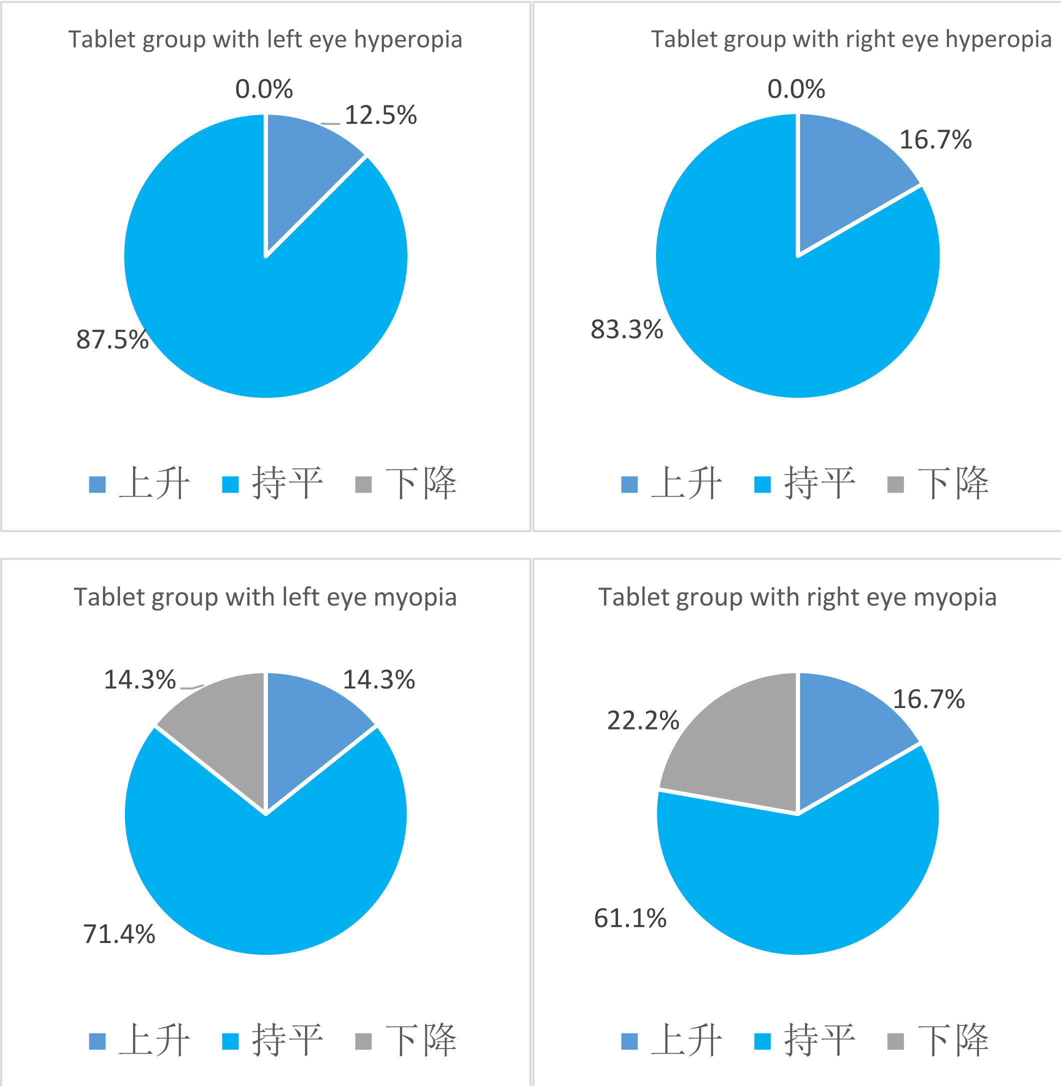


Fig.5-7 Percentage of vision change for left/right eye with abnormal vision

Note:
上升 Improved 持平 Unchanged 下降 Decreased

According to the statistics, we can conclude: the VR experiment can correct hyperopia to a certain degree (this is specific to subjects with initial vision less than 1.5, those with vision at 1.5 are not included). A part of the subjects with myopia also improved their vision in the VR experiment, and those reporting decreased vision accounted for less than 25%. As shown in Table 5-5, of all the subjects with abnormal vision, the percentage of decreased vision in the VR group is fairly close to that in the tablet group.

For both myopia and hyperopia, the symptoms can be temporarily relieved by focusing at a proper distance; vision can get closer to the higher value on the vision chart. This is the reason why both experiment groups have some subjects with improved vision.

A typical set of data is as follows:

1) Tan, a fourth-grade subject, has hyperopia tendencies in both eyes, in the VR experiment:

Tan's right eye had a vision of 0.9 and diopter of 1.5 before the experiment; his vision changed to 1.0 and diopter to 1.0 after the experiment

The left eye had a vision of 0.9 and diopter of 0.5 before the experiment; his vision changed to 1.0 and diopter to 0.25 after the experiment

Since the virtual imaging distance inside HTC VIVE is fixed, it is preliminarily estimated that the virtual image distance was closer than Tan's focal length before the experiment; during the process of experiment, Tan's focal length was drawn in under the traction of the virtual image surface in the HMD. Therefore, after one hour of the experiment, the hyperopia symptoms of subjects are slightly alleviated.

2) Song, a fourth-grade subject, has myopia tendencies in both eyes, and participated in both the VR and tablet experiments:

In the VR experiment:

Song's right eye had a vision of 0.2 and diopter of -3.25 before the experiment, but after the VR experiment, his vision changed to 0.4 and diopter to -3.0;

The left eye had a vision of 0.3 and diopter of -2.75 before the experiment; his vision changed to 0.5 and diopter remained at -2.75 after the experiment

In the tablet experiment:

Song's right eye had a vision of 0.2 and diopter of -3.0 before the experiment, after the experiment, his vision was still 0.2 and diopter was still -3.0;

The left eye had a vision of 0.3 and a diopter of -2.75 before the experiment; the vision changed to 0.4 and diopter to -2.5 after the experiment.

Therefore, we can conclude: the subject already has myopia, and the virtual image distance of HTC VIVE and the distance between the eyes and the tablet are comparatively large, which requires the subject to watch at a distance with some effort, this is the reason why the vision is temporarily improved after long-term use of VR/ tablet, and the diopter also dropped slightly.

6 Conclusions and Summary

This experiment used an existing painting software in VR and on tablets and designed a process to study the effect of VR HMD on pre-teen users' vision by comparing the long-term use of VR devices and tablets. The observation means adopted in this experiment include phoropters, visual acuity chart boxes, and asthenopia questionnaires.

6.1 Conclusions

As the experimental data shows, subjective fatigue brought on by VR experience and visual fatigue brought on by tablets can be alleviated by a short rest. As for vision, the majority of pre-teen subjects reported that their vision was unchanged or even improved after the experiment; that is because of the considerable amount of simulated distance vision scenes used in VR. Meanwhile, according to the experimental data, a higher portion of VR subjects had improved vision compared with the subjects who used tablets continuously for 1 hour. In conclusion, for pre-teen users, VR HMDs and tablets have a similar influence on vision and using VR HMDs may have a more positive influence.

According to the experiment data, the following conclusions can be drawn:

Conclusion 1: most subjects who use VR HMD for less than 1 hour show unchanged or improved vision;

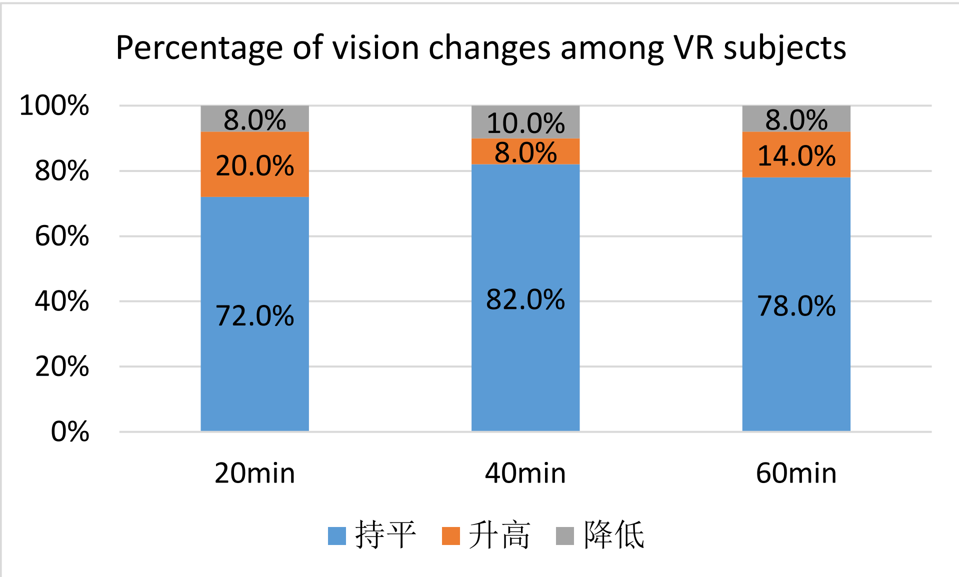


Fig.6-1 Percentage chart showing vision changes among VR subjects

Note:
持平-unchanged 升高-improved 降低-decreased

This result is affected by a large percentage of subjects with hyperopia tendencies, which brings up the measured vision. As shown in Table 5-3, the average vision after using VR for 20 min, 40 min, and 1 hr are consistently higher than the vision before the experiment; Fig.6-1 is derived from three sub-graphs concerning the VR subject group in Fig. 5-3, it shows the percentage of vision changes in three different duration among the VR subjects with vision other than 1.5. As shown in Fig.6-1, 90% of VR subjects show unchanged or improved vision after 1-hour VR use, only 10% of them report decreased vision.

Conclusion 2: After 1-hour continuous use of tablet devices, the subjects' vision cannot recover completely in 20 minutes of rest, while the VR subjects show more positive changes;

According to Fig. 5-2 and Table 5-3, it is found that during the 20-minute rest after the experiment, the vision of the tablet group slowly drops and the final vision and initial vision of sixth-grade tablet subjects are the same; the final vision of fourth-grade tablet subjects is even lower than the initial vision. Compared with the tablet group, vision of the VR subjects basically remained unchanged or even improved. As is shown in Fig. 5-4, after the experiment, as many as 14% of VR subjects have improved vision to some degrees while only 7.7% of tablet subjects have improved vision. The number of subjects with improved vision in the VR group is almost twice that of the tablet group. Therefore, we can conclude that with proper contents and usage methods, VR can improve the vision of pre-teen users to some extent.

Conclusion 3: VR HMD has a stronger impact on pre-teen users' vision;

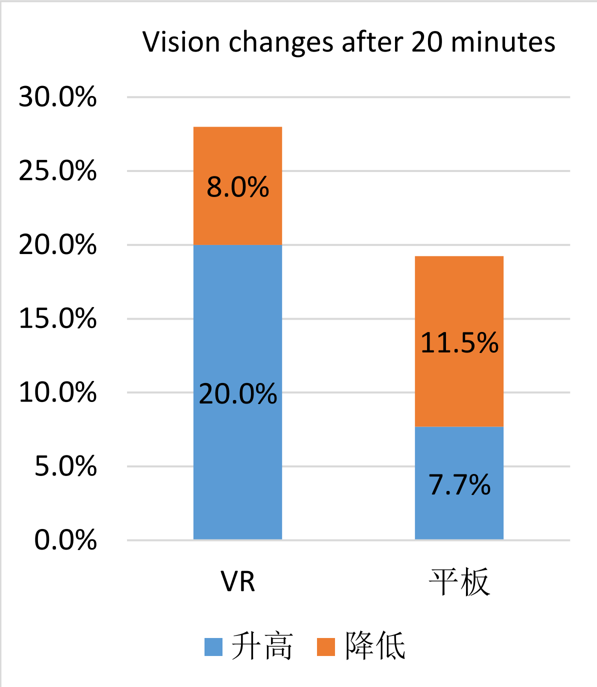


Fig.6-2 the percentage of vision changes after 20-minutes of VR use among subjects with vision other than 1.5

Note:
平板-Tablet 升高-Improved 降低-Decreased

Fig.6-2 is derived from the subgraph of Table 5-3 which describes the first 20 min; it reflects the percentage of subjects whose vision is affected at 20min. After 20 minutes, 28% of the VR subjects' vision is affected while less than 20% of the tablet device subjects report vision change. This indicates that VR has a greater impact on subjects' vision than that of a tablet device.

According to the experimental data, short-term VR use can affect the vision of pre-teen users with myopia/hyperopia problems. As Fig.5-7 and Table 5-5 show, 41.2% of VR subjects with hyperopia in their left eye reported improved vision after 1 hour of VR use, and 20% of those with hyperopia in their right eye reported improved vision; 13.6% of VR subjects with myopia in their left eye reported improved vision, and 19.4% with myopia in their right eye reported improved vision. In addition, the actual virtual image distance of the VR device (HTC Vive) in this experiment is about 1.7 m, which is longer than the 0.3 m to 0.45 m focal distance of commonly-used tablets. With proper content, greater virtual image distance is more beneficial for subjects with a long usage time.

Therefore, if the virtual image distance of HMD is properly set, the HMD will have a corrective effect on vision; otherwise, it will further impair the users' vision.

6.2 Suggestions

Based on the foregoing analysis of the experimental data, the project team offers the following suggestions:

(1) VR HMDs can be used as vision correction devices

Pseudo-myopia and pseudo-hyperopia commonly seen among pre-teen users can recover; but, if pre-teen users are frequently exposed in fixed-focus conditions for a long time, their visions may become fixed. Therefore, HMDs designed for normal adult eyes and featuring a close distance and fixed virtual focal points on the market are not suitable for frequent and long-term use by children.

Children often do not wear glasses for vision correction. If VR HMDs can correct the abnormal vision of pre-teen users by means of the variable virtual image distance while presenting entertaining content, they can make significant contributions to the protection of pre-teen users' vision.

Therefore, given the high eye elasticity of pre-teen users, if a VR HMD has adjustable single left/right-eye screens, allows users to increase the virtual image distance for a myopic eye and decrease it for a presbyopia eye while ensuring clarity, then it can effectively correct young peoples' unbalanced vision, pseudo-myopia, and pseudo-hyperopia. Young people with normal vision can effectively prevent myopia by adjusting the virtual image distance on a regular basis.

(2) Pre-teen users should use customized VR HMDs

As stated in conclusion 3, the vision distribution among pre-teen users is mixed. If pre-teen users are required to use VR HMDs for a long time, a suggestion is: to protect the user's eyes, we should understand his/her actual vision through vision examination and adjust the VR HMD accordingly. Supposing the pupillary distance could be adjusted at a broader range or VR devices were smaller and lighter, theoretically, VR could be applicable for users along a wider age range.

6.3 Limitations of the experiment

This experiment only measures the impact of one-hour VR use on young users' vision. Due to the constraints of the experiment itself, the conclusion is not without limitations, which mainly manifest as follows:

(1) On the current market, there is no mainstream VR HMD product specifically designed for children. In this long-term experiment, the device used, HTC VIVE HMD, is one of the relatively high-end HMDs available in the market, which features better performance in resolution, screen refresh rate, system delay, etc. Moreover, the virtual image distance of the HTC Vive is relatively large, which makes it more suitable for the experiment to some extent. Based on initial empirical statistics of the experiment, researchers concluded that HTC Vive can be used by children older than 10 if they wear the device properly and suitable content is chosen. Moreover, the conclusion is only applicable to premium VR HMDs with equally high performance. Other HMDs, like smart phone-based HMD, which have lower performance (for example, longer delay, excessively shorter virtual image distance, etc.) may cause greater fatigue and negatively impact

vision. This experiment has not fully considered the effects of such HMDs over long-term use.

(2) This experiment does not consider the effects of environmental illumination. As previous studies showed, different brightness and flickering frequency have significantly different effects on users' level of fatigue and vision. Subject to its own conditions, this experiment only selects properly-illuminated VR scenarios and does not discuss the impact of different brightness in VR on vision and fatigue. Some VR scenarios that are too dark, too bright or subject to frequent illumination changes may lead to more severe visual fatigue and decreased vision.

(3) This experiment tests long-time (1-hour) VR use, but it is performed on a short-term basis, and thus does not reflect the impact of long-term frequent VR use. For the so-called "use for a long time" for the effects of visual acuity and visual fatigue, the content of the more appropriate exposure time is 2-5 hours. However, considering the younger users visual safety, as well as in the past did not have the experiment precedent for younger users using of HDM, this experiment still limits the time within an hour in safety. This is a safety period for young users to play video games and won't have a negative impact. Since previous studies show that the long-term use of blue-ray and other elements will impair vision and cause diseases, supplemental test data is required before this experiment conclusion is applied to long-term scenarios.

(4) To minimize the measurement time, this experiment uses the Sheedy visual fatigue scale, which is relatively short. Such scale provides the respective extent of the nine symptoms rather than the overall visual fatigue of each measurement, which is not conducive to macroscopic visual fatigue comparison.

6.4 Negative reaction report of this experiment

Among the fourth-grade subjects in this experiment, one suffered physical discomfort from VR use: In the 40th minute, the subject asked to rest for one more minute after visual examination and questionnaire survey; and in the third stage of this experiment (the 40th minute to the 60th minute), which is 20 minutes long, the subject requested to terminate the experiment after 18 minutes. The subjects' subjective response shows that he enjoys sports and dislikes painting; The past VR research experience shows that their interests to experiment content will drastically impacte comfort of using VR. So in the circumstance that absence of relevant experimental precedent, eyestrain is speculated that in addition to hardware factors such as HMD, another possible cause of anxiety is his strong resistance to painting, which comes from the subject's dislike for the content of the experiment (painting) and being isolated from contents other than painting tools in the virtual environment.

Appendix I: Subjective test scale for visual fatigue

Q1: Do your eyes burn? (Burning)

0 points ... 100 points

None Mild Moderate Severe Very severe

Q2: Do you feel pain in the eyes? (Ache)

0 points ... 100 points

None Mild Moderate Severe Very severe

Q3: Do you feel any eye strain? (Strain)

0 points ... 100 points

None Mild Moderate Severe Very severe

Q4: Do your eyes feel irritated? (Irritation)

0 points ... 100 points

None Mild Moderate Severe Very severe

Q5: Are your eyes watery? (Tearing)

0 points ... 100 points

None Mild Moderate Severe Very severe

Q6: Is your vision blurry? (Blurring)

0 points ... 100 points

None Mild Moderate Severe Very severe

Q7: Do your eyes get double vision? (Double Vision)

0 points ... 100 points

None Mild Moderate Severe Very severe

Q8： Do you feel dryness in your eyes? (Dryness)

0 points 100 points

None Mild Moderate Severe Very severe

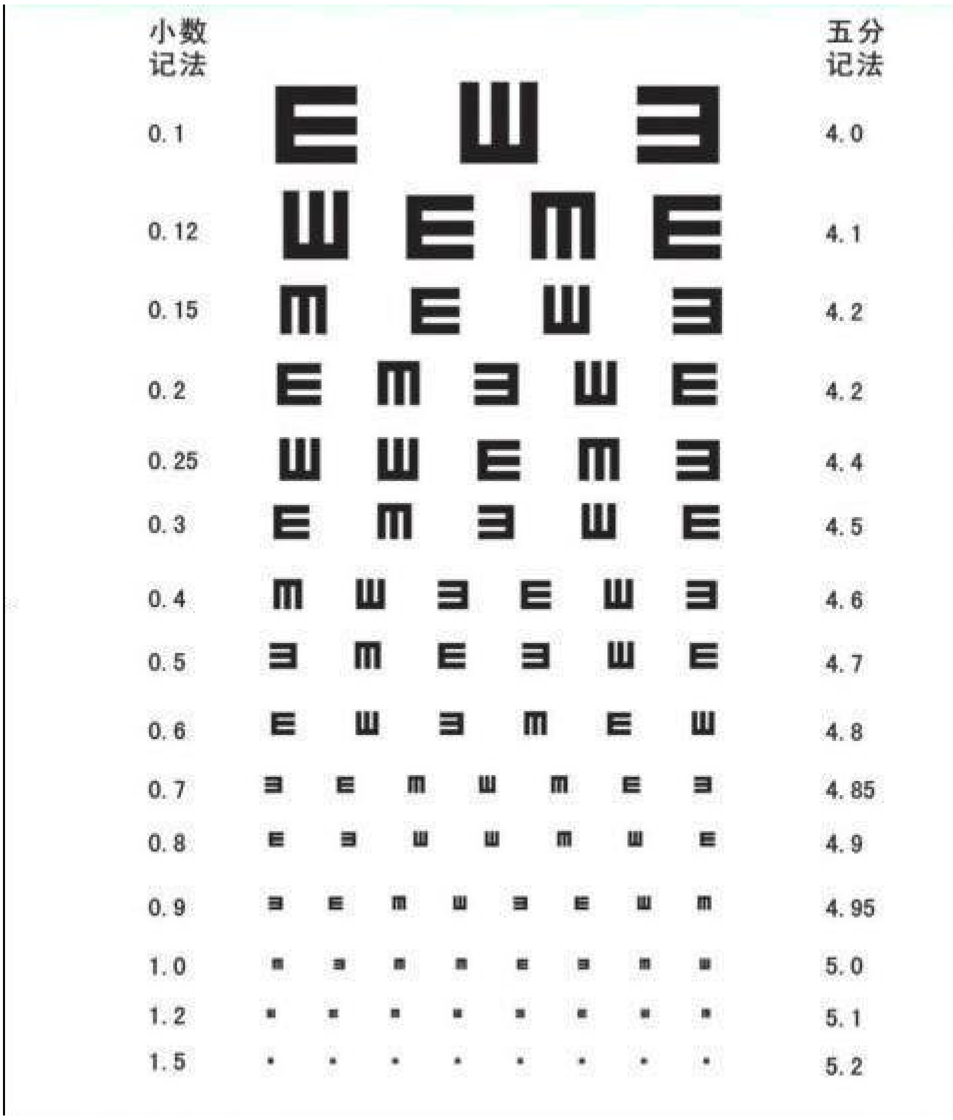
Q9： Do you have a headache now? (Headache)

0 points 100 points

None Mild Moderate Severe Very severe

Appendix II: Visual acuity chart and conversion basis

The decimal records act in the chart is an international standard widely used by medical workers, this experiment stored the initial vision of subjects in this format. The five-division notation on the right, also known as the logarithmic visual acuity chart, is an original vision record method in China, this experiment recorded the final vision data in this format.



Note：

小数记法 Decimal notation

五分记法 Five-scale notation

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