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Effects on Visibility and Lens Accommodation of Stereoscopic Vision Induced by HMD Parallax Images

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The visual function of lens accommodation was measured while subjects used stereoscopic vision with a head mounted display (HMD). Eyesight while viewing stereoscopic Landolt ring images displayed on HMD was also studied. 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 visual accommodation. Accommodation should be adjusted to the position of virtual stereoscopic images induced by parallax. A 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. The results of this study suggest that stereoscopic moving images on HMD induced 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.

Key words: Convergence, 3D Display, Head Mounted Display, Crystalline Lens, Eyesight

1. Introduction

The practical use of 3D has begun to spread rapidly throughout the world, and head mounted displays (HMDs) (Fig. 1) are now widely used for viewing stereoscopic images. HMDs have two small displays in front of the two eyes. An advantage of HMDs is that they can directly display the left image for the left eye and the right image for the right eye without contamination of binocular parallax images. Moreover, HMDs can display stereoscopic vision without deterioration in resolution, unlike the 3D systems of CRT with liquid crystal shutter glasses that reduce resolution horizontally to half, or systems of parallax barrier LCDs that reduce resolution vertically to half. HMDs may thus be expected to be more popular for stereoscopic vision. However, visual functions during stereoscopic vision on HMDs have been little studied.

In natural viewing, the two eyes see an object from different positions as the pupil distance. This is referred to as parallax. Stereoscopic images can be recognized using binocular parallax (Fig. 2). Stereoscopic vision induced by binocular parallax is caused from the difference between the images in the right eye and left eye. Convergence of the binocular viewing directions is the stimulation that causes stereoscopic recognition. It has been stated in many reports (Wann *et al.*, 1995; Watt *et al.*, 2005) that dissociation of accommodation and convergence occurs in stereoscopic vision.

However, lens accommodation with stereoscopic HMDs has not been measured, because the eyes are very close to the HMD (Fig. 1(b)). Does accommodation agree with the distance of the fusion image at the convergence point or the distance of the virtual display of HMDs? We previously reported that the focus is not fixed on the surface of the display when the stereoscopic images are being viewed by other 3D systems (Miyao *et al.*, 1996; Omori *et al.*, 2005, 2009). If the accommodation agrees with a fusion image that is different from the virtual display position, does the visibility of the stereoscopic image deteriorate from the lack of focus?

To investigate the effects on human vision of stereoscopic images seen on HMDs, we conducted two experiments. In experiment 1, we measured lens accommodation in subjects as they watched stereoscopic images on an HMD. In experiment 2, the visibility of stereoscopic images was measured using 3-D Landolt rings displayed on an HMD.

2. Method

2.1 Method of experiment 1: Accommodation measurement

Lens accommodation was measured using a modified version of an original apparatus (Miyao *et al.*, 1992) (Fig. 3) for 40 sec as subjects gazed at 3D images of a CG sphere that moved virtually toward and away from the subject with a frequency of 10 sec (Fig. 4) on HMDs. Measurements

(a) HMD (b) Wearing an HMD

Fig. 1. Individual wearing HMD.

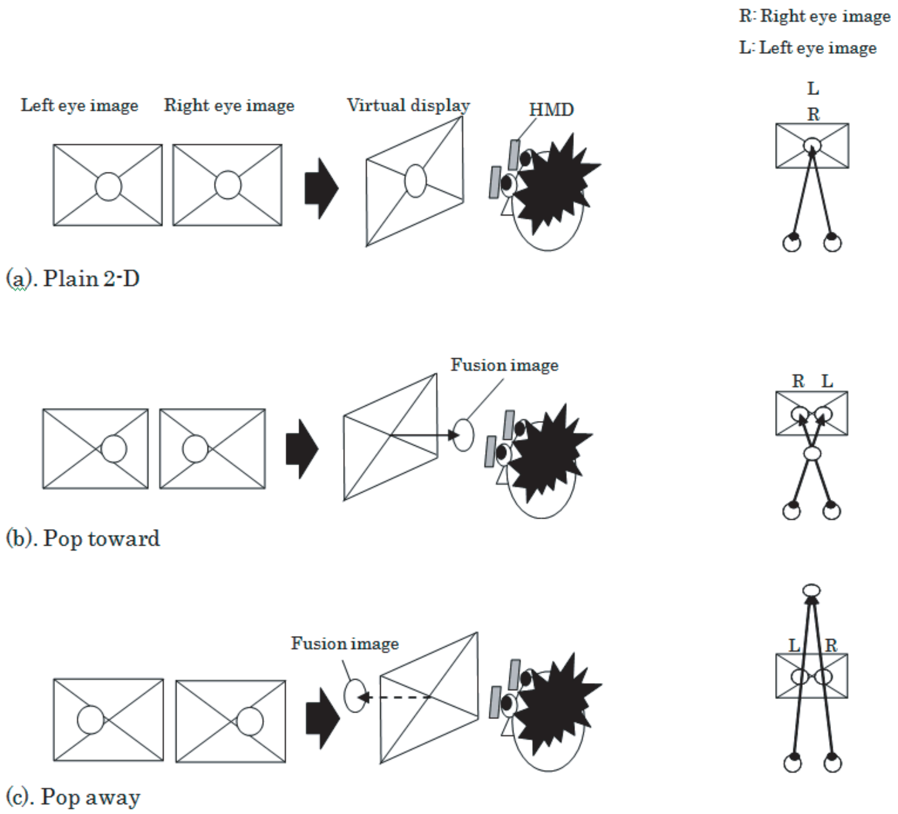

Fig. 2. Stereoscopic vision using binocular Parallax.

were made when subjects gazed at the three kinds of moving images of 3D, pseudo 3D, and 2D with natural binocular vision (Fig. 5). The images used in this experiment were as follows.

(a) 2D: No parallax. The right eye image and left eye image are the same without parallax. This is not stereoscopic vision although the sphere repeatedly grows big and then small.

(b) Pseudo 3D: Fixed parallax. The parallax is constant regardless of the sphere distance. Stereoscopic vision can be recognized; however, the cross points of parallax are constant at a point a little deeper than the distance from the display.

(c) 3D: Stereoscopic image. Appropriate parallax corresponding to the distance was applied to the sphere images.

We conducted the experiment using an HMD (Vuzix Corp; iWear AV920, 640 × 480 dot; Fig. 1) and Power 3D software (Olympus Visual Communications Corp.) for

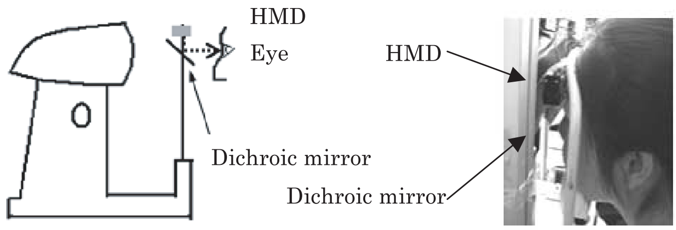

Fig. 3. Lens accommodation measured with a 3D content generation method on an HMD. An accommodo-refractometer (Nidek AR-1100) was used when the subjects gazed at the presented image via a small mirror with both eyes.

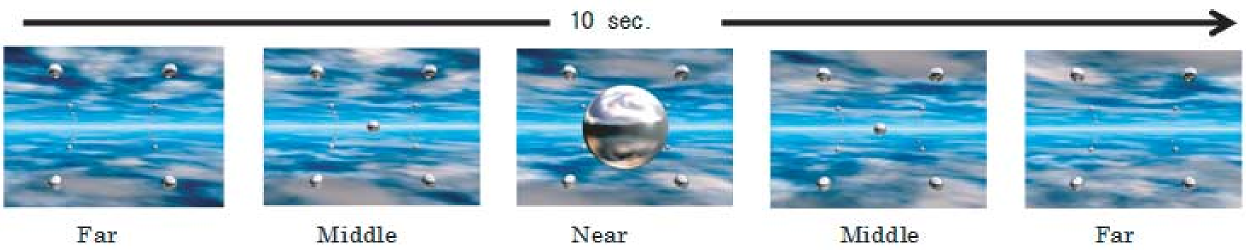

Fig. 4. Stereoscopic target movement.

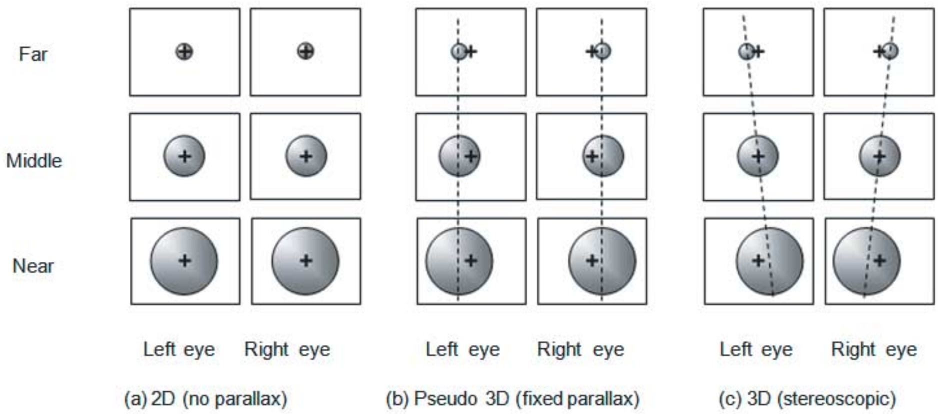

Fig. 5. Three parallax modes used in this experiment.

moving CG images.

While both eyes were gazing at the stereoscopic image, the lens accommodation of the right eye was measured and recorded for all subjects watching the 3D, pseudo 3D, and 2D moving images. The subjects were 15 healthy Japanese volunteers (five persons with uncorrected vision, 10 who wore soft contact lenses) aged 21–42 years (27.4 ± 7.1 years), from whom consent was obtained.

Informed consent was received from all of the subjects.

2.2 Method of experiment 2: Visibility measured using Landolt rings

To investigate the visibility of stereoscopic images, eyesight was measured using 3D Landolt ring (Fig. 6) images displayed on the HMD.

In experiment 2, 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 (Fig. 7).

The HMD (Vuzix Corporation iWear AV230XL+, 320 × 240 pixel) displayed a 44 inch virtual screen at a viewing distance of approximately 270 cm. Landolt rings were shifted horizontally without size change, to make parallax for 9 different stereoscopic virtual distances (100, 150, 200, 250, 300, 350, 400, 450 and 500 cm) from the eye to the fusion image. Three hundred cm was viewed without parallax, where parallax was calculated with 6 cm pupil distance (Fig. 7).

Subjects wearing the HMD first adjusted the focus of both the left and right glasses using the dial on the HMD while viewing 300 cm images that had no parallax, and then watched stereoscopic images of 9 distances without change of the focus dial positions. The smallest size of Landolt ring resolved by the subjects was recorded with a value of 0.2–2.0. Eighteen subjects (24.6 ± 7.9 years) with naked vision

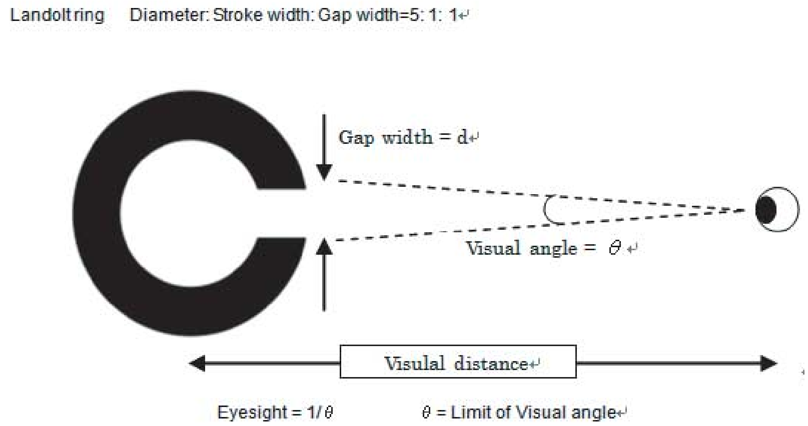

Fig. 6. Landolt ring and visual acuity measurement.

or wearing contact lenses or glasses were studied only when they could view fusion stereoscopic images.

Informed consent was received from the subjects.

3. Results

3.1 Results of experiment 1: Accommodation measurement

The presented image was a 3-dimensionally displayed sphere that moved in a reciprocating motion toward and away from the subject with the cycle of 10 sec (Fig. 4). The subjects gazed at the sphere for 40 sec. The results for 2D, pseudo 3D and 3D (Fig. 5) are shown in Fig. 8.

Figure 8(a) shows the results for subject A (age: 21, female, naked eyes), and (b) shows the results for subject B (age: 33, male, soft contact lenses).

The results showed that a large amplitude of accommodation synchronizing with convergence was seen only in 3D mode.

Accommodation occurred together with the movement of the stereoscopic image in 3D mode on the HMD (Fig. 8), and the lens accommodated so that the near point focus corresponded to the time when the visual target reached the nearest point virtually. It was shown that the focus then moved to a distant point with virtual movement of the visual target away from the subject. The amplitude of accommodation became smaller both in 2D and pseudo 3D.

A similar characteristic was shown in the measured data of many subjects in addition to the two people whose results are shown in Fig. 8.

Accommodation to the virtual objects was shown during the viewing of 3D computer graphic stereoscopic images, but was not shown when the images were displayed without appropriate binocular parallax. It was found that stereoscopic moving images on HMD induced visual accommodation by expansion and contraction of the ciliary muscle, in synchrony with convergence. The results suggested agreement of accommodation and convergence.

3.2 Result of experiment 2: Visibility measured using Landolt rings

The results of experiment 2 are shown in Figs. 9 and 10.

The graph in Fig. 9 shows the smallest Landolt ring size expressed by the value for visual acuity from a 300 cm

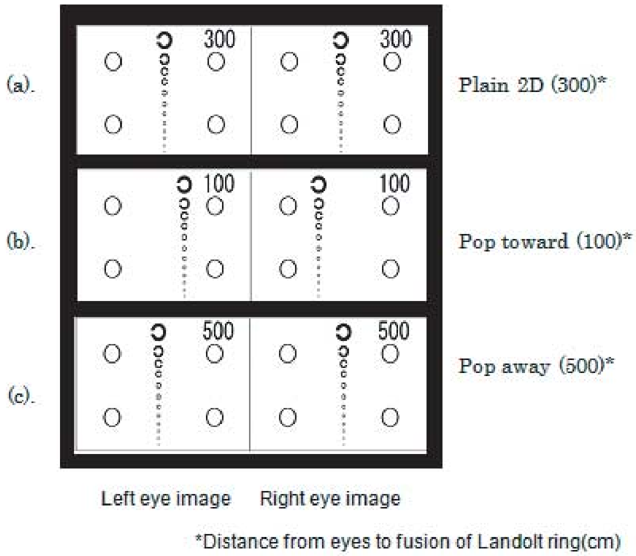

Fig. 7. Stereoimage used in experiment 2: Visibility measured using Landolt rings.

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 in which the value of the non-fusion cases was 0.0, △ 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. 10.

Many subjects exceeded the fusional upper limit by 100 cm and 150 cm (the fusion limit field was different depending on the individual variation or the characteristic factor of HMD). However, the graph in Fig. 9 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.

4. Discussion

Lens accommodation was measured with subjects gazing at a 3D image under conditions of binocular vision using a CRT (Miyao *et al.*, 1996) and LCD (Omori *et al.*, 2009). In experiment 1, a large amplitude of accommo-

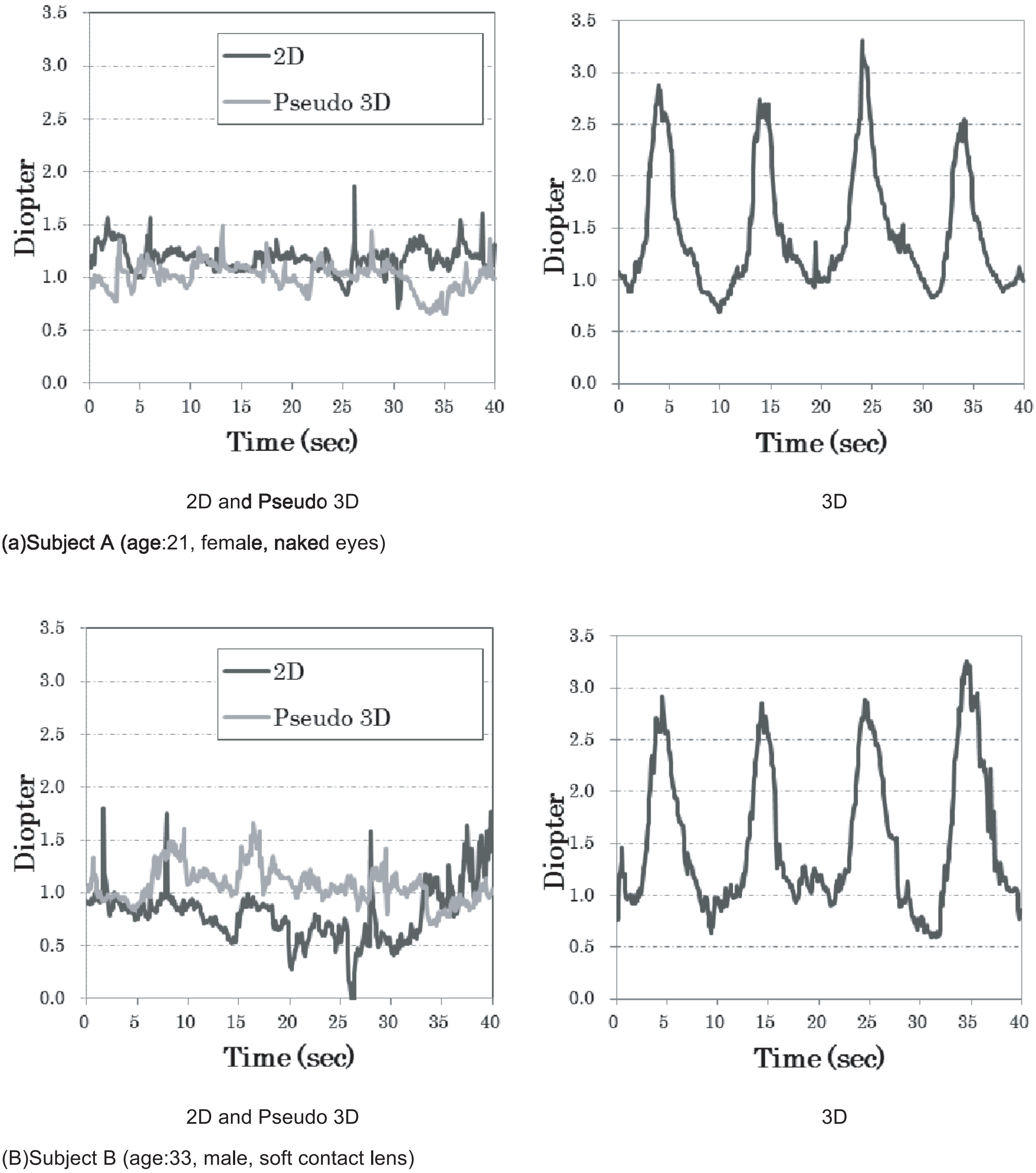

Fig. 8. Effect of different image content on lens accommodation. 2D, pseudo 3D and 3D were shown in figure.

dation was also shown with the use of HMD. When the sphere moved closer, accommodation was made to approximately 3 diopters in front of the eyes in the subject with the largest amplitude of accommodation. Immediately before the sphere reached the most distant point, the accommodation was about 1 diopter. This result showed accommodation caused by convergence stimulation and suggested that there is agreement of accommodation and convergence in stereoscopic vision. This demonstrates objectively that the ciliary muscle and ciliary zonule tense during near vision and relax during far vision, even when that vision is with virtual movement of a 3D image on an HMD.

This result shows that focus to the appropriate parallax 3D images was not fixed on the screen distance, but moved synchronizing to the changes in convergence.

Are the figures displayed on screen unfocused? To determine this, visual acuity in persons gazing at a 3D object should be measured.

The influence of blur images on the success rate of stereoscopic viewing or the relation between stereoscopic acuity and perception of depth has been studied from many points of view. Some examples are the relation between Magic

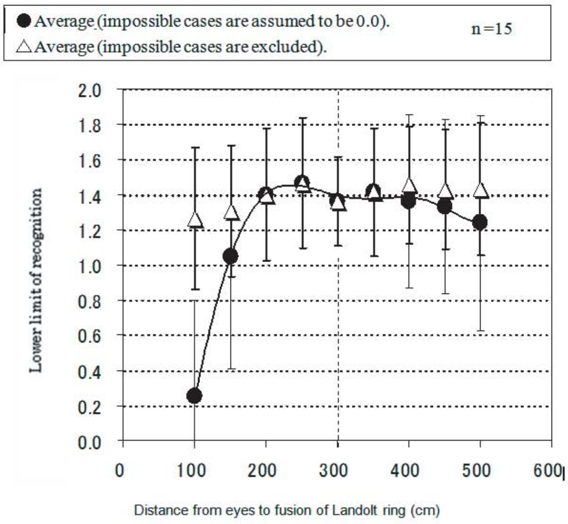

Fig. 9. Result of experiment 2: Visibility measured using Landolt rings.

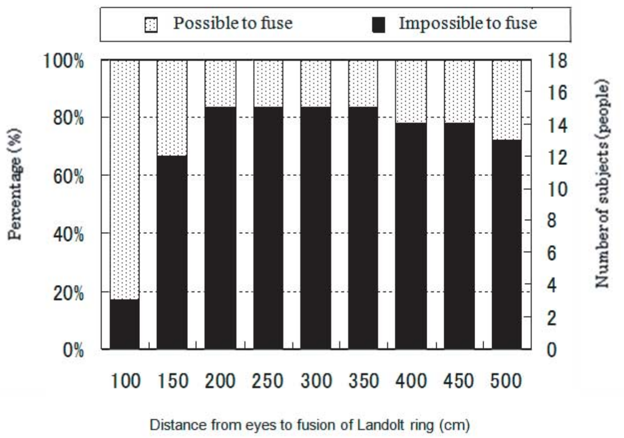

Fig. 10. Number of subjects who could/could not see stereoscopic views.

Eye™ skill and stereoacuity (Wilmer and Backus, 2008), the conditioning of blur adaptation in 3D viewing contexts (Battaglia *et al.*, 2004; Yaroslavsky *et al.*, 2005), and the relation between stereoscopic acuity and observation distance (Wann *et al.*, 1995; Bradshaw and Glennerster, 2006). However, few studies have reported the measurement of visual acuity estimated using stereoscopic Landolt rings.

We therefore estimated the visibility of 3D images using a Landolt ring test in experiment 2. Visibility did not deteriorate regardless of the depth of the 3D images if the parallax was not larger than the fusional upper limit.

5. Conclusion

In this study, agreement of accommodation and convergence in stereoscopic vision and undeteriorated visibility of the fusion images were shown when fusion vision was possible. Appropriate parallax of stereoscopic vision on HMD induced accommodation to stereoscopic fusion images by expansion and contraction of the ciliary muscle and did not reduce the visibility of stereoscopic virtual objects. Guidelines for safe and harmless stereoscopic images should be developed based on scientific knowledge in the near future.

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