FOR 3D DISPLAYS, LENS ACCOMMODATION IS VARIABLE AND IT IS CONSISTENT WITH CONVERGENCE

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Abstract: Recently, 3D technology has been developing. It is generally explained to the public that, "During stereoscopic vision, accommodation and convergence are mismatched and this is the main reason for the visual fatigue caused by 3D". The aim was to compare fixation distances between accommodation and convergence in young subjects while they viewed 2D and 3D video clips. Measurements were made using an original machine, and 2D and 3D video clips were presented using a liquid crystal shutter system. As results, subjects' accommodation and convergence were found to change the diopter value periodically when viewing 3D images. These findings suggest that the ocular functions when viewing 3D images are very similar to those during natural viewing. When subjects are young, accommodative power while viewing 3D images is similar to the distance of convergence, and the two values of focusing distance are synchronized with each other.

1 INTRODUCTION

Recently, 3D technology has been developing. Today, 3D is not only used in movie theaters. Each home appliance maker has started to sell 3D TVs and 3D cameras.

It is generally explained to the public that, "During stereoscopic vision, accommodation and convergence are mismatched and this is the main reason for the visual fatigue caused by 3D. During stereoscopic vision, while accommodation is fixed on the display that shows the 3D image, convergence of left and right eyes crosses at the location of the stereoimage". Studies by Wann et al. and Yano et al. (Wann, 1995); (Yano, 2004) found that in natural vision lens accommodation is consistent with convergence; that is, accommodation and convergence matched. However, they noted that fatigue might occur after extensive viewing of 3D images because accommodation and convergence are not matched when viewing these images. According to the findings presented in our previous report (Miyao, 1996), however, such explanations are mistaken. We found that lens accommodation for 3D images is in fact consistent with convergence among young subjects. However, our research has not been recognized in the world. This may be because the experimental evidence obtained in our previous studies, where we did not measure accommodation and convergence simultaneously, was not strong enough to convince people. We therefore developed a new device that can simultaneously measure accommodation and convergence.

The aim was to compare fixation distances between accommodation and convergence in young subjects while they viewed 2D and 3D video clips.

2 METHOD

In this experiment, the subjects were six healthy, young men and women in their twenties (two had uncorrected vision and four used soft contact

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lenses). We obtained informed consent from all the subjects and the approval from the Ethical Review Board of the Graduate School of Information Science at Nagoya University.

We placed an LCD monitor facing the subjects at a distance of 1m from them. We presented either a 2D or a 3D video clip on the monitor; in both images, a spherical object moved forward and backward with a cycle of 10 seconds (Figure 1). The spherical object appeared as a 3D video clip located at a virtual distance of 1m (i.e., the location of the LCD monitor) and moved toward the subjects to a virtual distance of 0.35m in front of them. We asked the subjects to gaze at the center of the spherical object for 40 s and measured their lens accommodation and convergence distance during that time. The 3D video clip was presented using a liquid crystal shutter system and a circular polarizing filter system. The 2D video clip was presented using only a liquid crystal shutter system.

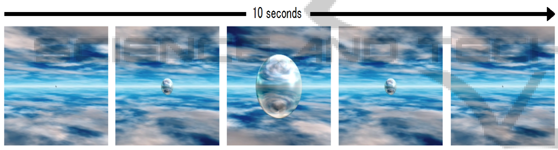

Figure 1: Spherical object video clips.

We developed an original machine by combining WAM-5500® and EMR-9® to perform these simultaneous measurements

Figure 2: WAM-5500.

WAM-5500 (Figure 2) is an auto refractometer (Grand Seiko Co., Ltd.) that can measure accommodative power under natural conditions for the case in which both eyes are open. It can continuously record accommodative focus distance at a rate of 5 Hz, thus achieving reliable and accurate measurements of accommodation.

EMR-9 (Figure 3) is an eye mark recorder (NAC Image Technology Inc.) that can measure the convergence distance using the pupillary/corneal reflex method. Its resolution for eye movement is 0.1 degree, with a measurement range of 40 degrees and sampling rate of 60 Hz. The convergent focus distance can be easily calculated from the obtained binocular eye movement data.

Figure 3: Eye mark recorder EMR-9.

We used a liquid crystal shutter system or a circular polarizing filter system combined with the respective binocular vision systems to present 2D and 3D video clips. The experimental environment is shown in Figure 4.

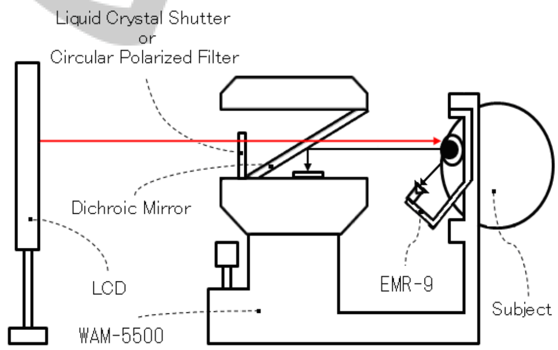

Figure 4: Overview of the experiment.

The video clips we used in the experiment are trademarked as Power 3D® video clip (Olympus Visual Communications, Corp.). Power 3D is an image creation technique that combines near and far views in a virtual space and has multiple sets of virtual displays whose positions can be adjusted. Power 3D presents a video clip that is similar to a natural image.

3 RESULT

The measurements for the six subjects showed roughly similar results. For 3D vision, the results of 2D and 3D for one subject are shown respectively in Figs. 5 and 6, as typical examples.

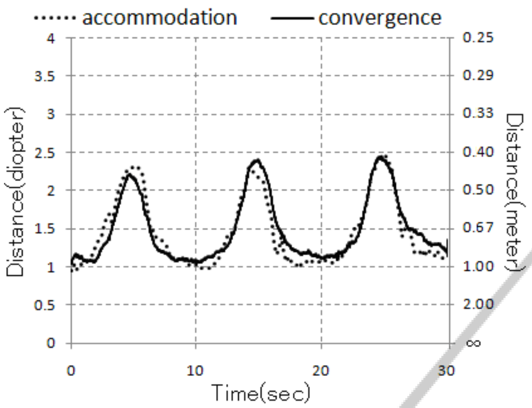

Figure 5: 3D liquid crystal shutter system (age:23, male).

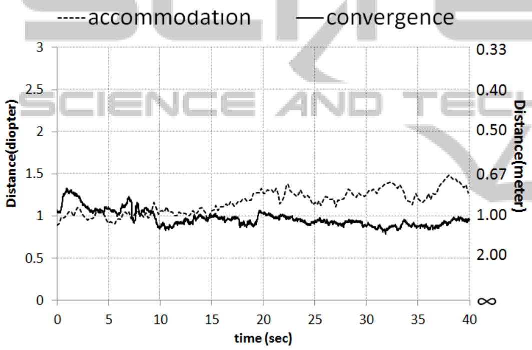

Figure 6: 2D liquid crystal shutter system (age:23, male).

When Subject (23-year-old male wearing soft contact lenses) viewed the 3D video clip presented using the liquid crystal shutter system, accommodation varied between approximately 1.0 diopter (100cm) and 2.5 diopters (40cm), whereas convergence varied between approximately 1.0 diopter (100cm) and 2.7 diopters (37cm). The changes in the respective diopter values had almost the same amplitude and were in phase, fluctuating synchronously with a cycle of 10 s, which corresponded with the cycle of the 3D video clip movement.

When the subject was viewing the 2D video clip, the diopter values for both accommodation and convergence remained almost constant at around 1 diopter (1m).

The mean values of accommodation and convergence for the six subjects viewing the 2D video clip were 0.96 ± 0.12 and 0.96 ± 0.07, respectively. The difference between accommodation and convergence was negligible. When the subjects were viewing the 3D video clip, the values of accommodation and convergence were 1.29 ± 0.11 and 1.32 ± 0.08, respectively. The difference between accommodation and convergence in this case was approximately 0.03 diopters, which is also negligible. Therefore, we can say that there is not much quantitative difference in the fixation distances between accommodation and convergence when the subject views either the 2D or 3D video clip.

4 DISCUSSION

Wann et al. 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. stated that the natural coupling of eye accommodation and convergence while viewing a real-world scene is broken when viewing stereoscopic displays (Hong, 2010).

In addition to the above two, Hoffman et al. and Ukai et al. (Hoffman, 2008); (Ukai, 2008) stated that if there is inconsistency between accommodation and convergence, then accommodation to a 3D object is fixed at the position of the display. In this study, however, the result showed good synchronization between accommodation and convergence during stereoscopic vision and this did not occur. This suggests that the difference between accommodation and convergence is probably not the main reason for visual fatigue, motion sickness, and other problems.

We can also say that the kind of results presented herein could be obtained because the 3D images used in the experiments were produced not by conventional means but with Power 3D, whose images are extremely close to natural viewing.

In fact, conventional 3D and the Power 3D on HMD have been compared experimentally in our previous study (Hasegawa, 2009). This study found that the result of Power 3D is closer to natural vision than that of conventional 3D.

Therefore, we consider that as long as 3D images are made using a proper method, accommodation and convergence should almost always coincide, and that we can view such images more easily and naturally.

In conventional “accommodation-convergence discrepancy theory,” accommodation is fixed on the display during virtual 3D vision, although focus of convergence is consistent with the location of the virtual image.

However, our present experiment findings suggest that accommodative focus is nearly consistent with the location of the stereoimage. There is also an opinion that an image is seen as blurred if the accommodative focus is not on the display but on the virtual position. In this experiment, however, all subjects said that the image was clear.

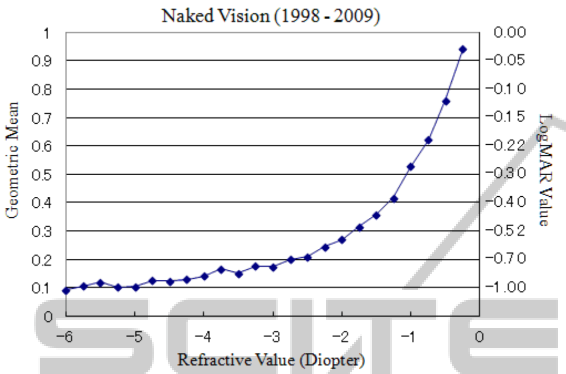

Figure 7: Naked vision for primary school child in 1998-2009.

The blue solid line indicates naked vision value corresponding to refractive value. The X axis indicates the refractive value, the left Y axis indicates naked vision value measured in geometric mean, and the right Y axis indicates LogMAR values. LogMAR is the visual acuity log transformed.

Let us consider at the case of virtual 3D images popping forward, for example the case in Fig. 5 in which an LCD monitor was placed 100 cm in front of the subjects and then a virtual spherical object moved to 40 cm in front of subjects. The theoretical blurring that occurs with virtual 3D images is approximately equal to that of a subject who has a myopic view of infinity of -1.5 diopters (nearly equal to >5.0 m). That is blurring of far visual acuity such as in a subject with myopia of -1.5 diopters. The Nagoya City Education Committee has a statistics on myopic children and visual acuity with no astigmatism (Fig. 7). This data is the result of detailed examination of thousands children (11 years old) in Nagoya city (Japan) by more than 100 ophthalmologists. According to Fig. 7, among these children visual acuity of -1.5 diopters is about the geometric mean value of 0.35 (LogMAR value is about -0.46). In addition, blurring is also greatly affected by pupil diameter (Smith, 1991). For bright virtual 3D images, pupil diameter contraction and focal depth becomes deeper. Therefore, blurring is reduced. In fact, the subjects in present experiments did not recognize blurring in the 3D video clips.

5 CONCLUSIONS

In this experiment, we simultaneously measured accommodation and convergence for subjects viewing 2D and 3D video clips. The difference in the eye movements for accommodation and convergence is equally small in the cases of the observation of both 2D and 3D video clips. This suggests that the difference between accommodation and convergence is probably not the main reason for visual fatigue, motion sickness, and other problems.

In the future works, we are going to investigate subjects' visual information, for example, whether subjects see a blurred image, and so on. In this experiment, subjects didn't accommodate on the display in gazing 3D video clip. However there is no report that subjects could not see a video clip. Therefore, it is very important to investigate more accurately the information which subjects get when viewing 3D vision.

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