Measurement of Lens Accommodation During Viewing of DFD Images

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Abstract. Recently, a stereoscopic technology called DFD (Depth-fused 3D) developed in NTT. With this method two images are overlapped, displaying two planes with different depths. Humans usually perceive such overlapped two images as one image with one depth. When Humans perceive the depth of the DFD image, it is assume that they use factors of depth perception, such as lens accommodation, convergence and binocular parallax. Researchers have studied depth perception factors during the viewing of DFD images. However, studies have not clarified the effects of viewing of DFD images on accommodation. In this study, we measured lens accommodation in subjects who gazed at DFD images. We verified that a viewer's lens accommodation can adjust to DFD images.

Keywords: Depth-fused 3D (DFD) · Lens accommodation · Luminance ratio

1 Introduction

Recently, manufacturers have introduced many stereoscopic 3D (3-dimensional) technologies. Examples of stereoscopic 3D technology include the binocular 3D method, which makes stereoscopic vision possible with binocular parallax, the multi-viewpoint method that enables viewers to see multiple viewpoints, and holography, which records light waves and reconstructs them. Stereoscopic technology called DFD (Depth-fused 3D) developed in NTT [1, 2]. With this method two images are overlapped, displaying two planes with different depths. Humans usually perceive such overlapped two images as one image with one depth. As shown in Fig. 1, the viewer interprets the depth by the effects of luminance on a plane. For example, if the image is displayed only on the rear plane, the luminance of front image is 0 %, and the luminance of rear image is 100 %. If the image is displayed only on the front plane, the luminance of front image is 100 %, and the luminance of rear image is 0 %. Both the luminance of front and rear images are

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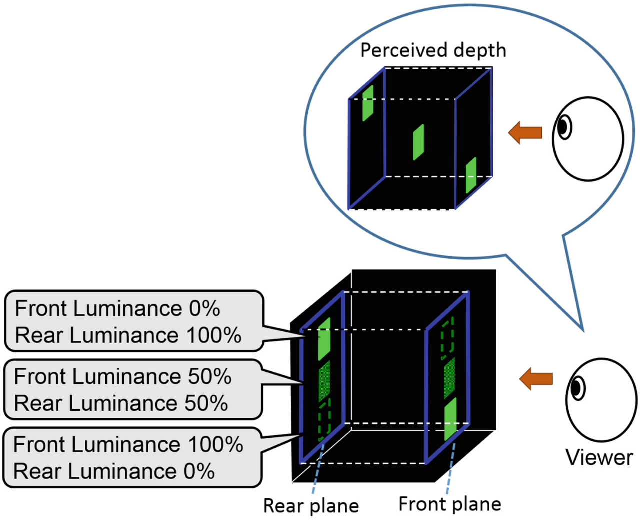

Fig. 1. Depth perception of DFD images

50 %, viewers perceive the DFD image with a depth perception just in the middle of the two planes. We can adjust the depth of the image by controlling the luminance ratio. These DFD images can be viewed without special glasses and is promising as a stereoscopic technology that is easy on the eyes [3, 4].

A DFD image is formed by a slight shift of the front and rear images. We can recognize the edge shift of the front and rear images as one virtual edge. When Humans perceive the depth of the DFD image, it is assume that they use factors of depth perception, such as lens accommodation, convergence and binocular parallax. Researchers have studied depth perception factors during the viewing of DFD images. However, studies have not clarified the effects of viewing of DFD images on accommodation. In this study, we measured accommodation in subjects who gazed at DFD images. We argue that the accommodation focus moves to the depth of the DFD images.

2 Method

2.1 Subjects

In this study, we measured subject's lens accommodation during the viewing of DFD images. We carried out experiments with 122 healthy subjects between the ages of 15 to 82 years. We gave detailed descriptions of the experiment to the subjects in advance to obtain their informed consent. The study was approved by the ethics committee of the Graduate School of Information Science, Nagoya University.

The subjects were divided into the following four groups: young subjects (n = 30, 29 years of age or younger), young middle aged subjects (n = 30, 30–44 years of age), middle aged subjects (n = 46, 45–64 years of age), and elderly subjects (n = 16, 65 years of age or older). This grouping was done because the crystalline lens loses elasticity with age and the changes of their refractive power also decreases [5, 6].

- Young subjects: The young group had sufficient accommodative power.
- Young middle aged subjects: The young middle aged group had somewhat weak accommodative power and did not suffer from presbyopia.
- Middle aged subjects: The middle-aged group had mild difficulty in seeing near objects because of presbyopia.
- Elderly subjects: The elderly group had severe presbyopia, and felt difficulty in seeing near objects.

2.2 Measurement Instrument

We used an auto ref/keratometer WAM-5500 made by Shigiya Machinery Works, Ltd. in this experiment., As shown in Fig. 2, this instrument can measure the refractive value (accommodation value) of a single eye when the subject gazes at a target at a given distance at a sampling frequency of 5 Hz.

Because the distance between two planes is very narrow (about 5–10 cm), it is difficult to detect the movement of accommodation focus with our instrument. Thus, we proposed the binocular DFD method to widen the distance between two planes [7].

2.3 Binocular DFD Method

If a edge shift becomes large, it is difficult to perceive the DFD image as a single image at one depth, as shown in Fig. 3 [8], and it is difficult to increase the interval between two planes. Thus, we combined the circular polarized 3D method and the DFD method to widen the distance between two planes. We defined this method as binocular DFD. This is a stereoscopic method to separate the left and right images using the filter through a different circularly polarized light, which allows for a binocular parallax.

There is no edge shift in the front and rear images displayed by binocular DFD for right eye, but there is a luminance ratio. The images for the left eyes are the same. These images were delivered to each eye through the circular polarized filter. This

Fig. 2. WAM-5500

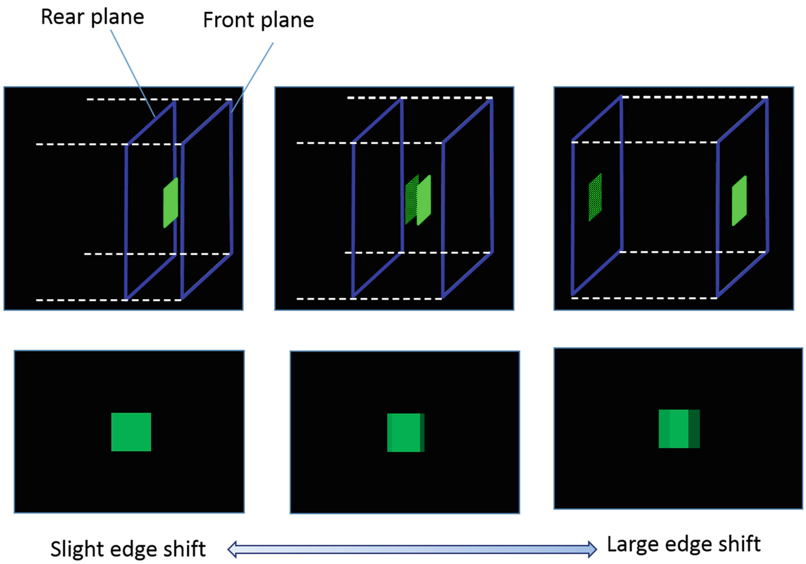

Fig. 3. Depth separation of DFD image

method is artificially possible and allows fort the appearance of the DFD images to fuse the images in the brain. In the case of binocular DFD method, it is necessary to consider that the edge of two images reflected in each eye does not increase. Hence, we must display the binocular DFD image with an appropriate parallax corresponding to the pupillary distance of the subject. Thus, we measured the pupillary distance of the subjects before taking the measurement of their lens accommodation. During a measurement of the pupillary distance, subjects gazed an image of a white spot on a black background displayed on the rear plane at 1.0 D.

2.4 Experimental Procedure

In this study, we measured the subject's eye accommodation during the viewing of DFD images. We argue that the accommodation focus moves to the depth of the DFD images.

We used a binocular DFD to display the image while taking the measurement of accommodation. Figure 4 shows a schematic diagram of the experimental apparatus, while specifications for stereoscopic display are shown in Table 1. In the experiment, the two planes were arranged at right angles with a half mirror at 45 degrees. By putting the half mirror in place, it is possible that the front plane is displayed on the virtual position. We set the front plane at the location of the 1.5 D (0.67 m), and the rear plane at the location of the 1.0 D (1.0 m). The rear image was 1.5 times larger than the front image. As shown in Table 2, we used five patterns images in the experiment. The DFD image moved in five steps between the two planes. As the DFD image moved, we measured the pupillary distance of the subjects before taking the measurement of

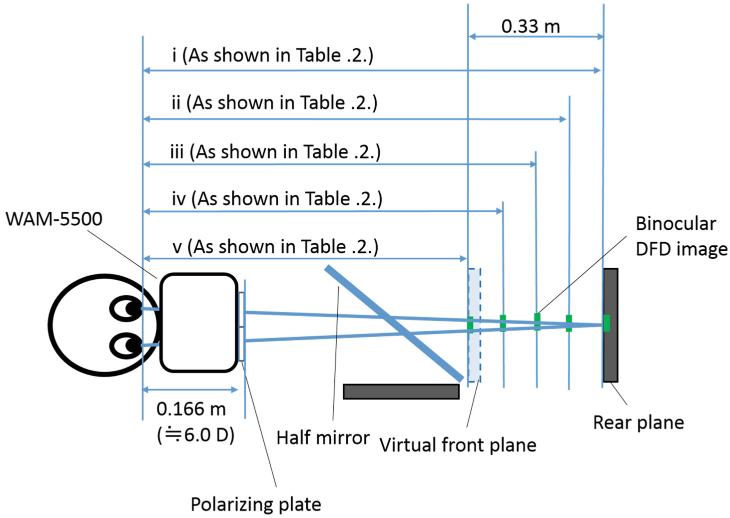

Fig. 4. Schematic diagram of experimental apparatus

Table 1. Specifications for stereoscopic display

Manufacturer	Mitsubishi Electric Corp.
Screen size	23 In.
Resolution	1920 × 1080
Refresh rate	60 Hz
3D data format	Top and bottom
Average of illuminance of the screen	27.5 cd/m^2

Table 2. Luminace and distance of DFD images

	i	ii	iii	iv	v
Luminance of the front image (%)	0	25	50	75	100
Luminance of the rear image (%)	100	75	50	25	0
Distance (m)	1.00	0.92	0.83	0.75	0.67
Distance (D)	1.00	1.09	1.20	1.33	1.50

accommodation. We chose the image by the pupillary distance of the subjects. In this experiment, we set a parallax which fixed convergence on the position of 1.0 D to exclude the influence of its stimuli. In other words, the subjects perceived the depth as a factor of the luminance ratio.

Before taking the measurement of accommodation, we made a fine adjustment of the parallel of the two planes and the horizontal and vertical position. We arranged the front and rear planes which displayed the five spot images arranged in a cross-like pattern for all subjects to perceive the DFD image as a single image at one depth.

First, an image of a white spot on a black background was displayed at the depth of 1.0 D for 5 s. Next, the images of an RGB (0, 255, 0) colored object (Maltese cross) on a black background were displayed for 5 s per each luminance ratio (as shown in Table 2). We decided this was one trial. We repeated this for four trials during one measurement, and made measurements three times per subject. Therefore, we obtained data of 12 trials per subject. However, there were special cases in which the measurements were made only one or two times in consideration of the subject's health condition.

3 Result

3.1 Typical Example of Accommodation Data

In this study, we acquired the data of accommodation during viewing of DFD images. First, typical accommodation data is shown in Fig. 5. In this figure, the vertical axis shows the accommodation focus, and the horizontal axis shows the measurement time. The DFD image moved every five seconds. We found that the subject's lens accommodation focus moved with a change of the depth of DFD image. The result indicated that the accommodation focuses on the DFD image, did not focus on each two plane.

3.2 Statistical Analysis

In this study, we statistically analyzed the data of accommodation. Incidentally, we executed data cleansing to remove any error value or missing data before the statistical analysis.

The WAM-5500 measured accommodation every 0.2 s because the sampling frequency was 5 Hz. First, we excluded accommodation values measured on the subject side of the position of a polarizing plate at 6.0 D. We excluded the data for missing

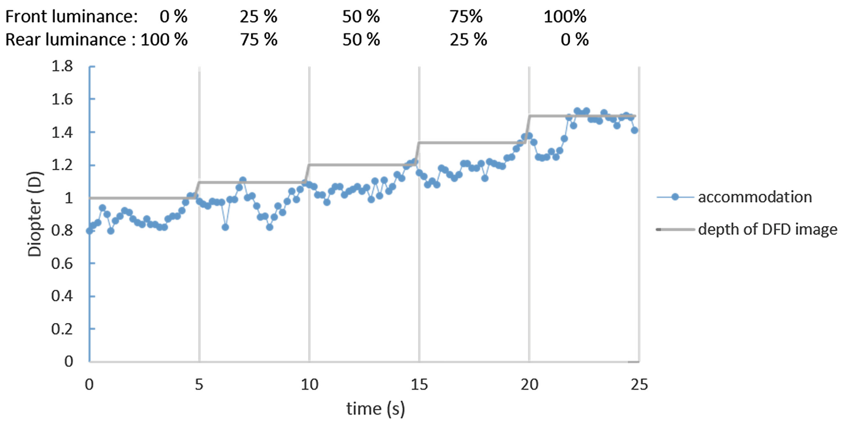

Fig. 5. Typical accommodation data (female, 35 years old)

Table 3. Number and age of subjects

	Number	Age (average ± standard deviation)
All subjects	78	39.40 ± 14.25
Young subjects	25	22.96 ± 2.79
Young middle aged subjects	23	38.65 ± 4.24
Middle aged subjects	27	51.30 ± 5.06
Elderly subjects	3	75.00 ± 1.00

ratios of over 50 % per the data for one trial. Furthermore, we also excluded the values that did not have an average ± 2.58 standard deviation (99 % confidence interval of a normal distribution) of the data for one trial. We calculated the average values by time at intervals of 0.2 s using the data of at most 12 trials per subject. This data set was the typical accommodation data set for each subject. In addition, we did not adopt the accommodation data of those subjects that had existed missing values in these data sets. Table 3 shows the accommodation data sets of the 78 subjects.

We calculated the group average of the accommodation data sets, as shown in Figs. 6, 7, 8, 9. Moreover, we employed a one-way ANOVA (analysis of variance) and the Tukey-Kramer test to the accommodation data set as the dependent variable and depth of the five steps as the independent variable (at 5 % significance level). Because there was a slight error between the start time of the moving image and the measurement instrument, we did not use the accommodation values of the first one second from the beginning and the last one second to the end in five seconds while the DFD image on each luminance was displayed. The results of the one-way ANOVA are shown in Tables 4, 5, 6, 7. The results of the Tukey-Kramer test are shown in Figs. 10, 11, 12, 13.

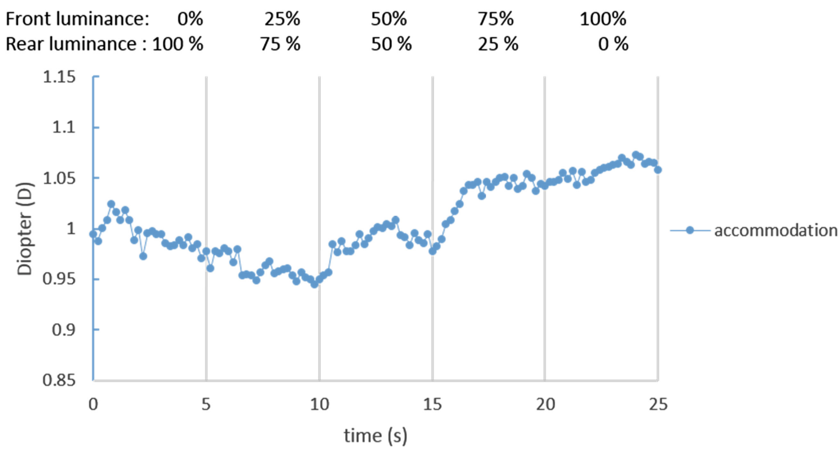

Fig. 6. Average accommodation of the young subjects (n = 25)

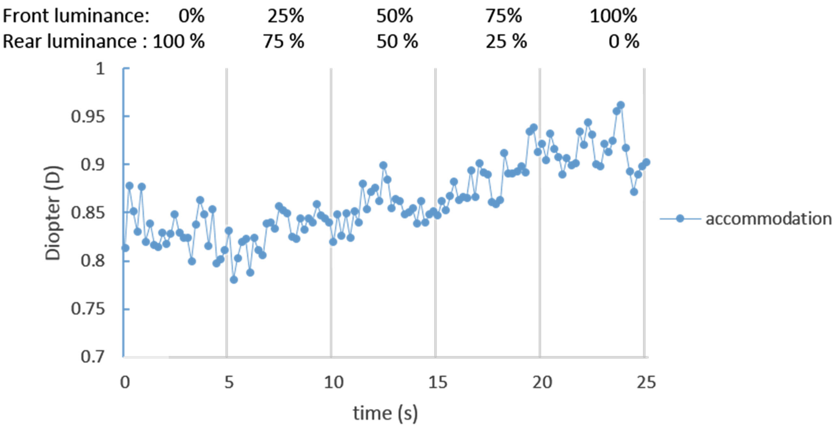

Fig. 7. Average accommodation of the young middle aged subjects (n = 23)

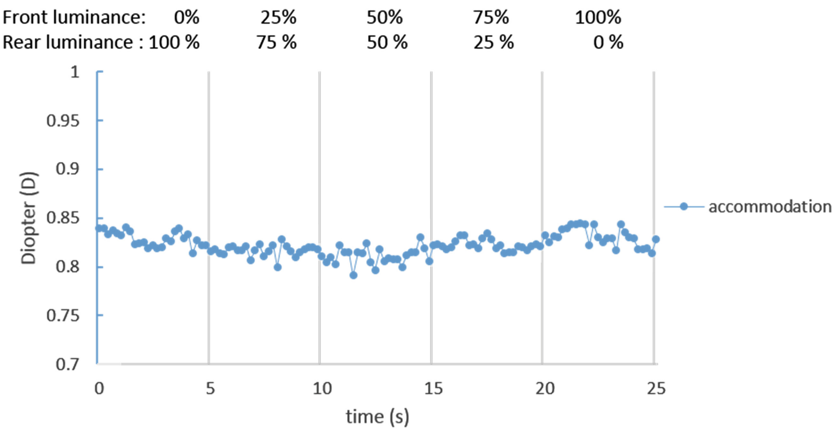

Fig. 8. Average accommodation of the middle subjects (n = 27)

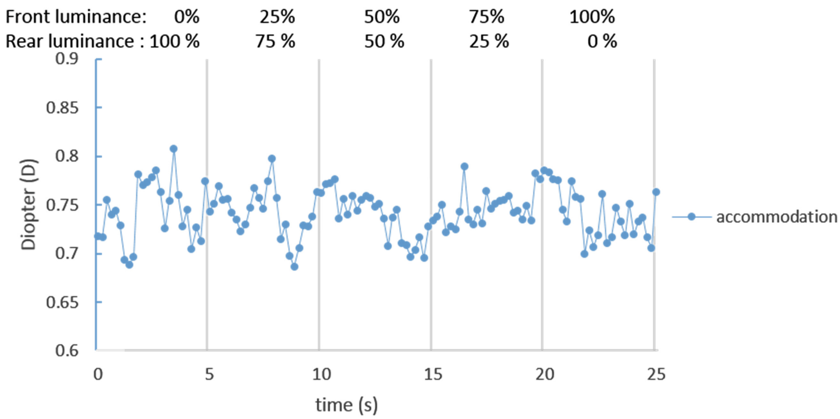

Fig. 9. Average accommodation of the elderly subjects (n = 3)

Table 4. Result of one-way ANOVA of the young subjects (n = 25)

	Df	Sum sq	Mean sq	F value	Pr(>F)
Factor	4	2.29	0.57	6.26	0.000
Residual	1870	171.15	0.09		

Table 5. Result of one-way ANOVA of the young middle aged subjects (n = 23)

	Df	Sum sq	Mean sq	F value	Pr(>F)
Factor	4	1.96	0.49	4.16	0.002
Residual	1720	202.80	0.12		

Table 6. Result of one-way ANOVA of the middle aged subjects (n = 27)

	Df	Sum sq	Mean sq	F value	Pr(>F)
Factor	4	0.2	0.04	0.16	0.961
Residual	2020	498.5	0.25		

Table 7. Result of one-way ANOVA of the elderly subjects (n = 3)

	Df	Sum sq	Mean sq	F value	Pr(>F)
Factor	4	0.01	0.00	0.03	0.998
Residual	220	13.07	0.06		

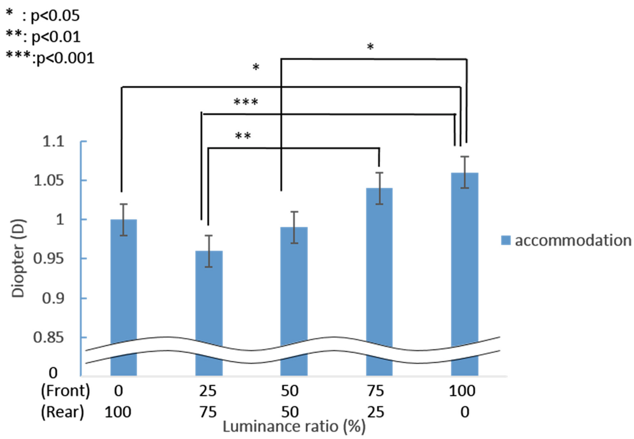

Fig. 10. Result of Tukey-Kramer test of the young subjects (n = 25)

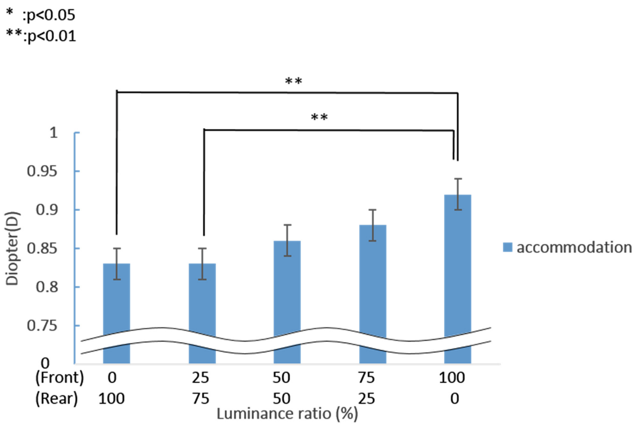

Fig. 11. Result of Tukey-Kramer test of the young middle aged subjects (n = 23)

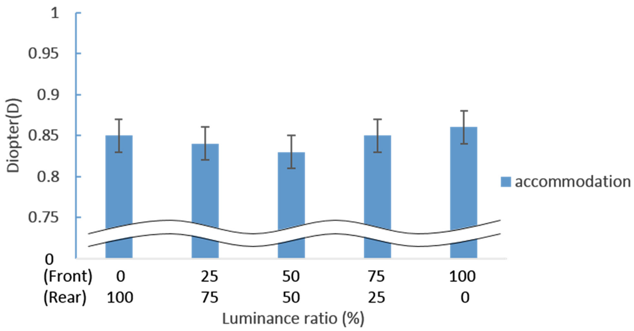

Fig. 12. Result of Tukey-Kramer test of the middle aged subjects (n = 27)

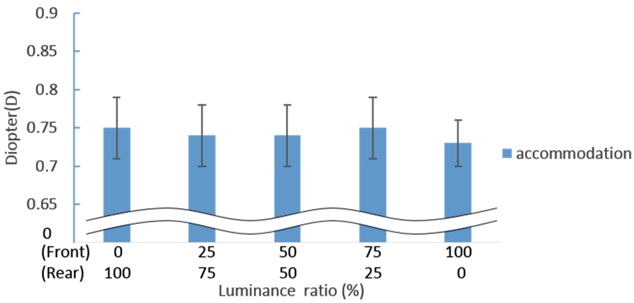

Fig. 13. Result of Tukey-Kramer test of the elderly subjects (n = 3)

4 Discussion

Previous studies have shown that when a person views stereoscopic images, a visual discrepancy occurs because convergence, which focuses at the position of the virtual object, and lens accommodation which is fixed on the screen. However, authors have not found such a mismatch in experiments with young subjects [6, 9]. In addition, studies have not clarified the effects of viewing of DFD images on accommodation. Thus, we investigated it.

As shown in Fig. 6, the accommodation focus of the young subjects clearly couldn't be seen the characteristic change when the luminance of front image was 0 % and the luminance of rear image was 100 %, and when the luminance of front image was 25 % and the luminance of rear image was 75 %. The accommodation focus of the young subjects approached the DFD image when the luminance of front image were 50 % or more. We inferred that subjects did not recognize that the DFD image was approaching them when the luminance of front image changed from 0 % to 25 % and the luminance of rear image changed from 100 % to 75 %. This indicates that the subjects perceived that the DFD image was approaching them when the luminance of front image were 50 % or more. As shown in Fig. 7, the accommodation focus of the young middle aged subjects approached the DFD image when the luminance of front image was 25 % or more. This indicates that the subjects perceived that the DFD image was approaching them. As shown in Figs. 8, 9, the accommodation focus of the middle aged and the elderly subjects did not change much. We presume that the changes of their refractive power decreases with age.

As shown in Tables 3, 4, 5, 6, and Figs. 10, 11, 12, 13, there were significant difference in the young and the young middle aged subjects. The accommodation focus was significantly moved toward the DFD image as the DFD image was approaching the subjects. There were no significant difference in the middle aged and the elderly subjects. The results suggest that the subjects perceived the DFD image was moving and they altered their lens accommodation because of the changes in luminance. In addition, this trend was seen in the young and the young middle aged subjects.

5 Summary

In this study, we verified that a viewer's lens accommodation can adjust to DFD images. We measured lens accommodation in subjects who gazed at DFD images. As a result, there were significant difference between the measurement data with depth of the five steps as the factor in the young and the young middle aged subjects. The young and young middle aged subjects perceived the approach of the DFD image. There were no significant difference in the middle aged and elderly subjects because with older individuals the crystalline lens loses elasticity with age and the changes of their refractive power also decreases. Hence, we concluded that lens accommodation was affected by the changes of luminance in the DFD image. Viewer adjusted their lens accommodation because of the changes in luminance.

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