# Effect of Weak Hyperopia on Stereoscopic Vision

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**Abstract.** Convergence, accommodation and pupil diameter were measured simultaneously while subjects were watching 3D images. The subjects were middle-aged and had weak hyperopia. WAM-5500 and EMR-9 were combined to make an original apparatus for the measurements. It was confirmed that accommodation and pupil diameter changed synchronously with convergence. These findings suggest that with naked vision the pupil is constricted and the depth of field deepened, acting like a compensation system for weak accommodation power. This suggests that people in middle age can view 3D images more easily if positive (convex lens) correction is made.

**Keywords:** convergence, accommodation, pupil diameter, middle age and 3D image.

## 1 Introduction

Recently, a wide variety of content that makes use of 3D displays and stereoscopic images is being developed. Previous studies reported effects on visual functions after using HMDs. Sheehy and Wilkinson (1989) [1] observed binocular deficits in pilots following the use of night vision goggles, which have similarities to the HMDs used for VR systems. Mon-Williams et al (1993) [2] showed that physiological changes in the visual system occur after periods of exposure of around 20 min. Howarth (1999) [3] discussed the oculomotor change which might be expected to occur during immersion in a virtual environment whilst wearing HMD.

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Meanwhile, effects such as visual fatigue and motion sickness from continuously watching 3D images and the influence of binocular vision on human visual function remain insufficiently understood. Various studies have been performed on the influence of stereoscopic images on visual function [4] [5] [6]. Most prior studies discussed the effects of visual image quality and extent of physical stress. These studies have employed bioinstrumentation or surveys of subjective symptoms [7]. To find ways to alleviate visual fatigue and motion sickness from watching 3D movies further studies are needed.

Under natural viewing conditions the depth of convergence and accommodation agrees in young subjects. However, when viewing a stereoscopic image using binocular parallax, it has been thought that convergence moves with the position of the reproduced stereoscopic image, while accommodation remains fixed at the image display, resulting in contradictory depth information between convergence and accommodation, called discordance, in the visual system [8]. With the aim of qualitatively improving stereographic image systems, measurements under stereoscopic viewing conditions are needed. However, from objective measurements of the accommodation system, Miyao et al., [9] confirmed that there is a fluctuating link between accommodation and convergence in younger subjects during normal accommodation.

In middle-aged and elderly people gazing at forward and back movement for a long time, it is said that the discordance is such that even during natural viewing there is a slight difference between accommodation and convergence, with accommodation focused on a position slightly farther than that of real objects and convergence focused on the position of the real objects. However, we obtained results that indicate discordance between accommodation and convergence does not occur in younger subjects gazing at a stereoscopic view for a given short time.

Weal (1975) [10] reported the deterioration of near visual acuity in healthy people is accelerated after 45 years of age. We found a similar tendency in near vision in this experiment [11]. Similar to presbyopia, cataract cloudiness gradually becomes severer with age after middle age. Sun and Stark [12] also reported that middle-aged subjects have low accommodative power, that their vision should be properly corrected for VDT use, and that more care should be taken to assure they have appropriate displays than for their younger counterparts.

In fact, it may be possible for middle-aged and elderly people with weak hyperopia to supplement accommodative power when they are watching 3D images by deepening the depth of field with trigger pupil contraction. However, this pupil contraction due to near reaction makes it a little harder to see with reduced light. The possibility is therefore suggested that pupil contraction is alleviated with correction by soft contact lenses.

The purpose of this experiment was to investigate pupil expansion by simultaneously measuring accommodation, convergence and pupil diameter.

## 2 Methods

### 2.1 Accommodative and Convergence Measurement and Stimulus

In this experiment, visual function was tested using a custom-made apparatus. We combined a WAM-5500 auto refractometer and EMR-9 eye mark recorder to make an original machine for the measurements. The WAN-5500 auto refractometer (Grand Seiko Co., Ltd.) can measure accommodation power with both eyes opened under natural conditions, and the EMR-9 eye mark recorder (Nac Image Technology, Ltd) can measure the convergence distance. 3D images were presented using a liquid crystal shutter system.

In this experiment, 3D image was shown with a display set 60 cm in front of subjects. The distance between the subjects' eyes and the target on the screen was 60 cm (1.00/0.6 = 1.67 diopters (D)) (Note: diopter (D) = 1/distance (m); MA (meter angle) = 1/distance (m)). The scene for measurements and the measurement equipment are shown in Fig. 1. Convergence, accommodation and pupil diameter were measured simultaneously while subjects were watching 3D images.

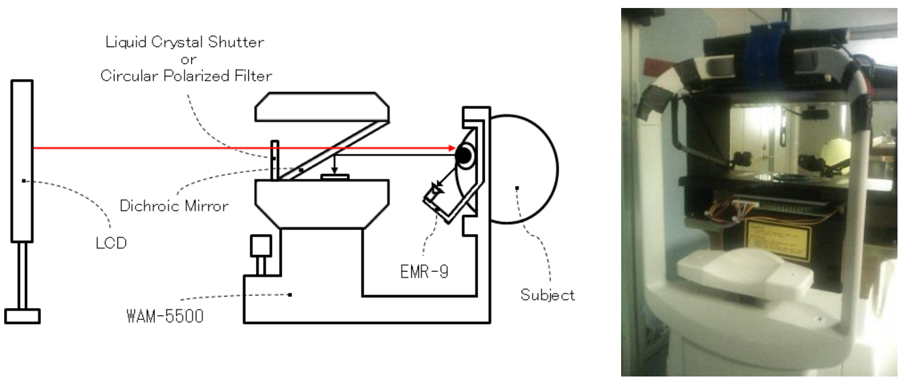


**Fig. 1.** Experimental Environment

## 2.2 Experiment Procedure

The subjects were three healthy middle-aged people (37, 42, and 45 years old) with normal uncorrected vision, one healthy younger person (25 years old) with correction using soft contact lenses and one healthy elderly person (59 years old) with normal uncorrected vision. The subjects were instructed to gaze at the center of the sphere with the gaze time was set at 40 seconds. All subjects had a subjective feeling of stereoscopic vision. While both eyes were gazing at the stereoscopic image, the lens accommodation of the right eye was measured and recorded. Informed consent was obtained from all subjects and approval was received from the Ethical Review Board of the Graduate School of Information Science at Nagoya University.

The concept of stereoscopic vision is generally explained to the public as follows: During natural vision, lens accommodation (Fig. 2) coincides with lens convergence (Fig. 3). Gaze time was 40 seconds, and the accommodation of the right eye was measured and recorded while the subjects gazed at the stereoscopic image with both eyes. The sphere moved virtually in a reciprocating motion range of 20 cm to 60 cm in front of the observer with a cycle of 10 seconds (Fig. 4). They gazed at the open-field stereoscopic target under binocular and natural viewing conditions.

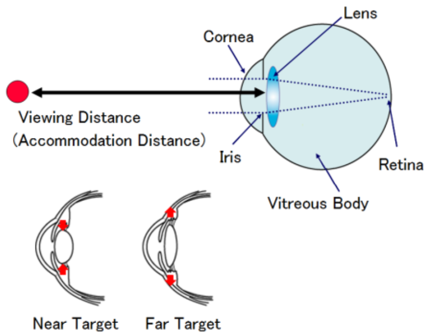


**Fig. 2.** Lens Accommodation

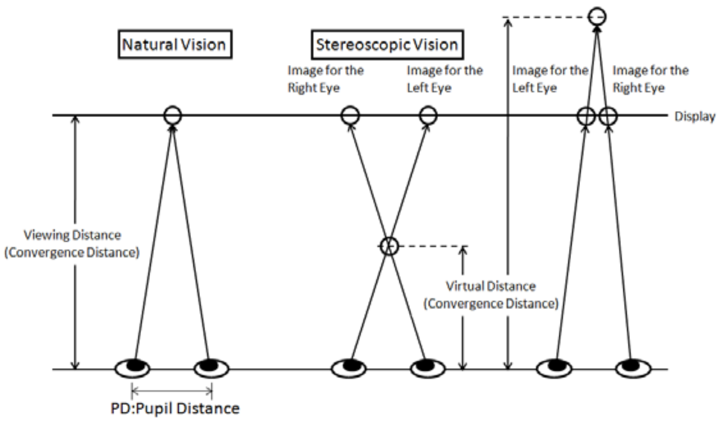


**Fig. 3.** Convergence

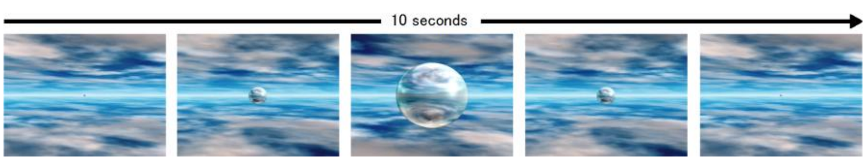


**Fig. 4.** Spherical Object Movies (Power 3D™ : Olympus Visual Communications, Corp.)

Measurements were made three times under two conditions: (1) with the subjects using uncorrected vision and (2) with subjects using soft contact lenses (+1.0 D). Subjects used their naked eyes or wore soft contact lenses, and their refraction was corrected to within ±0.25 diopter. ("Diopter" is the refractive index of a lens and an index of accommodation power. It is the inverse of meters, for example, 0 stands for infinity, 0.5 stands for 2 m, 1 stands for 1 m, 1.5 stands for 0.67 m, 2 stands for 0.5 m, and 2.5 stands for 0.4 m). Middle-aged and elderly subjects with normal vision of the naked eyes also wore soft contact lenses (+1.0).

The experiment was conducted according to the following procedures (Table 1). Subjects' accommodation and convergence were measured as they gazed in binocular vision at a sphere presented in front of them. The illuminance of the experimental environment was about 36.1 (lx), and the brightness of the sphere in this environment was 5.8 (cd/$m^2$).

**Table 1.** Experimental Environment

| | | |
|---|---|---|
| Brightness of Spherical Object(cd/$m^2$) | 5.8 | |
| illuminance(lx) | 36.1 | |
| Size of Spherical Object (deg) | Far | 0.33 |
| | Near | 12 |

## 3 Results

Convergence, accommodation and pupil diameter were measured simultaneously while subjects were watching 3D images. The following results were obtained in experiments in which subjects were measured with naked eyes or while wearing soft contact lenses, with their refraction corrected to within ±0.25 diopters (Figure 5, 6, 7).

Figure 5 shows the results for Subject A (25 years of age), Figure 6 shows the results for Subject B (45 years of age) and Figure 7 shows results for Subject C (59 years of age). Figures 8 and 9 show the results for subjects who wore soft contact lenses for near sight. Figure 8 shows measurement results for Subject B (45 years of age), and Figure 9 shows the results for Subject C (59 years of age). These Figures show accommodation and convergence with diopters on the left side vertical axis. The right vertical axis shows pupil diameter. Table 2 shows the average pupil diameter for middle-aged Subject B and elderly Subject C.

Subjects' convergence was found to change between about one diopter (1 m) and five diopters (20 cm) regardless of whether they were wearing the soft contact lenses. The diopter value also fluctuated with a cycle of 10 seconds. In addition, we confirmed that the accommodation and pupil diameter changed synchronously with convergence. Thus, the pupil diameter became small and accommodation power became large when the convergence distance became small.

The accommodation amplitude every 10 seconds was from 2D to 2.5D with the naked eye (Figure 5), Figure 6 shows 0.5D, Figure 7 shows from 0.5D to 0.8D, and when the subjects were wearing soft contact lenses (+1.0 D) for mild presbyopia, Figure 8 shows from 0.5D to 1D, and Figure 9 shows from 0.5D to 1.5D.

From the results in Table 2, it is seen that the average pupil diameter with naked eyes was larger than with corrected soft contact lenses. The dilation in the diameter was 0.4 mm for Subject B and 0.2 mm for Subject C.

**Table 2.** Average of pupil diameter with uncorrected and soft contact lenses (+1.0 D)

| | middle-aged Subject B | elderly Subject C |
|---|---|---|
| Average of pupil diameter with subjects using uncorrected vision | 3.69 mm | 2.02 mm |
| Average of pupil diameter with subjects using soft contact lenses (+1.0 D) | 4.05 mm | 2.20 mm |

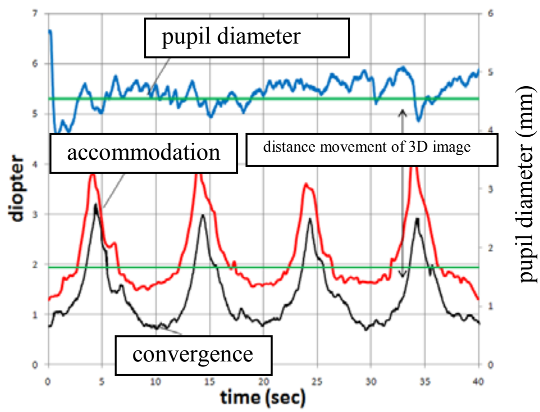


**Fig. 5.** Subject A (25 years of age) wore soft contact lenses for near sight

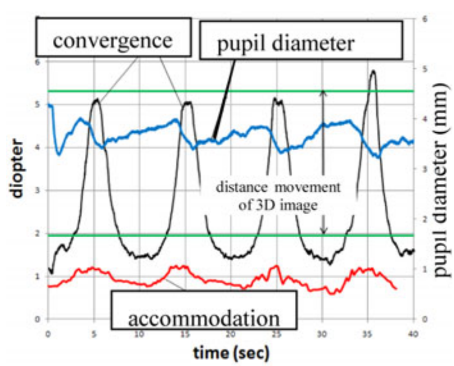


**Fig. 6.** Subject B (45 years of age) with naked eyes

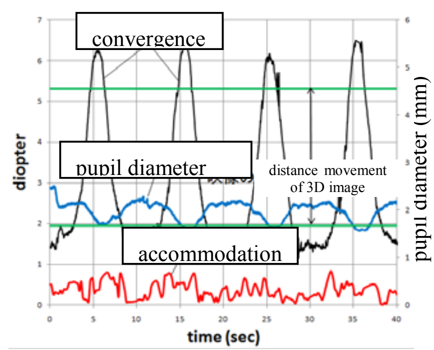


**Fig. 7.** Subject C (59 years of age) wore soft contact lenses for near sight

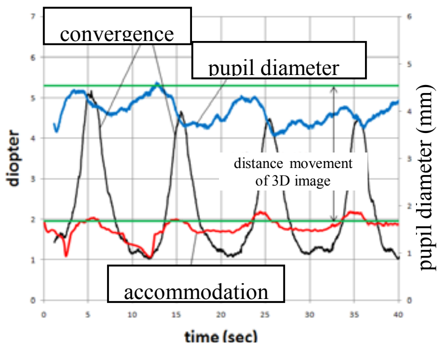


**Fig. 8.** Subject B (45 years of age) wore soft contact lenses for near sight

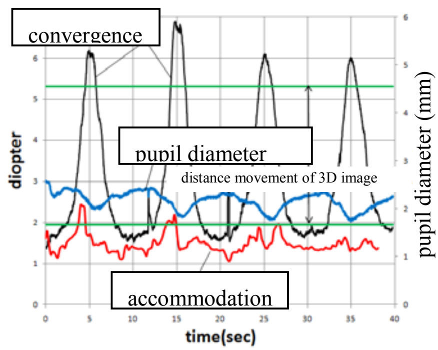


**Fig. 9.** Subject C (59 years of age) wore soft contact lenses for near sight

## 4 Discussions

It was shown that the focus moved to a distant point as the virtual movement of the visual target away from the subject. The change occurred at a constant cycle of 10 seconds, synchronously with the movement of the 3D image. By measuring the accommodation movement in response to the near and far movement of the 3D image, the distant view was shown to be about from 1D to 5D (1 meter to 0.2 meters). These results were consistent with the distance movement of the 3D image (0.6 – 0.2 meter). Thus, we were able to measure the results as subjects' watched 3D image with both eyes. Figure 5 shows large movements in both accommodation and convergence.

Wann et al. [13] stated that within a virtual reality system, the eyes of a subject must maintain accommodation at the fixed LCD screen, despite the presence of disparity cues that necessitate convergence eye movements to capture the virtual scene. Moreover, Hong et al. [14] stated that the natural coupling of eye accommodation and convergence while viewing a real-world scene is broken when viewing stereoscopic displays.

In the 3D image with the liquid crystal shutter system, the results of this study differed from those of a previous study in which accommodation was fixed on the LCD. Meanwhile, the change in accommodation was smaller than the large movement seen in convergence. These results show the influence of aging in the deterioration of accommodation. However, accommodation in Subject B and Subject C was fixed behind the display. Accommodation was not fixed on the display in any case. This also did not match the previous study.

At the closest the distance, the difference between accommodation and convergence was about 4D in Figure 6, about 5-6D in Figure 7, about 2-3D in Figure 8 and about 4-5D in Figure 9. In Figures 5–7, the accommodation change gradually becomes smaller and more irregular, and the values become closer to 0. This is related to a lack of accommodation power due to presbyopia. In Figures 6–7, the pupil diameter becomes smaller in synchronization with the near vision effort of convergence. It is suggested that a near response occurs with 3D images similar to that with real objects. It is reported that near response occurs gradually from 0.3 m (3.3D), and then pupil diameter reaches the maximum with rapid contraction at 0.2 m (5D). Figures 6–8 show similar results. However, contraction of pupil diameter is not seen in Figure 5.

The above suggests that the reason of middle-aged subject are able to view 3D images stereoscopically is that have supplemented accommodation power is supplemented with a deepened depth of field from pupil contraction. Thus, it is thought that with contraction of pupil diameter, images with left-right parallax can be perceived. On the other hand, pupil contraction implies that a decreased amount of light enters the retina. Therefore, it is suggested that elderly people perceive things as being darker than younger people do.

In this study, rapid changes in pupil diameter were seen from 5 second before the start of measurements (Figures 5–8). It may be that light reaction occurred because of the rapid change in the display from presentation of 3D images. It is reported that the amount of pupil diameter contraction from the light reaction becomes progressively smaller with age. The present experimental result was the same. It takes about 1 sec until the changes from the light reaction are over. Therefore, in this experiment, average pupil diameter from 10 sec to 20 sec, when no influence is seen, was compared.

In middle-aged Subject B and elderly Subject C, pupil diameter became about 10% larger when they wore soft contact lenses than with normal vision for near sight. Thus, it is suggested that pupil contraction is reduced as a result of compensation by soft contact lenses with near eye sight. Especially, it was shown in Figures 8 and 9 that accommodation follows convergence. This suggests that people in middle age can view 3D images more easily if positive (convex lens) correction is made.

## 5 Conclusions

In this study we used 3D images with a virtual stereoscopic view. The influences of age and visual functions on stereoscopic recognition were analyzed. We may summarize the present experiment as follows.

1. Accommodation and convergence change occurred at a constant cycle of 10 seconds, synchronously with to the movement of the 3D image.
2. In the middle-aged subject and elderly subject, accommodation showed less change than convergence.
3. The pupil diameter of the middle-aged subject and elderly subject contracted in synchronization with near vision effort of convergence.
4. Discordance of accommodation and convergence was alleviated with near sight correction with soft contact lenses. Contraction of pupil diameter was also alleviated.

These findings suggest that with naked vision the pupil is constricted and the depth of field is deepened, acting like a compensation system for weak accommodation power. When doing visual near work, a person's ciliary muscle of accommodation constantly changes the focal depth of the lens of the eye to obtain a sharp image. Thus, when the viewing distance is short, the ciliary muscle must continually contract for accommodation and convergence. In contrast, when attention is allowed to wander over distant objects, the eyes are focused on infinity and ciliary muscles remain relaxed (Kroemer & Grandjean, 1997) [15]. Consequently, it is thought that easing the strain of the ciliary muscle due to prolonged near work may prevent accommodative asthenopia.

In addition, this study is suggested that pupil contraction is reduced as a result of compensation by soft contact lenses with near eye sight. This suggests that people in middle age can view 3D images more easily if positive (convex lens) correction is made.

## References

1. Sheehy, J.B., Wilkinson, M.: Depth perception after prolonged usage of night vision goggles. Aviat. Space Environ. Med. 60, 573–579 (1989)
2. Mon-Williams, M., Wann, J.P., Rushton, S.: Binocular vision in a virtual world: visual deficits following the wearing of a head-mounted display. Ophthalmic Physiol. Opt. 13(4), 387–391 (1993)
3. Howarth, P.A.: Oculomotor changes within virtual environments. Appl. Ergon. 30, 59–67 (1999)
4. Heron, G., Charman, W.N., Schor, C.M.: Age changes in the interactions between the accommodation and vergence systems. Optometry & Vision Science 78(10), 754–762 (2001)
5. Schor, C.: Fixation of disparity: a steady state error of disparity-induced vergence. American Journal of Optometry & Physiological Optics 57(9), 618–631 (1980)
6. Rosenfield, M., Ciuffreda, K.J., Gilmartin, B.: Factors influencing accommodative adaptation. Optometry & Vision Science 69(4), 270–275 (1992)
7. Iwasaki, T., Akiya, S., Inoue, T., Noro, K.: Surmised state of accommodation to stereoscopic three-dimensional images with binocular disparity. Ergonomics 39(11), 1268–1272 (1996)
8. Hoffman, D.M., Girshick, A.R., Akeley, K., Banks, M.S.: Vergence-accommodation conflicts hinder visual performance and cause visual fatigue. Journal of Vision 8(3), 33.1–30 (2008)
9. Miyao, M., Ishihara, S.Y., Saito, S., Kondo, T.A., Sakakibara, H., Toyoshima, H.: Visual accommodation and subject performance during a stereographic object task using liquid crystal shutters. Ergonomics 39(11), 1294–1309 (1996)
10. Weale, R.A.: Senile changes in visual acuity. Transactions of the Ophthalmological Societies of the United Kingdom 95(1), 36–38 (1975)
11. Omori, M., Watanabe, T., Takai, J., Takada, H., Miyao, M.: An attempt at preventing asthenopia among VDT workers. International J. Occupational Safety and Ergonomics 9(4), 453–462 (2003)
12. Sun, F., Stark, L.: Static and dynamic changes in accommodation with age. In: Presbyopia: Recent Research and Reviews from the 3rd International Symposium, pp. 258–263. Professional Press Books/Fairchild Publications, New York (1987)
13. Wann, J.P., Rushton, S., Mon-Williams, M.: Natural problems for stereoscopic depth perception in virtual environments. Vision Res. 35(19), 2731–2736 (1995)
14. Hong, H., Sheng, L.: Correct focus cues in stereoscopic displays improve 3D depth perception. SPIE, Newsroom (2010)
15. Kroemer, K.H.E., Grandjean, E.: Fitting the Task to the Human, 5th edn. Taylor & Francis, London (1997)