Comparison by Simultaneous Measurement of Lens Accommodation and Convergence in 3D Vision and Their Distributions

T. Kojima, Y. Matsuura, M. Miyao, T. Shiomi, and H. Takada

Abstract—In general, disagreement between accommodation and convergence is considered to be a main reason for the visual fatigue and the visually induced motion sickness (VIMS). In this study, we devised a method to simultaneously measure lens accommodation and convergence, and used it to characterize 3D vision. Time courses of these fixation distances and their distributions are compared while they viewed 2D and 3D video clips. As a result, the convergence almost agreed with the distance between a subject and a 3D image. Therefore, we succeeded in measuring convergence while the distance of the accommodation focal length shifted.

Index Terms—3D movie, motion sickness, accommodation, convergence.

I. INTRODUCTION

Recently, the use of 3D images has been spreading rapidly, such as in 3D films and 3D televisions. Despite this increase in 3D display products and the many studies of stereoscopic vision, the influence of stereoscopic vision on human visual functions remains insufficiently understood [1], [2]. In considering the safety of viewing virtual 3D 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 viewing 3D images for a prolonged period of time. However, such problems are unreported for so-called natural vision. One of the reasons often given for these symptoms is that lens accommodation and convergence are inconsistent during the viewing of 3D images.

Accommodation is a reaction that occurs due to differences of refractive power achieved by the action of the *musculus ciliaris* changing the curvature of the lens and the elasticity of the lens. The result is that an image of the external world is focused on the retina. Convergence is a movement where both eyes rotate in their sockets, functioning to concentrate the eyes on one point in space.

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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 by each eye (parallax). At the same time, focusing on an object is achieved by accommodation.

The main method of presenting 3D images involves 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 an inconsistency between accommodation and convergence does not occur [7]. Even so, viewing inconsistency is still often given a cause of eye symptoms. In a previous study, we could not simultaneously measure accommodation and convergence. In order to resolve this inconsistency, we need to be able 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.

We performed comparative measurements of 3D vision, and show the results together.

II. MATERIAL AND METHODS

We conducted two experiments. The first experiment was performed in order to confirm whether or not this method of simultaneous measurement could be performed accurately. The second experiment was performed to compare natural and 3D vision. The devices used in these experiments were an autorefractor/keratometer, WAM-5500 (Grand Seiko Co. Ltd., Hiroshima, Japan) and an eye mark recorder, EMR-9 (NAC Image Technology Inc., Tokyo, Japan). Subjects were given a full explanation of the experiment in advance and consent was obtained. Subjects used their naked eyes or, as needed, wore soft contact lenses, and their refraction was corrected to within ±0.25 diopter (a "diopter" is the refractive index of lens and indicates the accommodation power. It is defined as 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 integrated, and we simultaneously measured the focused distances of accommodation and convergence while the subjects gazed at 2D and 3D images.

Another experiment was done 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 at an object (tennis ball: diameter 7 cm) and a 3D video clip presented in front of them in binocular vision. The object and the video clip showed exactly the same motion, moving within a range of 0.6 m to 1.6 m in 10 seconds, stopping at positions of 0.6 m and 1.6 m for 2 seconds, and moving again in four cycles of about 58 seconds. During this time, the subjects were asked to gaze at these objects, and we measured their accommodation and convergence. This measurement of the real object and the 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. For viewing of the 3D video clip, a JVC 3D LC monitor (46-inch, polarized) was positioned at a distance of 171.9 cm from the subject.

The distribution of the location of the virtual image was also compared with that of convergence focal length and the focal length of lens accommodation in accordance with the chi-square test. In this study, the significant level was set to be 0.05.
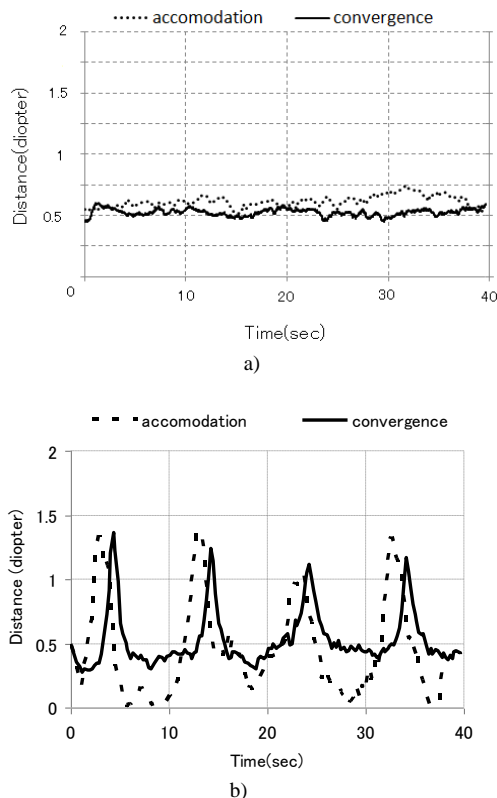
III. RESULTS

a)

b)

Fig. 1. Typical time courses of the location of the virtual image, accommodation, and convergence focal length while viewing a) a 2D video clip, b) a 3D video clip.

In this study, we simultaneously measured the accommodation and convergence of subjects while they were gazing at 2D and 3D video clips in binocular vision. The results of these measurements were comparable for all subjects.

The results of this experiment are shown by a typical example while viewing 2D and 3D video clips (Fig. 1). In

both these figures, "accommodation" stands for focal length of lens accommodation while "convergence" stands for convergence focal length, and "spherical object" stands for the location of the virtual image. Fig. 1 b) shows that the together and were always 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 (Fig. 1 b)). In contrast, when viewing the 2D images, the diopter values for both accommodation and convergence were almost constant at around $0.5 - 0.6$ D (Fig. 1 a)).
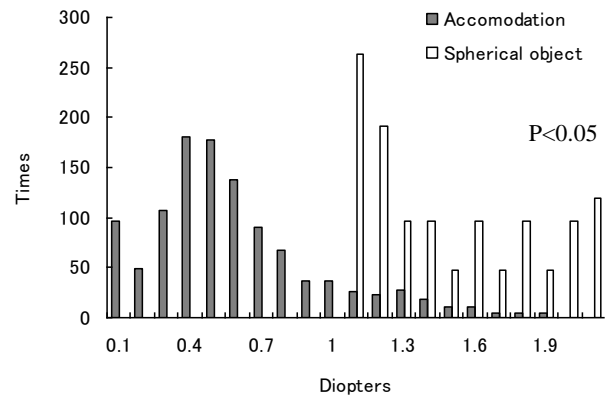

Fig. 2. Distributions of the location of the virtual image and the accommodation focal length obtained from all subjects.

The distribution of the location of the virtual image was herein compared with that of the focal length (Fig. 2). By the chi-square test, it was shown that the distribution of the location of the virtual image was significantly different from the distribution of the accommodation focal length of lens ($p<0.05$).

IV. DISCUSSION AND CONCLUSION

In this research, it was possible to simultaneously measure both accommodation and convergence when subjects gazed at 2D and 3D video clips (Fig. 1). In this experiment, both focal lengths were fixed at the position of the display when viewing the 2D images (Fig. 1 a)). As shown in Fig. 1b, the convergence almost AGREED with the distance between a subject and a 3D image. Thus, we found that this method succeeded in measuring convergence. The distance of the accommodation focal length shifts to slight larger than that of the virtual spherical object (Fig. 2).

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

have conducted experiments using them.

We had measured the accommodation and convergence distance while subjects watched an object [13]. We calculated the convergence 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 a near and far distance as they gazed at the object. Moreover, these changes occurred at a constant frequency, the same as that of the movement of the object. Therefore, subjects viewed the object with binocular vision, and we were able to measure the results. Though these distances were nearly consistent with the distance from the subject to the object, they often were located a little beyond the object. This is thought to originate from the fact that the index is seen even when the focus is not accurate because of the depth of field. With regards to this, our study appears nearly in agreement with our previous findings [7], [14], which indicate that the lens may not be completely accommodated at about 0.4D.

According to our previous study, accommodation does not agree strictly with the visual object but does agree with and the distance gap behind [7], [14]. On the other hand, in this study accommodation of 3D objects shifted significantly behind the 3D object, although its value changed with the movement of the 3D video clip (Fig. 1 b)). As described by Hoffman *et al.* and Ukai *et al.* [5], [6], if there is inconsistency between accommodation and convergence, then accommodation of the 3D object would be fixed at the position of the display. However, this does not occur. Our previous study showed that the gap of accommodation behind the object was within 0.4D, but the gap in this experiment was larger and more significant (Fig. 2).

Landy *et al.* [15] observed that in addition to binocular vision and motion parallax, the texture of an object is an important cue in perceiving the accurate location of an object. In this EXPERIMENT, the 3D image of the spherical object was represented as a tennis ball in order to match the conditions of the 3D object to those of the real ones as closely as possible. Therefore, an unnatural image seemed to pop out from the display.

For the NEXT step, it is necessary to further investigate the reliability of a measurement method by increasing the number of subjects.

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