Stereoscopic Vision Induced by Parallax Images on HMD and Its Influence on Visual Functions

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Abstract. Visual function of lens accommodation was measured while subjects used stereoscopic vision in a head mounted display (HMD). Eyesight with stereoscopic Landolt ring images displayed on HMD was also studied. In addition, the recognized size of virtual stereoscopic images was estimated using the HMD. Accommodation to virtual objects was seen when subjects viewed stereoscopic images of 3D computer graphics, but not when the images were displayed without appropriate binocular parallax. This suggests that stereoscopic moving images on HMD induced the visual accommodation. Accommodation should be adjusted to the position of virtual stereoscopic images induced by parallax. The difference in the distances of the focused display and stereoscopic image may cause visual load. However, an experiment showed that Landolt rings of almost the same size were distinguished regardless of virtual distance of 3D images if the parallax was not larger than the fusional upper limit. However, congruent figures that were simply shifted to cause parallax were seen to be larger as the distance to the virtual image became longer. The results of this study suggest that stereoscopic moving images on HMD induced the visual accommodation by expansion and contraction of the ciliary muscle, which was synchronized with convergence. Appropriate parallax of stereoscopic vision should not reduce the visibility of stereoscopic virtual objects. The recognized size of the stereoscopic images was influenced by the distance of the virtual image from display.

Keywords: 3-D Vision, Lens Accommodation, Eyesight, Landolt ring, Size Constancy.

1 Introduction

Stereoscopic vision (3D) technology using binocular parallax images has become popular, used for movies, television, camera, and mobile displays. 3D vision enables the display of real and exciting images with information of stereoscopic space. However, 3D viewing may cause asthenopia more often than watching 2D images or

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natural vision. Influences of 3D viewing on visual functions should be studied. It is necessary to understand the mechanisms of recognition and the effects of 3D vision to make safe and natural 3D images.

Three examinations have been conducted in order to study the effects of 3D vision on visual functions. First we measured the recognized size of a figure displayed stereoscopically (Experiment 1). Same size figures could be perceived as if their sizes were different (Fig. 1) because of the size constancy. How are the sizes of stereoscopic figure recognized?

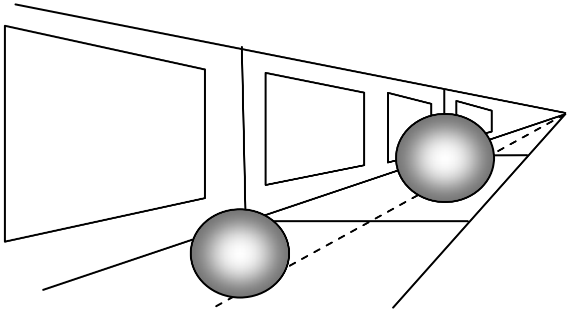


Fig. 1. Example of illusion by size constancy. The right sphere looks as if it is larger than the left one, although the sizes are the same.

Another experiment (Experiment 2) was to measure binocular visual acuity while viewing 3D Landolt rings (Fig. 2). The focus is not fixed on the surface of the display, but moving near and far synchronously with the movement of the 3D images being viewed, as we previously reported [1-5]. The accommodation agrees with a convergence fusion image that is different from the virtual display position [6]. Does the visibility of the stereoscopic image deteriorate from the lack of focus?

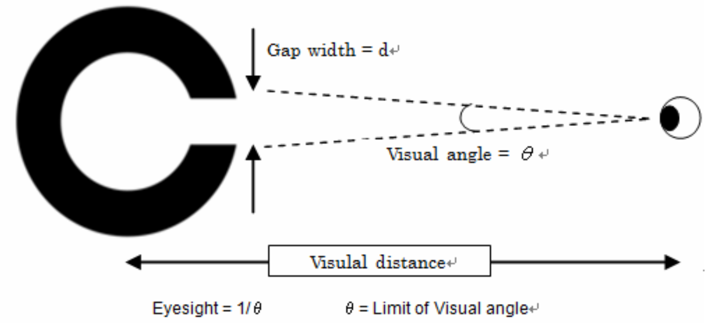


Fig. 2. Landolt ring and visual acuity measurement

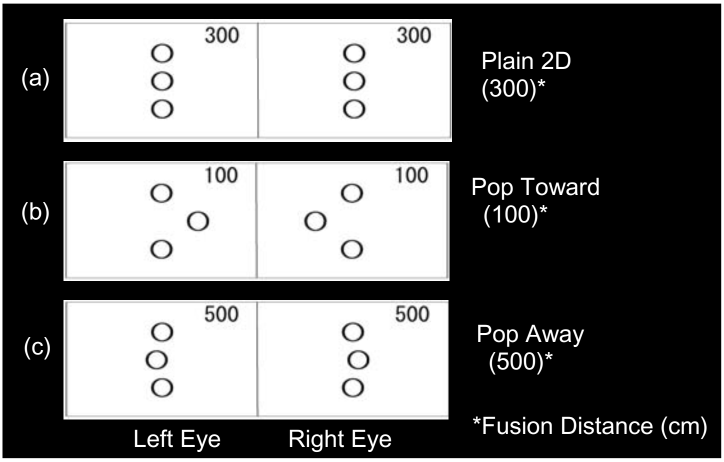
In Experiment 3, lens accommodation was measured while watching 3D vision. Ordinary 3D (cross point camera image) and Power3D^{TM} (Olympus visual communications Co., Ltd) were used for this experiment. A method to make natural 3D vision was suggested.

Details of these Experiments are described below.

2 Methods

2.1 Method of Experiment 1: Recognized Size Estimation

The HMD (Vuzix Corp. iWear AV230XL+, 320×240 pixel) displayed a 44 inch virtual screen at a viewing distance of approximately 300 cm (270 cm). The center circle of three circles was shifted horizontally without size change, to make parallax for 9 different 3D virtual distances of 100, 150, 200, 250, 300 (2D), 350, 400, 450 and 500 cm from the eye to the fusion image (Fig. 3a). Subjects viewed these images (Fig. 3b) and recorded recognized size with pencil on the paper sheet shown in Fig. 3c.



(a) Examples of 3D images displayed on HMD

(b) Viewing 3D images on HMD (c) Recognized size recording sheet

Fig. 3. Experiment 1: Recognized size estimation

2.2 Method of Experiment 2: Visual Acuity for 3D Landolt Ring

An HMD (same apparatus in Exp. 1) was used. Still images of parallax with a side-by-side format were prepared for display of Landolt rings of 12 sizes (0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.9, 1.0, 1.2, 1.5 and 2.0) and visual acuity of 300 cm. Landolt rings were shifted horizontally without size change, to make parallax for 9 different stereoscopic virtual 3D virtual distances of 100, 150, 200, 250, 300 (2D), 350, 400, 450 and 500 cm to the fusion image (Fig. 4). Subjects wearing the HMD adjusted the focus of both the left and right glasses first using the dial on the HMD while viewing 300 cm images that had no parallax. They then watched stereoscopic images of 9 distances without changing the focus dial positions. The smallest size of Landolt ring resolved by the subjects was recorded with a value of 0.2-2.0 (eyesight value shown in Fig. 2). Eighteen subjects (24.6 ± 7.9 years) with naked vision or wearing contact lens or glasses were studied only when they could view fusion stereoscopic images.

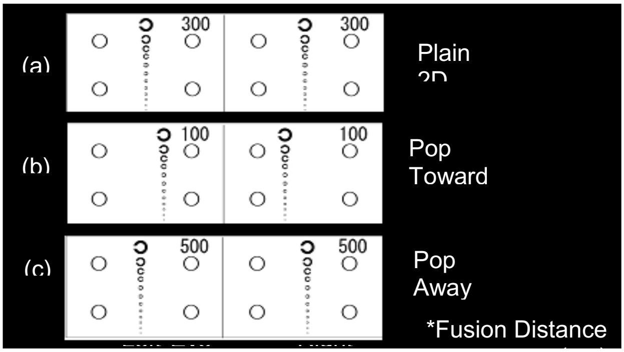


Fig. 4. Examples of 3D images used in Experiment 2: Visual Acuity for 3D

2.3 Method of Experiment 3: Accommodation Measurement

The image used in Experiment 3 was a moving 3D-CG sphere displayed stereoscopically. The sphere moved virtually in a reciprocating motion toward and away from the observer with the cycle of 10 seconds (Fig. 5).

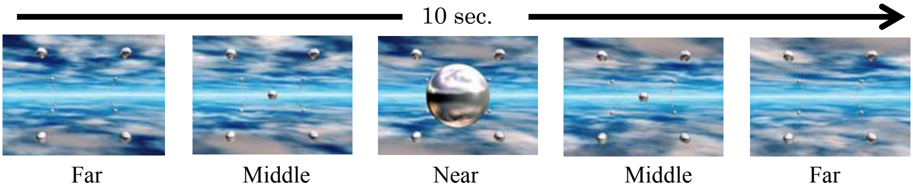


Fig. 5. Moving 3D image used in Experiment 3

Moving images (Fig. 5) were prepared by four type of 2D (Fig. 6a), Pseudo 3D (Fig. 6b), Cross point 3D (Fig. 6c with Fig. 7a) and POWER3D^{TM} (Fig. 6c with Fig. 7b).

A modified version of an original apparatus [3] to measure lens accommodation was used in the experiment 3 (Fig. 8). Accommodation was measured for 40 seconds under natural viewing conditions with binocular vision while a 3D image (Fig. 5) moved virtually toward and away from the subject on an HMD (Fig. 8). For the accommodation measurements, the visual distance from the HMD to the subjects'

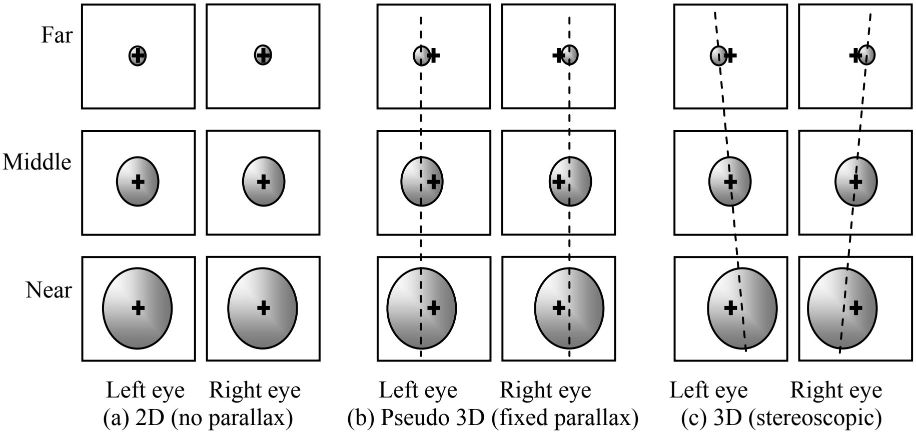


Fig. 6. Three parallax modes used in Experiment 3

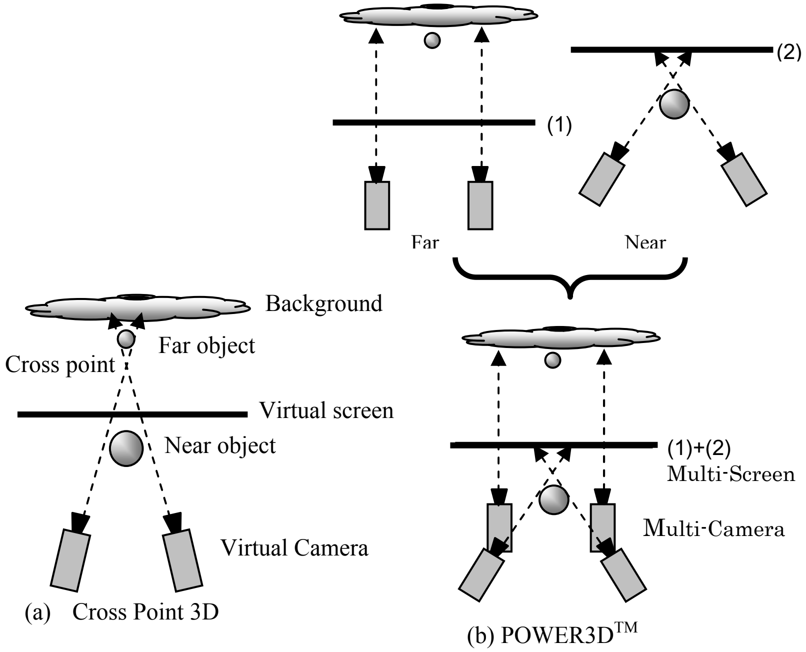


Fig. 7. Two 3D photography modes used in Experiment 3

eyes was 3 cm. The refractive index of the right lens was measured with an accommodo-refractometer (Nidek AR-1100) when the subjects gazed at the presented image via a small mirror with both eyes. The HMD (Vuzix Corp. iWear AV920, 640×480 pixel) was positioned so that it appeared in the upper portion of a dichroic mirror placed in front of the subject's eyes (Fig. 8). The 3D image was observed through the mirror. The stereoscopic image displayed in the HMD could be observed with natural binocular vision through reflection in the dichroic mirror, and refraction could be measured at the same time by transmitting infrared rays.

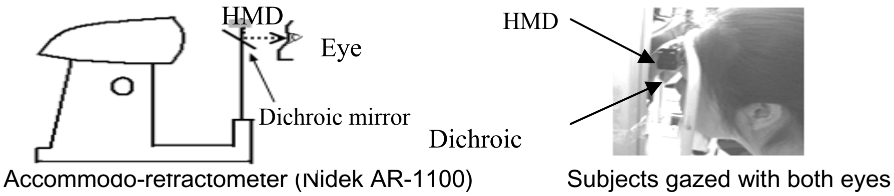


Fig. 8. Lens accommodation measurement while watching 3D movie on HMD

The subjects were instructed to gaze at the center of the sphere with binocular eyes. All subjects viewed four types of images of 2D, Pseudo 3D, Cross point 3D and POWER 3D^{TM} (Fig. 6, Fig. 7). While both eyes were gazing at the stereoscopic image, the lens accommodation of the right eye was measured and recorded.

3 Results

3.1 Result of Experiment 1: Recognized Size Estimation

Fig. 9 shows the result of the Experiment 1. Four subjects recorded the recognized size of 3D circle on the sheet shown in Fig. 3c. Ratio to the size of 2D (fusion distance: 300 cm) was plotted, except when subjects could not fuse 3D images. Additionally, the theoretical line mentioned below is shown in the same graph.

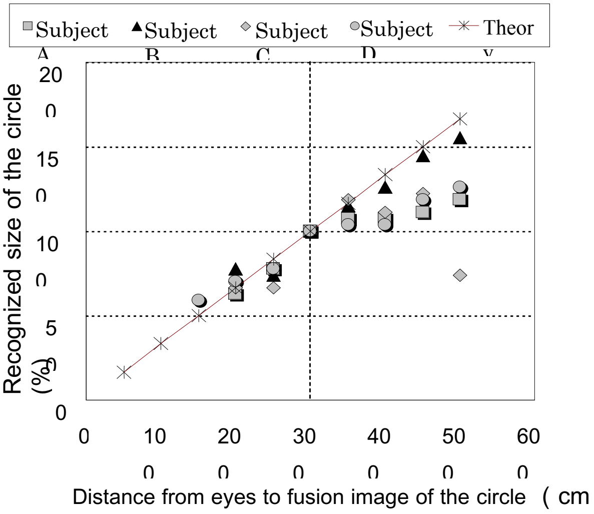
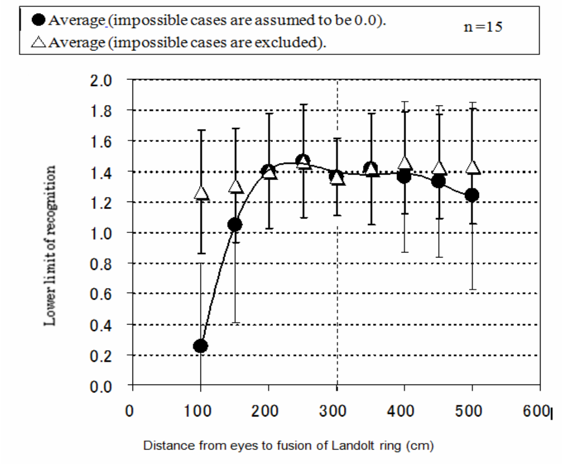
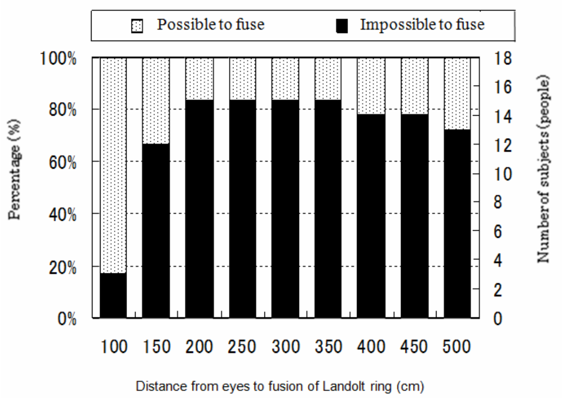


Fig. 9. Result of Experiment 1



(a) Lower limit of recognition



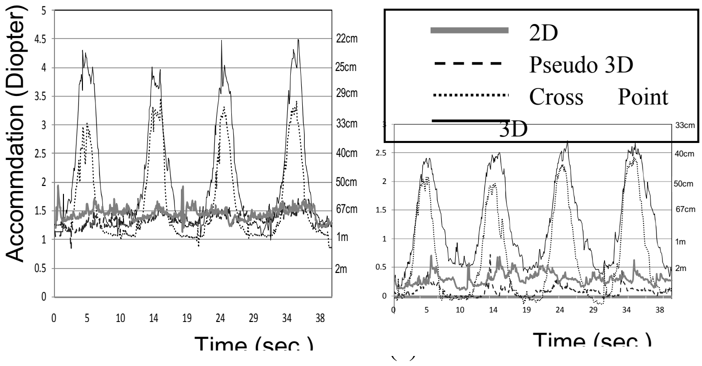
(b) Rate of subjects possible to fuse and impossible to fuse

Fig. 10. Result of Experiment 2

3.2 Result of Experiment 2: Visual Acuity for 3D Landolt Ring

The result of Experiment 2 is shown in Fig. 10. Fig. 10a shows the smallest Landolt ring size expressed by the value for visual acuity from a 300 cm distance, averaged for 15 subjects (excluding 3 who could view fusion images for neither parallax). In this graph, ● shows the average of visual acuity points (eyesight value shown in Fig. 2) in which the value of the non-fusion cases was 0.0, and △ shows the average of only cases of successfully viewed fusion.

The number and percentage of subjects who could and could not view fusion images are shown in Fig. 10b. There are a lot of subjects who exceed the fusional upper limit by 100 cm and 150 cm.



(a) Accommodation of Subject E (b) Accommodation of Subject F

Fig. 11. Result of Experiment 3

The fusion limit field is different depending on the individual variation or the characteristic factor of HMD. However, Fig. 10a △ shows that almost the same size Landolt ring was distinguished regardless of the virtual distance of 3D images if the parallax was not larger than the fusional upper limit for each subject.

3.3 Result of Experiment 3: Accommodation Measurement

The presented image was a 3D-CG sphere that moved in a reciprocating motion toward and away from the observer with the cycle of 10 sec. (Fig. 5). The subjects gazed at the sphere and accommodation was measured for 40 seconds (Fig. 8). The results for 2D, Pseudo 3D, CrossPoint3D and POWER3D (Fig. 6, Fig. 7) are shown in Fig. 11 for two subjects.

Figure 11 (a) shows results for subject E (age: 24, male), and (b) for subject F (age: 39, female). The results showed that large amplitude of accommodation synchronizing with convergence is shown only in both 3D modes of Cross Point 3D and POWER3D but in neither 2D nor Pseudo 3D. Individual difference among subjects was large, however. POWER3D induced larger amplitude accommodations than Cross Point 3D in both subjects.

4 Discussion

Stereoscopic images induced the illusion that pop away figures were recognized as being larger than the size on the display screen (Fig. 9), although the rate was saturated except in one subject of ▲ in Fig. 9. The theoretical line shown in Fig. 9 is the calculated size ratio according to the principle shown in Fig. 12. The saturation of the expansion of the pop away image size might be caused by ‘size consistency’ (Fig. 1).

The reason why the size of the pop-toward image was recognized as being smaller and the pop-away as larger (Experiment 1, Fig. 9) may be that the images on the retina of subjects' eyes agreed with the screen images although the recognized distances were on the fusion point of the parallax images (Fig. 12). Hori and Miyao *et. al* [6] have reported the accommodation agreed with fusion distance while watching 3D images. Some scholars have said the 3D images might be unfocused because the accommodations focused on the pop toward/away images though images were displayed on the screen. However, the result of Experiment 2 (Fig. 10) showed that the eyesight did not deteriorate regardless of the pop toward/away distances if subjects could successfully view fusion within the depth of field.

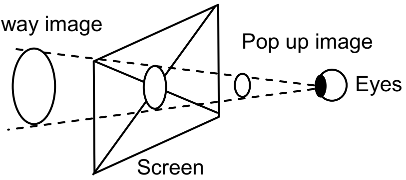


Fig. 12. The principle of expansion and contraction of recognized 3D images

Accommodation was induced by the movement of the stereoscopic image in 3D mode on the HMD (Fig. 11), and the amplitude was larger in POWER3D than in ordinary Cross Point 3D. One of the reasons why some people feel artificiality in stereoscopic viewing was the fixed camera angles in photography (Fig. 7). POWER3D induced the larger accommodation without fusion failure, and may be more natural for 3D viewers than the conventional method of Cross Point 3D (Experiment 3, Fig. 11).

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