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Effects of binocular parallax in 360-degree VR images on viewing behavior

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Abstract

The purpose of this research is to clarify the effects of binocular parallax in 360-degree images. Specifically, we measured and analyzed gazes during viewing stimuli for 60 seconds with different parallax distributions. The parallax distributions were four types of all 2D / all 3D / left and right 3D / front and back 3D. From the results, it was suggested that disparity distributions changed the viewing behavior with the passage of time, and even if parallax is added to a part of the image, the subjective stereoscopic effect increased. From these facts, it is suggested that there is effective 3D representation in the 360-degree images.

1. Introduction

Recently, virtual reality (VR) technology has been developing and spreading. In particular, the VR experience using a head-mounted display (HMD) is higher in sense of presence and immersion then the viewing on the flat display. Therefore, the utilization in the game and entertainment field is progressing. Then, a platform for 360-degree VR video is formed at video distribution sites, etc. It is considered that viewing a 360-degree video at the consumer level becomes more popular, coupled with standalone HMD and smartphone HMD.

On the other hand, discomfort is concerned in viewing a 360-degree image using an HMD. Conventional research on this topic has focused on the performance of HMD such as frame rate and viewing angle, and drawing system such as resolution and delay [1-4]. There are also studies focusing on the effect on the attitude and equilibrium function when using HMD [5-6]. In recent years, the performance improvement of HMD is remarkable, and updating research is necessary considering that. For example, Singla et al studied viewing 360-degree images using two commercially HMDs [7]. The results showed that the contents of the video content and the quality of the HMD were related to viewing behavior and simulation sickness. In addition, Palmisano et al. studied simulation sickness based on vections which are frequently problematic [8]. The results suggested that the inconsistency between the head movement and its perceived are greatly related to motion sickness, but the relation between vections and motion sickness is strongly affected by other factors.

Studies on stereoscopic images related to visual fatigue and safety [9-10] and focused on psychological or emotional [11-12]. As one of greatly related to this study is the attractiveness of stereoscopic images. For example, Hakkinen et al. compared the gaze movement during viewing 2D / 3D movies [13]. The results found that the gaze moved naturally also to the part outside the range of the interest to which the stereoscopic effect was added. In addition, Tanaka et al. studied the gaze tendency with respect to the stereoscopic effect of 3D images [14]. From the results, it is suggested that visual salience is seen in the protruding part of the 3D image.

The authors have studied physiological and psychological effects by observing 360-degree images using HMD so far [15]. From the results, in the observation of 360 - degree images using HMD, a characteristic tendency was observed in the movement of each body part of the participant. Also, differences in the influence of content were suggested. Especially, in the content where the "front" where the movement of the viewpoint is intense like a roller coaster is clear, the line of sight tends to concentrate in the moving direction. On the other hand, there was also a tendency for gaze gathering at certain places even in contents which cannot specify "front" where special features cannot be seen in one direction of the stoppage point of view like landscape. A heat map of the line of sight of each feature of contents is shown figure XX. This study focused attention on the attractiveness of 3D images and conducted an experimental study on binocular parallax in 360-degree images.

2. Method

2.1. Equipment

An SMI Mobile Eye Tracking HMD (Samsung Gear VR with Samsung Galaxy S7), which can direction of gaze, was used. Considering the influence of the sound, the earmuff was worn. The swiveling chair was used and fixed in order not to move.

2.2. Stimulus

The 360-degree camera (Insta 360 Pro) was used to create experimental stimulus which takes full circumference 3D shooting. The stimulus resolution was 3840 × 3840 pixels in equirectangular format. Four stimulus were prepared with different parallax distribution (2D / 3D / Front-Back 3D / Left-Right 3D). The 3D stimulus was whole 3D images the camera taken. In the 2D stimulus, images for the left eye of 3D stimuli were presented to both eyes. In

Figure 1. Layout of Experimental

Figure 2. Stimulus image

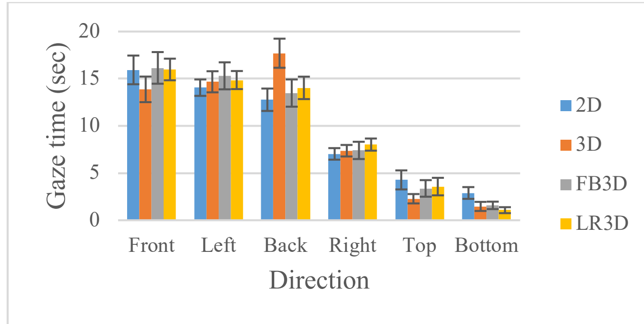

Figure 3. Gaze time in each direction by stimulus

the Front-Back 3D stimulus, the right eye images corresponding to 90 degrees on the right and left was replaced with the left eye images, and the replaced boundary part to alpha mask in 15 pixels not to clear the boundary line. In this study, the front means the direction starting the viewing images. In the Left-Right 3D stimuli, the same process was applied to 90 degrees on the front and back.

2.3. Evaluation

As the objective index, gaze movement was measured. The measurable field of view was 90 degrees in the horizontal and vertical directions, and the measurement frequency was 50 Hz.

As the subjective index, the rating 7 scale was taken (Strongly disagree – neutral – Strongly agree). The Evaluation items were from the previous study on the evaluation of 3D images [16] – image quality, reality, discomfort, stereoscopic and preference.

2.4. Procedure

The participants were 20 college students (17 males and 3 females). The purpose and method of the experiment was explained in advance and their consent was gained. Participants were familiarized with the experimental procedure through preliminary trials. During these trials, they adjusted the focus with the dial on the top of the HMD. They watched the calibration marker, then they watched each image, each image was viewed for 60 seconds. The questionnaires were completed after viewing. The calibration showed a white cross on the center of the black background. Considering the possible influence of viewing order, the image presentation order was randomized.

3. Results

3.1. Gaze distribution by stimulus

The result of gaze time for each direction divided in the horizontal and vertical directions like a cube is shown in Figure 3. The horizontal axis represents the direction, and the vertical axis represents the gaze time. A two-way ANOVA was conducted to analyze the stimulus and the direction on the gaze time. The direction had a significant effect ($p < .01$). The multiple comparisons showed significant differences between the front / left / back and right / top / bottom, and right and top / bottom ($p < .01$). From these results, it suggested that the gaze did not stay in a specific direction due to parallax.

3.2. Gaze distribution by time

The result of gaze time for each direction every 10 seconds from the start viewing the image is shown in Figure XX. A three-way ANOVA was conducted to analyze the stimulus, the direction and the time. The direction had a significant effect ($p < .01$), and

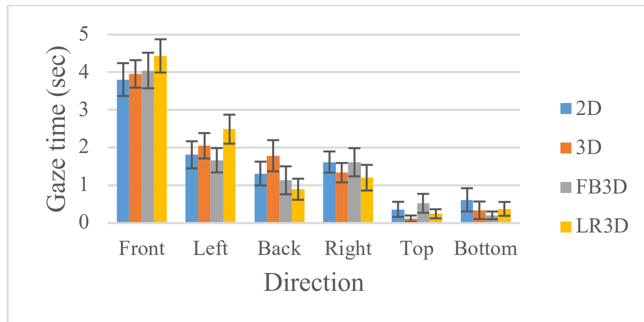

Figure 4. Gaze time in each direction by time (0-10 sec)

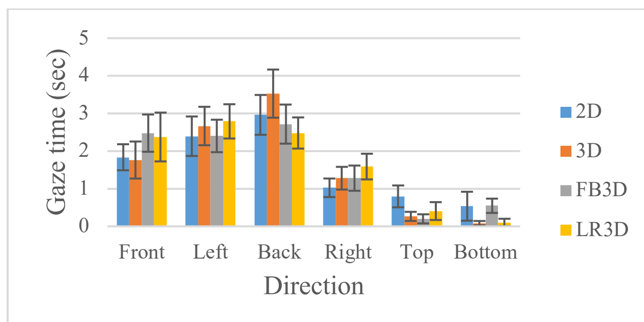

Figure 5. Gaze time in each direction by time (10-20 sec)

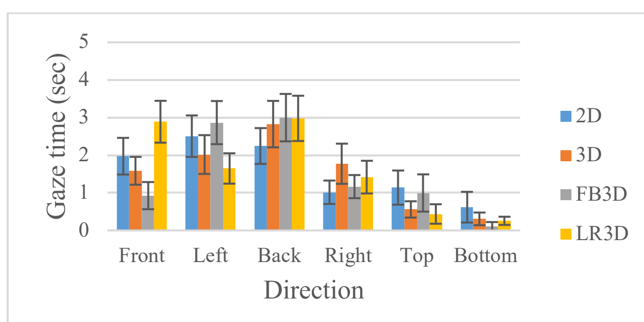

Figure 6. Gaze time in each direction by time (20-30 sec)

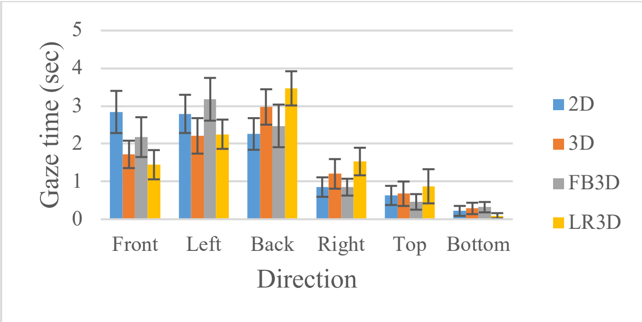

Figure 7. Gaze time in each direction by time (30-40 sec)

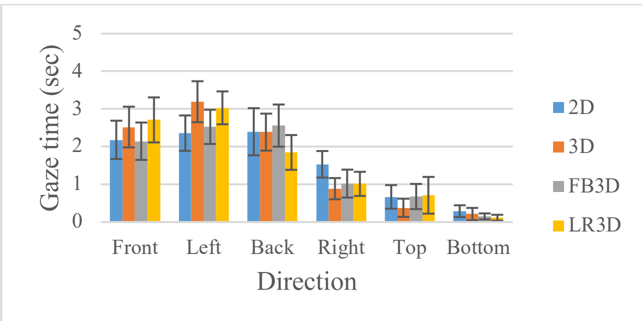

Figure 8. Gaze time in each direction by time (40-50 sec)

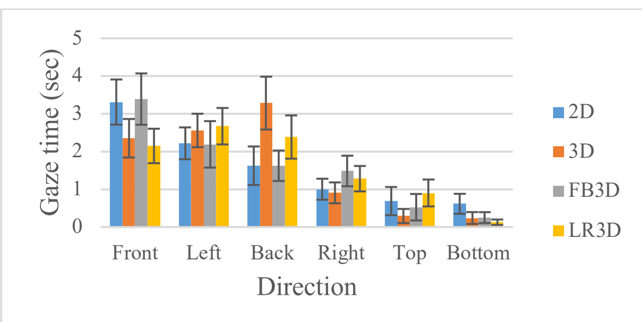

Figure 9. Gaze time in each direction by time (50-60 sec)

there was a two-way interaction between the direction and the time ($p < .01$).

3.3. Subjective index

An ANOVA was carried out on the score of each subjective index. There was a significant effect on the stereoscopic ($p < .05$), and a significant trend on the reality ($p < .10$). The multiple comparisons on the stereoscopic showed a significant difference between 2D and 3D / Front-Back 3D ($p < .05$), and a significant trend between 2D and Left-Right 3D ($p < .10$). The multiple comparisons on the reality showed a significant trend between 2D and 3D ($p < .10$).

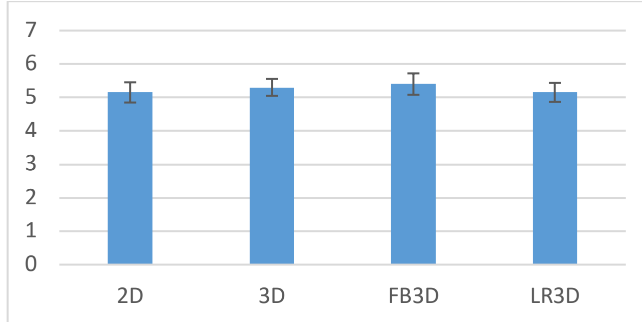

Figure 10. Image quality

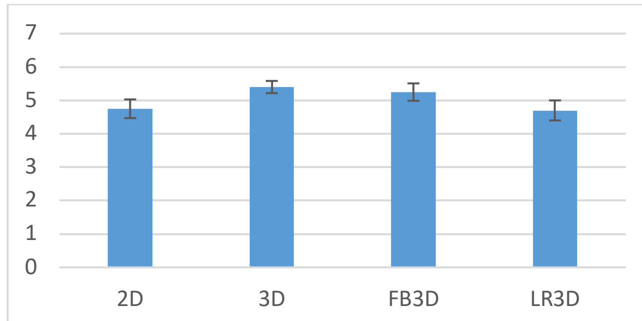

Figure 11. Reality

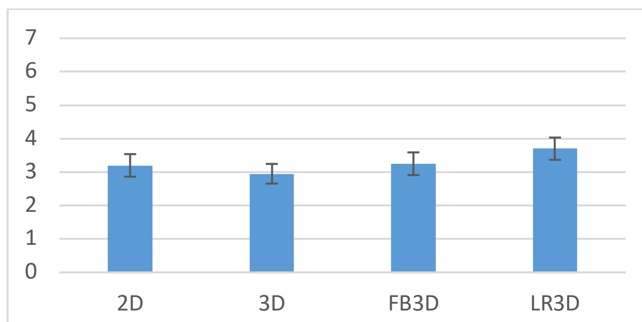

Figure 12. Discomfort

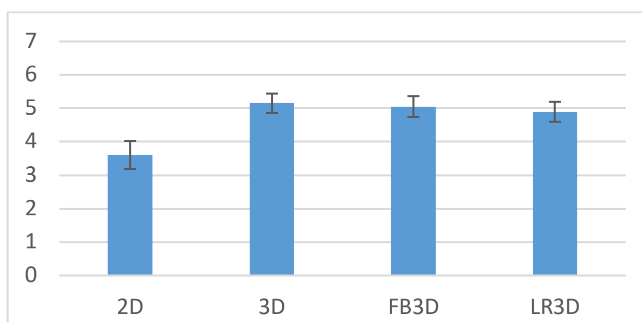

Figure 13. Stereoscopic effect

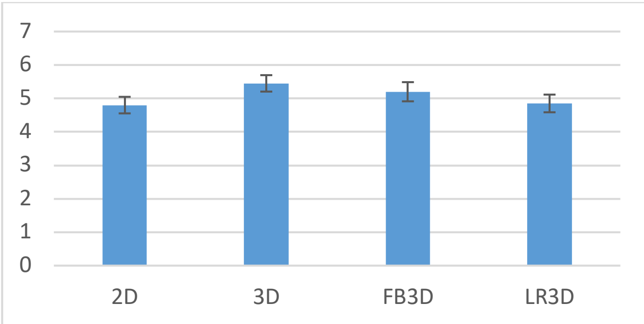

Figure 14. Preference

4. Discussion

From the gaze distribution by stimulus, no difference was found between the parallax conditions. From this result, it was suggested that the gaze does not concentrate in a specific direction based on the binocular parallax information. At the stimulus, there are many objects in front, left, and back, there are few objects in the other direction. Therefore, it seems that there was a tendency for the gaze to move to space with a large amount of visual information. Also, 3D attractiveness means the gaze to move outside the range of interest and concern in 3D visuals as compared to 2D images. Since HMD selects viewing angle of view and watches, active observation is performed. It is thought that conscious active observation had a greater influence than unconscious attractiveness.

In the gaze distribution by time, significant differences were found between the conditions depending on time. In 0 to 10 seconds, the bias of the gaze was seen the back in the Front-Back 3D conditions and in the left direction in the Left-Right 3D condition. From these results, it is suggested that parallax is likely to be affected immediately after starting viewing. There is no significant difference in the stimulus but there is the large varies on each parallax condition. Therefore, it is considered that the viewing direction is depending on individuals and so the influence of binocular parallax changes with the passage of time, but there are individual differences how much affected.

Regarding the stereoscopic effect, a difference was found between 2D and other conditions. From this result, it was suggested that even if parallax was added to a part of the image, the subjective three-dimensional feeling increased. Regarding items other than stereoscopy, slight differences were seen in the figure, but no significant difference was observed. The cause may be that the resolution was high. Also, since there were not all the people reporting that they noticed the difference in disparity distribution from introspective reports, it is possible that the evaluation could be divided between people who are sensitive to parallax and those who are not sensitive.

5. Conclusion

This research focused on parallax distribution in VR images experimentally from the viewpoint of observing behavior. From the results, the following findings were obtained.

- It cannot be said that the gaze stops in a specific direction due to parallax
- The influence of parallax is large immediately after the start of viewing
- The influence of parallax differs over time and individual differences
- Subjective three-dimensional feeling increases as part of 360 degrees in stereoscopic

These findings suggest that there is an effective 3D representation in VR images. As future tasks, there are studies such as attractiveness in the case of local stereoscopic and changing parallax distribution with time.

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