Comparison of simultaneous measurement of lens accommodation and convergence in natural vision and 3D vision

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Abstract

In this study, we invented a method to simultaneously measure lens accommodation and convergence used for natural and 3D vision. We found that there is almost never a difference between natural vision and 3D vision in terms of accommodation and convergence.

Author Keywords

simultaneous measurement, accommodation and convergence, comparison of natural vision and 3D vision, eye movement.

1. Objective and Background

Recently the use of 3-dimensional images has been spreading rapidly, such as in 3D films and 3D television. Despite the many studies that have been done on stereoscopic vision as 3D use increased, the influence of stereoscopic vision on human visual function remains insufficiently understood [1, 2]. In considering the safety of viewing virtual 3-dimensional objects, investigations of the influence of stereoscopic vision on the human body are important. People often report symptoms such as eye fatigue and 3D sickness when continuously viewing 3-dimensional images.

However, such problems are unreported with so-called natural vision. One of the reasons often given for these symptoms is that lens accommodation and convergence (Fig.1) are inconsistent during the viewing of 3D images. Accommodation is a reaction that occurs due to the differences of refractive power by changing the curvature of the lens with the action of the *musculus ciliaris* of the eye along with the elasticity of the lens. The result is that the retina focuses on an image of the external world.

Convergence is a movement where both eyes rotate internally, functioning to concentrate the eyes on one point in the front.

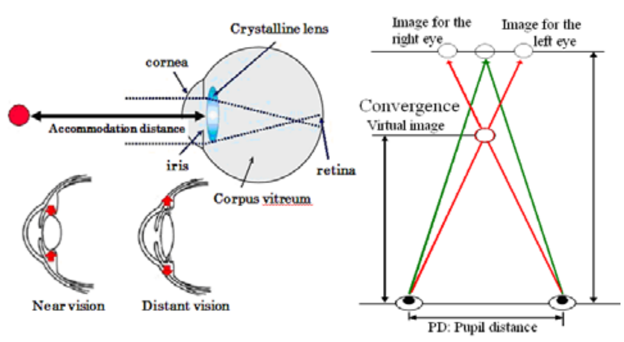

Figure 1. Principle of lens accommodation and convergence

There is a relationship between accommodation and convergence, and this is one factor that enables humans to see one object with both eyes. Convergence occurs when an image is captured differently with both eyes (parallax). At the same time, focusing on an object is achieved by accommodation.

The main method of presenting 3-dimensional images is through the use of the mechanism of binocular vision, and many improvements have been made in this technology [3, 4]. Much of the literature contends 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, 3D sickness, and other symptoms occur [5, 6].

However, we obtained results that indicate the inconsistency between accommodation and convergence does not occur [7]. Even so, viewing inconsistency is still often given as a cause of eye problems. In a previous study, we could not simultaneously measure accommodation and convergence. In order to resolve this inconsistency, we needed to measure accommodation and convergence simultaneously. Therefore, we developed a method to simultaneously measure accommodation and convergence.

A comparative measurement 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. Therefore, we focused on accurately measuring natural vision and reported the results of these measurements. We then measured and showed the result of comparing natural and 3D vision.

2. Method

We conducted two experiments. The first experiment was performed in order to confirm whether or not this method of simultaneous measurement can be done accurately. The second experiment was done to compare natural and 3D vision. The devices used in these experiments were an auto ref/keratometer, WAM-5500 (Grand Seiko Co. Ltd., Hiroshima, Japan) (Fig.2) and an eye mark recorder, EMR-9 (NAC Image Technology Inc., Tokyo, Japan) (Fig.3). 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 as needed, and their refraction was corrected to within ±0.25 diopter (A"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). The WAM-5500 and EMR-9 devices were combined, and we simultaneously measured the focused distances of accommodation and convergence when subjects were gazing at objects (Fig. 4).

Figure 2. Auto ref/keratometer WAM-5500 (Grand Seiko Co. Ltd.)

Figure 3. EMR-9 (NAC Image Technology Inc.)

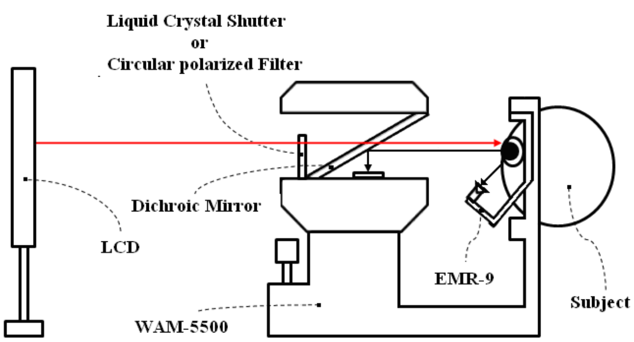

Figure 4. Pattern diagram of measurements

2.1 Simultaneous measurement of accommodation and convergence of real objects

The first experiment included six healthy young males (age: 20-37). The experiment was conducted according to the following procedures. The accommodation and convergence of the subjects were measured as they gazed in binocular vision at an object (tennis ball: diameter 7 cm) presented in front of them. The object moved at 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 (ℓ x), and the brightness of the object in this environment was 46.9 (cd/m^2).

2.2 Comparison of simultaneous measurement in natural and 3D vision

Another experiment was completed with ten healthy young males (age: 21-46). As with the previous experiment, the accommodation and convergence of the subjects were measured as they gazed in binocular vision at an object (tennis ball: diameter 7 cm) and a 3D video clip presented in front of them. The object and video clip showed exactly the same motion, moving at a range from 0.6 to 1.6 m in 10 seconds, and then stopped at a position of 0.6 m and 1.6 m for 2 seconds, and moved again with four cycles, about 58 seconds. During this time, subjects were asked to gaze at these objects, and we measured their accommodation and convergence. This measurement of the real object and 3D video clip was taken four times. The illuminance of the environment and the brightness of the object were the same as in the previous experiment. In viewing 3D vision, a JVC 3D LC monitor (46-inch, polarized) was positioned and used at a distance of 171.9 cm from the subject.

3. Results

In this study, we simultaneously measured the accommodation and convergence of subjects while they were gazing at an object and 3D video clip in binocular vision. The results of these measurements were comparable for all subjects.

3.1 Simultaneous measurement of accommodation and convergence of real objects

The results of this experiment are shown by a typical example (Fig. 5) and the average for all subjects is seen in Figure 6. In both these figures, "accommodation" and "ac_ave" stand for focal length of lens accommodation, while "convergence" and "con_ave" stand for convergent focal length, and "spherical object" stands for the location of an object. These figures show that the accommodation and convergence of subjects changed in agreement. The change in the diopter value occurred within a cycle of about ten seconds. Moreover, the value nearly agreed with the distance from the subject to the object.

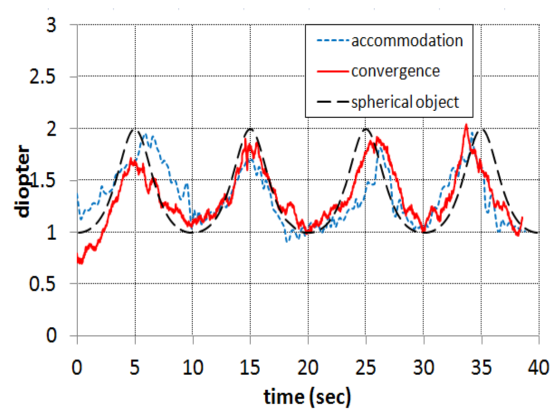

Figure 5. Example of measurement in real object

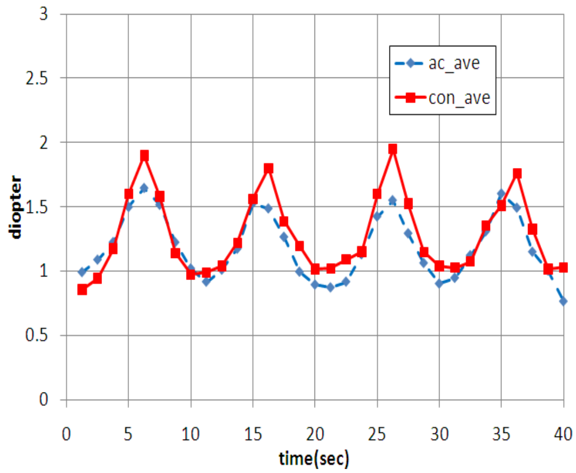

Figure 6. Average of measurement in real object

3.2 Comparison of simultaneous measurement of natural and 3D vision

The results of this experiment are shown as an average for all subjects (Fig. 7 and Fig. 8). Figure 7 shows the average value of accommodative distance for an elapsed time, and Fig. 8 shows the convergence. In both these figures, "ac" stands for focal length of lens accommodation, "con" for convergent focal length, "spherical object" for the location of an object and a virtual image, "real" for when subjects gazed at the real object, and "3D" for when subjects gazed at the 3D video clip. Both convergent distances in real and 3D vision nearly agreed with the spherical object as shown in Fig. 8. On the other hand, in Fig. 7, the accommodative distance of 3D was located quite further back compared to the real object and the location of the spherical object.

4. Impact

4.1 Simultaneous measurement of accommodation and convergence of real objects

In this experiment, we used the WAM-5500 and the EMR-9. An experiment was conducted with the WAM-5500 to examine the accuracy of its performance, and its accuracy was found to be -0.01D ± 0.38D. The experiment also revealed that the WAM-5500 can take measurements within the range of -6.38 to +4.88D [8]. Eyestrain and transient myopia were also investigated using the WAM-5500 [9, 10]. The eye mark recorder has been employed in various types of past research. For example, Egami et al. [11] investigated differences according to age, tiredness and the learning effect, showing several kinds of pictures. Sasaki [12] tried to forecasting people's movements from the data of the human glance obtained from the eye mark recorder, and he improved the running of a support robot based on this usage. As mentioned above, many studies have investigated the performances and characteristics of these instruments as well as have conducted experiments using them.

In this experiment, we measured the accommodative and convergent distance while subjects watched an object. We calculated convergent distance based on coordinated data for both eyes from the pupil distance. Our results showed that the accommodation and convergence of subjects changed to a position between near and far as they gazed 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 managed to measure the results.

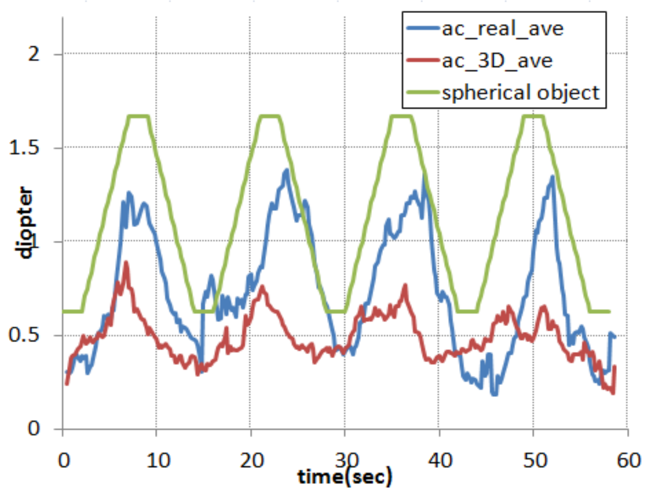

Figure 7. Average of accommodation

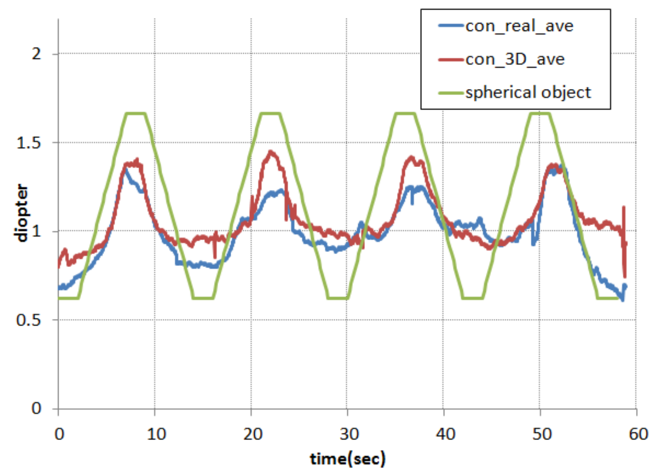

Figure 8. Average of convergence

Though these distances were nearly consistent with the distance from the subject to the object, they often were located a little beyond the object. Perhaps this originates from the fact that the subjects see the index even when the focus is not accurate because of the depth of field. With regards to this point, this study appears nearly in agreement with our previous findings [7, 13] which indicate that the lens may not be accommodated strictly at about 0.4D.

In conclusion, it was possible to simultaneously measure both accommodation and convergence when subjects were gazing at an object. The present measurement method is an effective technique for the measurement of visual function and correct values can be obtained even during stereoscopic vision. Next, we performed a comparison of the case of viewing real object and 3D vision using this method.

4.2 Comparison of simultaneous measurement of natural and 3D vision

In our previous study of young subjects gazing in 3D vision, we obtained the results that accommodation and convergence of young people varied with the movement of 3D images and argued that the inconsistency between accommodation and convergence did not occur (Fig. 9)[14].

In this past experiment, the convergence of vision in subjects

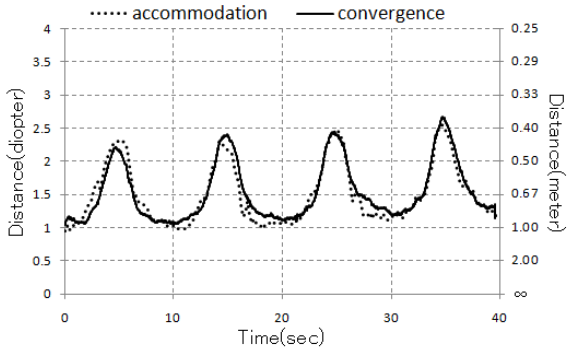

Figure 9. Result of young subject in gazing 3D vision in our previous study

almost agreed with the distance between the subject and the real object or 3D images. Thus, we found that this method succeeded in measuring convergence. As for accommodation, the distance of the real object shifts to slight less than that of the object.

According to our previous study, accommodation does not agree strictly with the visual object but does agree with the distance gap behind the object [7, 13]. On the other hand, in this study accommodation of viewing 3D shifted remarkably behind the 3D object compared to viewing a real object, though the value changed with the movement of 3D video clip. Hoffman et al. and Ukai & Howarth [5, 6] described that there is inconsistency between accommodation and convergence, and that the accommodation of the 3D object would be fixed at the position of the display. However, this did not occur in our findings. Our previous study showed that the gap of accommodation behind the object in young subjects was within 0.4D but the gap in the present experiment was larger. The following may be considered a reason for this difference. In order to match experimental conditions to real ones as much as possible, we planned to use a tennis ball as the spherical object of 3D images. However, a virtual tennis ball was seen as an unnatural and flat object instead of a spherical object. In fact, when the experiment was finished, several subjects said that they did not feel that the 3D images popped out much. Landy et al. [15] also said that the texture of an object is an important cue to perceive the accurate location of object, in addition to binocular vision and motion parallax. Therefore, different results may be obtained by using something other than the images used in such an experiment.

5. References

[1] V, V, Krishman, D, Shirachi & L, Stark “Dynamic measures of vergence accommodation.” Am. J. Optom. Physiol. Opt., 54, 470-473. (1977)

[2] K, Ukai, Y, Tanemoto and S, Ishikawa “Direct recording of accommodative response versus accommodative stimulus.” In: Advances in Diagnostic Visual Optic, edited by G.M. Breinin & I.M. Siegel, Springer-Verlag, Berlin, pp. 61-68. (1983)

[3] A, Cho, et al. “A study on visual characteristics binocular 3-D images.” Ergonomics, 39(11): 1285-1293. (1996)

[4] R, Sierra, et al. “Improving 3D imagery with variable convergence and focus accommodation for the remote assessment of fruit quality.” SICE-ICASE International Joint Conference 2006, pp. 3553-3558. (2006)

[5] D, M, Hoffman, A, R, Girshick, K, Akeley, and M, S, Banks “Vergence-accommodation conflicts hinder visual performance and cause visual fatigue.” Journal of Vision, 8(3): 33.1-30. (2008)

[6] K, Ukai and P, A, Howarth “Visual fatigue caused by viewing stereoscopic motion images: Background, theories, and observation.” Displays, 29, pp106-116. (2008)

[7] M, Miyao, et al. “Visual accommodation and subject performance during a stereographic object task using liquid crystal shutters.” Ergonomics, 39(11), pp.1294-1309. (1996)

[8] A, L, Sheppard and L, N, Davies “Clinical evaluation of the Grand Seiko Auto Ref/Keratometer WAM-5500.” Ophthal. Physiol. Opt. 30: 143–151(2010)

[9] C, Tosha, et al. “Accommodation response and visual discomfort.” Ophthal. Physiol. Opt. 29: 625–633. (2009)

[10] E, Borsting, et al. “Measuring near-induced transient myopia in college students with visual discomfort.” American Academy of Optometry, 87(10): 760-766. (2010)

[11] C, Egami, et al. “Developmental characteristics of visual cognitive function during childhood according to exploratory eye movements.” Brain & Development 31, pp750-757. (2009)

[12] T, Sakaki. “Estimation of intention of user arm motion for the proactive motion of upper extremity supporting robot.” 2009 IEEE 11th International Conference on Rehabilitation Robotics, Kyoto International Conference Center, Japan, June 23-26. (2009)

[13] Y, Otake, M, Miyao, et al. “An experimental study on the objective measurement of accommodative amplitude under binocular and natural viewing conditions.” Tohoku J. Exp. Med., 170, pp93-102.(1993)

[14] H. Hori, T. Shiomi, et al. “Comparison of accommodation and convergence by simultaneous measurements during 2D and 3D vision gaze.” FORMA Specieal Issue (2011)

[15] M, S, Landy, L, T, Maloney, E, B, Johnston, and M, Young “Measurement and modeling of depth cue combination: in defense of weak fusion.” Vision Research, 35(3), pp389-412. (1995)