

# Simultaneous Measurement of Lens Accommodation and Convergence to Real Objects

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**Abstract.** Human beings can perceive that objects are three-dimensional (3D) as a result of simultaneous lens accommodation and convergence on objects, which is possible because humans can see so that parallax occurs with the right and left eye. Virtual images are perceived via the same mechanism, but the influence of binocular vision on human visual function is insufficiently understood. In this study, we developed a method to simultaneously measure accommodation and convergence in order to provide further support for our previous research findings. We also measured accommodation and convergence in natural vision to confirm that these measurements are correct. As a result, we found that both accommodation and convergence were consistent with the distance from the subject to the object. Therefore, it can be said that the present measurement method is an effective technique for the measurement of visual function, and that even during stereoscopic vision correct values can be obtained.

**Keywords:** simultaneous measurement, eye movement, accommodation and convergence, natural vision.

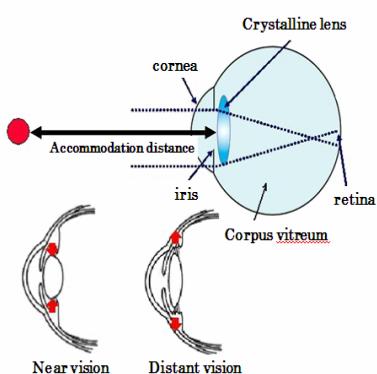
## 1 Introduction

Recently, 3-dimensional images have been spreading rapidly, with many opportunities for the general population to come in contact with them, such as in 3D films and 3D televisions. Manufacturers of electric appliances, aiming at market expansion, are strengthening their line of products with digital devices related 3D.

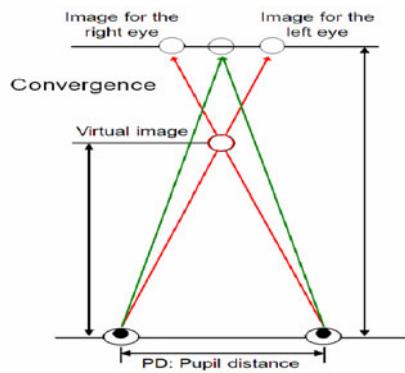
Despite this increase in 3D products and the many studies that have been done on binocular vision, the influence of binocular vision on human visual function remains

insufficiently understood [1, 2, 3, 4]. In considering the safety of viewing virtual 3-dimensional objects, investigations of the influence of stereoscopic vision on the human body are important.

Though various symptoms, such as eye fatigue and solid intoxication, are seen often when humans continue to view 3-dimensional images, neither solid intoxication nor eye fatigue is a symptom seen in the conditions in which we usually live, so-called natural vision. One of the reasons often given for this is that lens accommodation (Fig.1) and convergence (Fig.2) are inconsistent.



**Fig. 1.** Principle of lens accommodation



**Fig. 2.** Principle of convergence

Accommodation is a reaction that changes refractive power by changing the curvature of the lens with the action of the *musculus ciliaris* of the eye and the elasticity of the lens, so that an image of the external world is focused on the retina. Convergence is a movement where both eyes rotate internally, functioning to concentrate the eyes on one point to the front. There is a relationship between accommodation and convergence, and this is one factor that enables humans to see one object with both eyes. When an image is captured differently with right and left eyes (parallax), convergence is caused. At the same time, focus on the object is achieved by accommodation. Binocular vision using such mechanisms is the main method of presenting 3-dimensional images, and many improvements have been made [5, 6]. In explaining the inconsistencies above, it is said that accommodation is always fixed on the screen where the image is displayed, while convergence intersects at the position of the stereo images. As a result, eye fatigue, solid intoxication, and other symptoms occur.

However, we obtained results that indicate inconsistency between accommodation and convergence does not occur [7]. Even so, it is still often explained that inconsistency is a cause of eye symptoms. One reason is that we could not simultaneously measure accommodation and convergence in our previous study, and the proof for the results was insufficient. To resolve this inconsistency, it was thought that measuring accommodation and convergence simultaneously was needed. We therefore developed a method to simultaneously measure accommodation and convergence.

Comparison with measurements of natural vision is essential in investigating stereoscopic vision. For such comparisons, it is first necessary to make sure that the

measurements of natural vision are accurate. We therefore focused on whether we could accurately measure natural vision, and we report the results of those measurements.

## 2 Method

The experiment was done with six healthy young males (age: 20~37). Subjects were given a full explanation of the experiment in advance, and consent was obtained. Subjects used their naked eyes or wore soft contact lenses (one person with uncorrected vision, 5 who wore soft contact lenses), and their refraction was corrected to within  $\pm 0.25$  diopter. (“Diopter” is the refractive index of lens. It is 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). Devices used in this experiment were an auto ref/keratometer, WAM-5500 (Grand Seiko Co. Ltd., Hiroshima, Japan) and an eye mark recorder, EMR-9 (NAC Image Technology Inc., Tokyo, Japan).

### 2.1 WAM-5500

The WAM-5500 (Fig. 3) provides an open binocular field of view while a subject is looking at a distant fixation target, and has two measurement modes, static mode and dynamic mode. We used the dynamic mode in this experiment. The accuracy of the WAM-5500 in measuring refraction in the dynamic mode of operation was evaluated using the manufacturer’s supplied model eye (of power -4.50 D). The WAM-5500 set to Hi-Speed (continuous recording) mode was connected to a PC running the WCS-1 software via an RS-232 cable that allows refractive data collection at a temporal resolution of 5 Hz. No special operation was needed during dynamic data collection. It was necessary to depress the WAM-5500 joystick button once to start and again to stop recording at the beginning and end of the desired time frame, respectively.

The software records dynamic results, including time (in seconds) of each reading for pupil size and MSE (mean spherical equivalent) refraction in the form of an Excel Comma Separated Values (CSV) file [8, 9].



**Fig. 3.** Auto ref/keratometer WAM-5500 (Grand Seiko Co. Ltd., Hiroshima, Japan)

## 2.2 EMR-9

The EMR-9 (Fig. 4) measured eye movement using the papillary/corneal reflex method. The horizontal measurement range was 40 degrees, the vertical range was 20 degrees, and the measurement rate was 60 Hz. This consisted of two video cameras fixed to the left and right sides of the face, plus another camera (field-shooting unit) fixed to the top of the forehead. Infrared light sources were positioned in front of each lower eyelid. The side cameras recorded infrared light reflected from the cornea of each eye while the camera on top of the forehead recorded pictures shown on the screen. After a camera controller superimposed these three recordings with a 0.01 s electronic timer, the combined recording was recorded on a SD card. Movement of more than 1 degree with a duration greater than 0.1 s was scored as an eye movement. A gaze point was defined by a gaze time exceeding 0.1 s. This technique enabled us to determine eye fixation points. The wavelength of the infrared light was 850 nm. After data were preserved on an SD card, they were read into a personal computer [10,11].

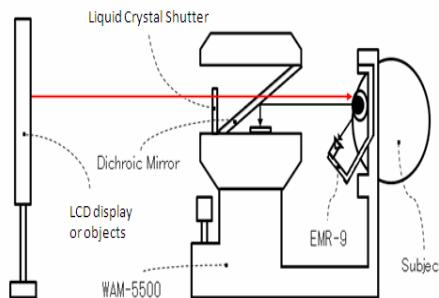


**Fig. 4.** EMR-9 (NAC Image Technology Inc., Tokyo, Japan)

## 2.3 Experiment

These two devices were combined, and we simultaneously measured focus distances of accommodation and convergence when subjects were gazing at objects (Fig. 5).

The experiment was conducted according to the following procedures. Subjects' accommodation and convergence were measured as they gazed in binocular vision at an object (tennis ball: diameter 7 cm) presented in front of them. The object moved in a range of 0.5 m to 1 m, with a cycle of 10 seconds. Measurements were made four times every 40 seconds. The illuminance of the experimental environment was about 103 (lx), and the brightness of the object in this environment was about  $46.9 \text{ (cd/m}^2\text{)}$ .

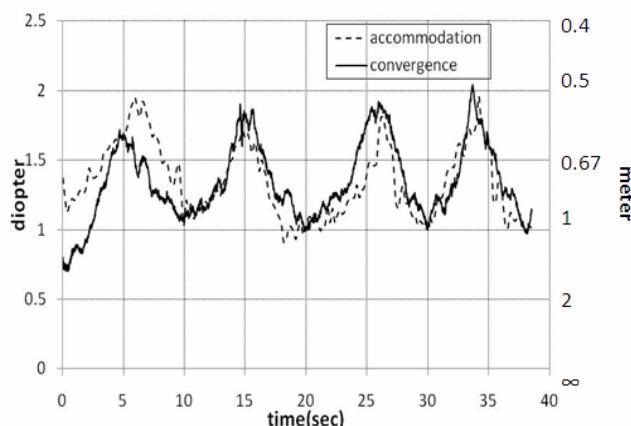


**Fig. 5.** Pattern diagram of measurements

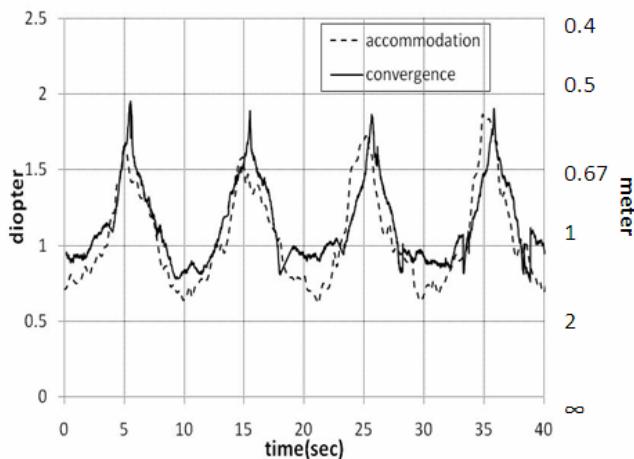
### 3 Results

In this study, we simultaneously measured subjects' accommodation and convergence while they were gazing at an object in binocular vision. The results of these measurements were comparable for all subjects.

The results of the experiment for two subjects are shown as typical examples (Fig. 6, Fig. 7). In Fig. 6 and 7, "accommodation" stands for focal length of lens accommodation, and "convergence" stands for convergence focal length. These figures show that the accommodation and convergence of both subject A and B changed in agreement. Moreover, the change in the diopter value occurred with a cycle of about ten seconds. Maximum diopter values of accommodation and convergence of A and B were both about 2D, which is equal to 0.5 m. This was consistent with the distance from the subject to the object. On the other hand, their minimum values were accommodation distance of 1 D, equal to 1 m, and convergence distance of 0.7 D, equal to 1.43 m. Convergence was consistent with the distance to the object, but accommodation was focused a little beyond the object (about 0.3 D).



**Fig. 6.** Example of measurement: subject A



**Fig. 7.** Example of measurement: subject B

## 4 Discussion

In this experiment, we used the WAM-5500 and the EMR-9. The experiment using the WAM-5500 examined the performance, and measurements with accuracy of  $-0.01D \pm 0.38D$  were possible by examining the results of measurements with WAM-5500 from the agreement with subjective findings within the range from -6.38 to +4.88D [9]. Eyestrain and transient myopia were also investigated using the WAM-5500 [12, 13]. Experiments that examined the accuracy of DCC (dynamic cross cylinder) have also been conducted, and significant differences in the values of test and measurement data were found. The reliability of DCC was questioned [14]. Queiros et al. [8] investigated the influence of the lens on the adjustment for paralysis and hyperopia using the WAM-5500. With respect to the eye mark recorder, Egami et al. [11] investigated differences according to the age in tiredness and the learning effect, showing several kinds of pictures. Sasaki [10] tried forecasting people's movements from the data of the glance obtained from the eye mark recorder, and improved running of a support robot based on it. In addition, Nakashima et al. [15] examined the possibility of early diagnosis of dementia from senior citizens' eye movements with the eye mark recorder. The eye mark recorder has thus been used in various types of research. As mentioned above, much research has investigated the performance and characteristics of these instruments, and experiments using them have been conducted. In this experiment, we measured the accommodation distance and the convergence distance while subjects watched an object. We calculated convergence distance based on coordinated data for both eyes from pupil distance. Our results showed that subjects' accommodation and convergence changed to a position between a near and far position from them while they were gazing at the object. Moreover, these changes occurred at a constant cycle, tuned to the movement of the object. Therefore, subjects viewed the object with binocular vision, and we could measure the results. The accommodation weakened about 0.3 D when there was

an object in the furthest position and the point of 1 m. This indicates that the lens may not be accommodated strictly at about 0.4D, nearly in agreement with our previous findings [16]. While convergence was almost consistent with the distance from the subject to the object, accommodation was often located a little beyond the object. This is thought to originate from the fact that the index is seen even if focus is not accurate because of the depth of field. These measurements were done in healthy young males. In this case, it can be said that accommodation and convergence were consistent with distance to the object when the subjects were gazing at the object. Further investigation is needed to see whether the same results will be obtained in different conditions, such as when the subjects are woman, not emmetropic, or older. In conclusion, it was possible to simultaneously measure both accommodation and convergence when subjects were gazing at an object. It can be said that the present measurement method is an effective technique for the measurement of visual function, and that correct values can be obtained even during stereoscopic vision. Additionally, in future studies, higher quality evaluation of 3-dimensional images will be possible by comparing subjects when they are viewing a 3-dimensional image and when they are viewing the actual object.

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