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Investigation of whether perspective guides vergence when gazing at moving object in 360-degree images

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Abstract

The vergence of subjects was measured while they observed 360-degree images of a virtual reality (VR) goggle. In our previous experiment, we observed a shift in vergence in response to the perspective information presented in 360-degree images when static targets were displayed within them. The aim of this study was to investigate whether a moving target that an observer was gazing at could also guide his vergence. We measured vergence when subjects viewed moving targets in 360-degree images. In the experiment, the subjects were instructed to gaze at the ball displayed in the 360-degree images while wearing the VR goggle. Two different paths were generated for the ball. One of the paths was the moving path that approached the subjects from a distance (Near path). The second path was the moving path at a distance from the subjects (Distant path). Two conditions were set regarding the moving distance (Short and Long). The moving distance of the left ball in the long distance condition was a factor of two greater than that in the short distance condition. These factors were combined to created four conditions (Near Short, Near Long, Distant Short and Distant Long). And two different movement time (5s and 10s) were designated for the movement of the ball only in the short distance conditions. The moving time of the long distance condition was always 10s. In total, six types of conditions were created. The results of the experiment demonstrated that the vergence was larger when the ball was in close proximity to the subjects than when it was at a distance. That was that the perspective information of 360-degree images shifted the subjects' vergence. This suggests that the perspective information of the images provided observers with high-quality depth information that guided their vergence toward the target position. Furthermore, this effect was observed not only for static targets, but also for moving targets.

Introduction

It is said that VR goggles give viewers a high sense of reality because they can display 360-degree images and the proportion of images that occupy the field of view is high. The depth cue based on the high sense of reality of 360-degree images relies on the perspective cue (unless the images have disparity).

Vergence and perspective information in viewing 360-degree images

360-degree images displayed on a VR goggle are flat images if the images don't have disparity. Theoretically, vergence, which is the angle of each eye's visual axis (Figure 1), positions the display image (Figure 2(A)). However, it was known that vergence is shifted by accommodation of the crystalline lens, change in size, perspective information and so on [1]-[4]. Although 360-degree images are flat, there is a possibility that vergence is shifted by the perspective information of 360-degree images in response to the target position in depth on 360-degree images (Figure 2(B)). In our previous study, vergence was shifted according to the depth position of the target in the stationary target condition [5]. In the same study, we compared vergence with targets that moved forward with targets that moved backward to investigate the effect of motion [5]. These targets moved along the same path, but in the opposite direction. But the differences of the vergence between the targets were not shown. In this study we created some different paths where targets moved in depth. And we compared the vergence when subjects observed the target moving in depth.

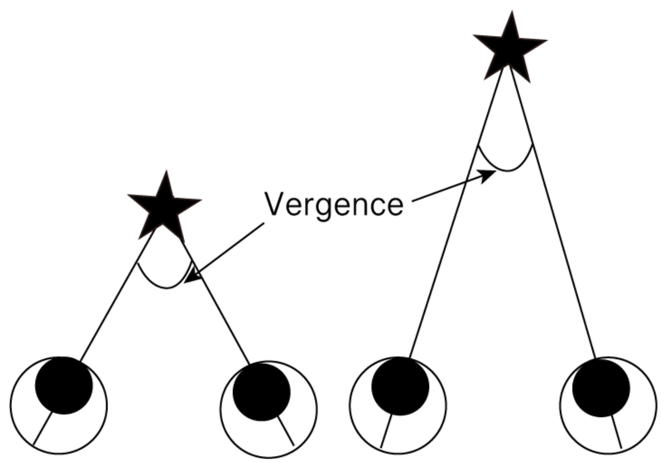


***Figure 1**. Overview of vergence*

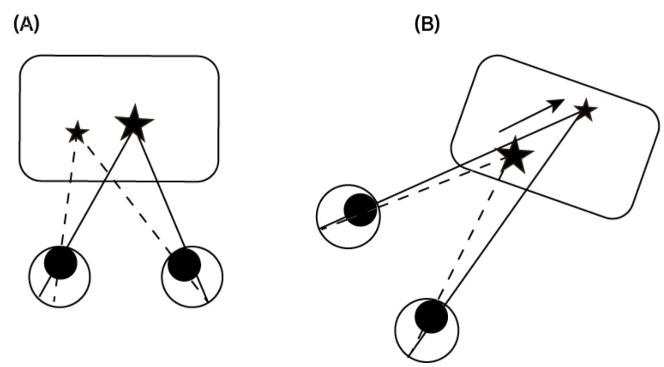


***Figure 2.** If the displayed image is perceived as a plane, vergence is not likely to fluctuate even when the gazing object in the displayed image differs (A). On the other hand, if the displayed image is perceived as a space by perspective information, vergence may be guided by the depth position of the displayed image (B).*

Table 1. *Six types of the left ball.*
The upper table showed near path conditions and the lower table showed distant path conditions. Refer to figure 5 and figure6 about the left ball's detailed movement status in each condition.

(Near Path)

Condition	Path	Distance	Time	Moving Distance Ratio	Velocity Ratio
NS5	Near	Short	5s	1	1(Fast)
NS10	Near	Short	10s	1	0.5(Slow)
NL10	Near	Long	10s	2	1(Fast)

(Distant Path)

Condition	Path	Distance	Time	Moving Distance Ratio	Velocity Ratio
DS5	Distant	Short	5s	1	1(Fast)
DS10	Distant	Short	10s	1	0.5(Slow)
DL10	Distant	Long	10s	2	1(Fast)

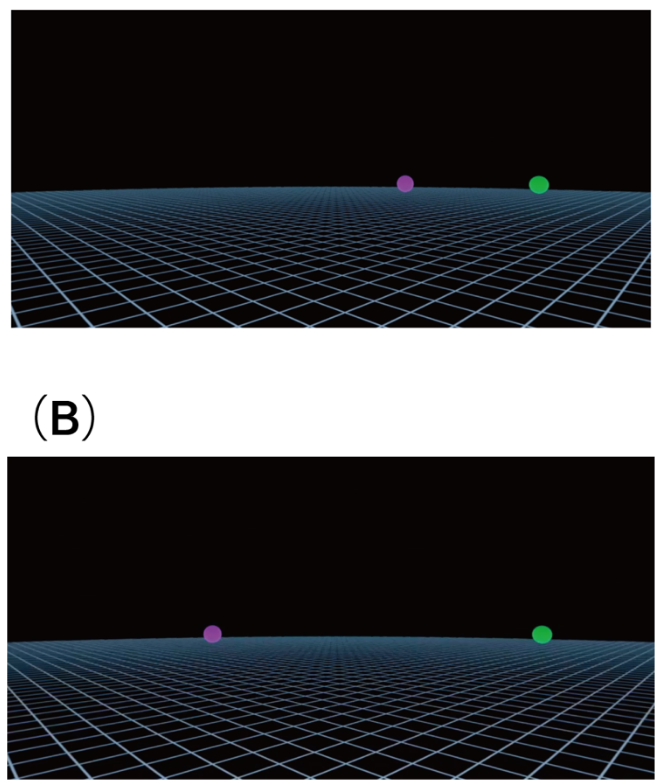
Figure 3. *Picture of the experiments*

Method

Subjects observed 360-degree images of the VR goggle (HTC VIVE PRO EYE (3DoF)) while wearing them (Figure 3). In the 360-degree images displayed in the VR goggle, two balls were presented (Figure 4). The right ball was stationary, while the left ball was in motion. Two distinct paths for the left ball were generated. One of the paths was the moving path that approached the subjects from a distance (Near path; see Figure 4, Figure 5 and Figure 6). The second path was the moving path at a distance from the subjects (Distant path). Two conditions were set regarding the moving distance (Short and Long). The moving distance of the left ball by the long distance condition was twice as long as that of the short distance condition. These factors were combined to created four conditions (Near Short, Near Long, Distant Short and Distant Long). And two different traveled time (5s and 10s) were designated for the movement of the ball only in the short distance conditions. After staying for 2s, the left ball of all conditions started to move. The moving time of long distance condition was always 10s. After all, six types of conditions were created (Table 1). In the short distance conditions, the velocity of the left ball moving for 5s (NS5 and DS5) was twice that of the left ball moving for 10s (NS10 and DS10). The moving times of the left ball in the conditions of NL10 and DL10 were twice that of it in the conditions of NS5 and DS5, respectively. Similarly, the distances moved by the left ball in the conditions of NL10 and DL10 were twice that in the conditions of NS5s and DS5. Consequently, the velocity of the left ball in the conditions of NL10 and DL10 was identical to the velocity of the left ball moving in the conditions of NS5 and DS5.

Each 360-degree image in Table 1 was presented 5 times to the subjects. The subjects' task was to gaze at the left ball. The subjects' vergence was measured by the data exported from VIVE PRO EYE. Eight subjects who participated in the experiment were in their 20s and had normal vision.

(A)



(B)

Figure 4*. Example of a 360-degree image displayed to subjects.*
(A) is the initial image in the conditions of NS5、NS10 and NL10. (B) is the initial image in the conditions of DS5, DS10, DL10. The left ball was in motion and the right ball was always stationary.

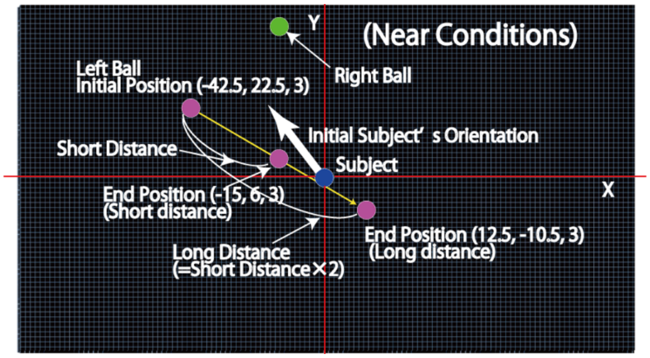


Figure 5. *The left ball's path in the conditions of NS5、NS10 and NL10*

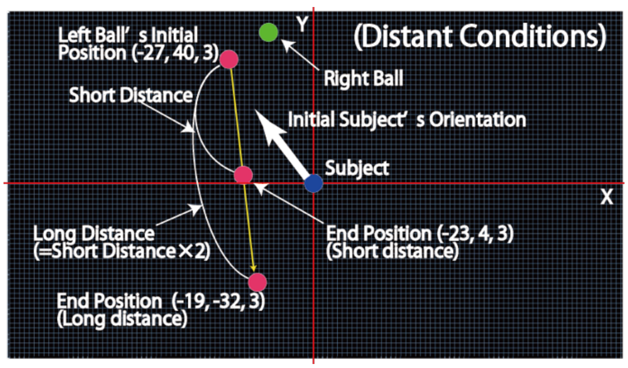


Figure 6*. The left ball's path in the conditions of DS5, DS10, DL10*

Results

The effect of moving path (Near and Distant)

The effect of the moving path of the left ball was investigated. At first, we discussed the short conditions (NS5, NS10, DS5 and DS10.) to investigate the effect of moving path. The velocity of the left ball in the condition of NS5 and DS5 was twice as fast as it in the condition of DS10 and DL10, respectively. In these conditions, the left ball which had a moving time was 5s was faster than it which had a moving time was 10s. Figure 7 depicts the mean vergence values for these conditions. Two-way ANOVA was conducted, with the path of movement (Near path and Distant path) and velocity of movement (5s (Fast) and 10s (Slow)) as factors. The results of the analysis indicated a statistically significant difference in the main effect of the moving path factor ($F(1,49) = 7.34$, $p = .0092$). The difference in the main effect of the velocity and the interaction effects were not statistically significant ($F(1,49) = 2.58$, $p = .1143$; $F(1,49) = 1.11$, $p = .2977$). The vergence in the left ball moving at a distance from the subjects was found to be lower than that in the ball closing to them. The results indicated that the vergence was guided by the perspective information of 360-degree images. The statistical analysis revealed that the velocity of the left ball did not exert a significant effect. The velocity did not affect the vergence in the range of the velocity of the left ball utilized in the experiment. In the preceding experiment, the vergence response remained unchanged when comparing approaching and receding targets moving along the same path [5]. However, when the path in depth was varied in this experiment, vergence was significantly shifted. Vergence was found to be smaller when subjects viewed the target closing to them than when they viewed it moving at a distance from them. These results suggest that perspective information provided by 360-degree images could cause vergence to shift, even when subjects gazed at moving targets on 360-degree images.

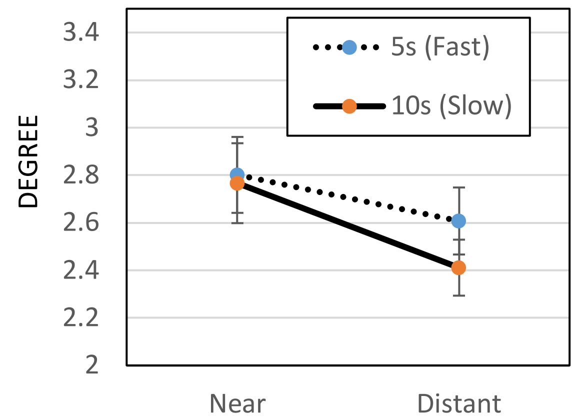
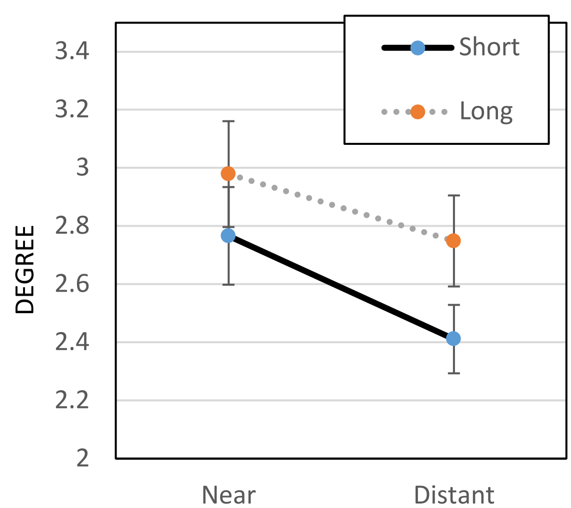


Figure 7*. The mean value of vergence under conditions where the moving distance was short (NS5, DS5, NS10 and DS10). Error bar showed the standard error.*

The effect of distance moved



Figurer 8*. The mean value of vergence under conditions where the velocity was same (NS5, DS5, NL10, and DL10). Error bar showed the standard error.*

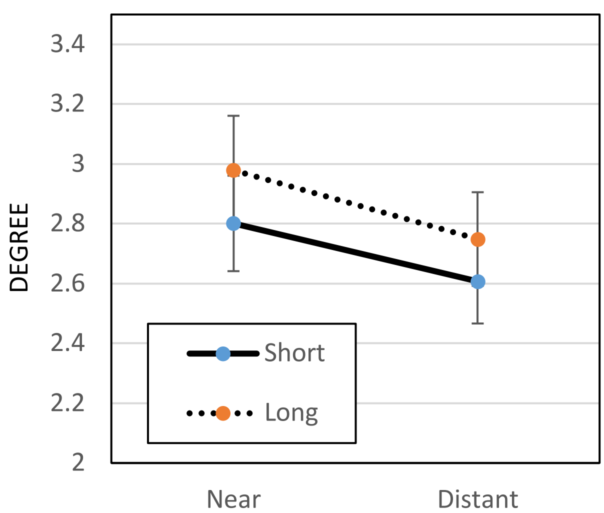


***Figure 9.** The mean value of vergence under conditions where the moving time was same (NS10, DS10, NL10 and DL10). Error bar showed the standard error.*

To investigate the effect of the moving distance of the objects, a comparison was made of the vergence in observing the left ball in the conditions of NS5, DS5, NL10 and DL10. Figure. 8 illustrates the mean vergence values for these conditions. In these conditions, the movement time differed between the two conditions (5 s and 10 s), yet the velocity of movement remained consistent (Table 1). A two-way ANOVA was conducted, with movement path (Near path and Distant path) and movement distance (Short and Long) serving as factors. The results of the analysis demonstrated a statistically significant difference in the main effect of the path of movement factor and the distance of movement factor ($F(1,49) = 4.68$, $p = .0354$; $F(1,49) = 4.84$, $p = .0326$). The interaction effects were not statistically significant ($F(1,49) = 0.0701$, $p = .7924$). The statistical analysis and the comparison between conditions with the value of vergence indicated that the vergence in the left ball moving at a distance from the subjects was lower than that in it moving closer to them. The results indicated that vergence was shifted by the perspective information of 360-degree images, a finding that was consistent with the results of the previous comparison between short distance conditions (NS5, NS10, DS5 and DS10). The vergence in the long distance conditions (DL10 and NL10) was greater than that in the short distance conditions (DS5 and NS5). This indicated that when the left ball was closing to the observer and moved past him, vergence was guided by perspective information rather than when stopping in front of the subject. But there was a possibility that the movement time affected vergence, as there were two types of movement time (5s and 10s).

Next, the comparison was conducted between the vergence in the conditions of NS10, NL10, DS10, and DL10. While the moving velocity of the left ball differed between conditions, the duration of its movement remained consistent. The results are illustrated in Figure 9, which depicts the mean value of vergence in these conditions. The velocity of the left ball in the condition of NL10 and DL10 was twice as fast as it in the condition of NS10 and DS10, respectively. A two-way ANOVA was conducted, with the path of movement (Near path and Distant path) and movement distance (Short and Long) serving as factors. The results of the analysis demonstrated statistically significant differences in the main effect of the path of movement and the distance of movement ($F(1,49) = 9.1255$, $p = .0040$) and ($F(1,49) = 11.3702$, $p = .0015$). The interaction effects were not statistically significant ($F(1,49) = 0.6314$, $p = .4307$). The statistical analysis and the comparison between conditions with the value of vergence indicated that the vergence in the left ball moving at a distance from the subjects (Distant path) was lower than that in it moving closer to them (Near path). These results were similar to those obtained when the left balls' velocity was kept constant. And statistically, the vergence in the long distance conditions (DL10 and NL10) was greater than that in the short distance conditions (DS10 and NS10). This result was similar to those obtained when the left balls' velocity was kept constant, too. It showed that the distance of movement affected vergence, as all condition's moving time was equal (10s).

The effect of moving distance was observed both when the velocity of the left ball was kept constant and when the moving time kept constant. The left ball in the long distance condition was approaching to the subjects than in the short distance condition. Given this consideration, the results of experimentation proposed that the shorter the distance between the object of gaze and the subject, the greater the vergence. This indicates that perspective depth information was more effective than motion itself.

Conclusion

This study examined whether vergence was guided by the perspective information of a moving object when a subject observed a 360-degree images in a VR goggle. The results of the experiment demonstrated that vergence was greater when the left ball which was the gaze target was near the subjects than when it was at a distance. These results indicated that the perspective information of 360-degree images in a VR goggle could induce vergence to the left ball, even when the left ball was in motion. In addition, subjects' vergence in short distance and long distance conditions were compared, both when the time of movement of the left ball was matched between the conditions and when its velocity was matched. The moving distance in the long distance conditions was twice as in the short distance conditions. The left ball in the long distance condition was closing to the observer and moved past him. On the other hand, it in the short distance conditions stopped in front of the subjects. The results demonstrated that the vergence in the long distance conditions was significantly greater than that measured in the short distance condition. These results indicate that perspective information may be a contributing factor. The reason was that the left ball in the long distance conditions was closer to subjects than it in the short distance conditions.

The findings of the experiment suggest that perspective information in 360-degree images may guide vergence when an observer gazes at an object that is moving in addition to a stationary object displayed in it.

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Author Biography

Hisaki Nate is received his PhD in human sciences from Osaka University (2001). He worked at Telecommunications Advancement Organization of Japan (Advanced 3-D Tele-Vision Project) after receiving his PhD. He is currently the professor in Faculty of Arts at Tokyo Polytechnic University. His research focuses on the characteristics and methods that enable effective use of 360-degree images from observers' gaze data.

Tamaki Takamura received his BS in arts from Tokyo Polytechnic University (2021). Currently he studies at Tokyo Polytechnic University as a graduate school student. He creates artworks using VR technology, and his research focus is on visual perception when viewing 360-degree images.

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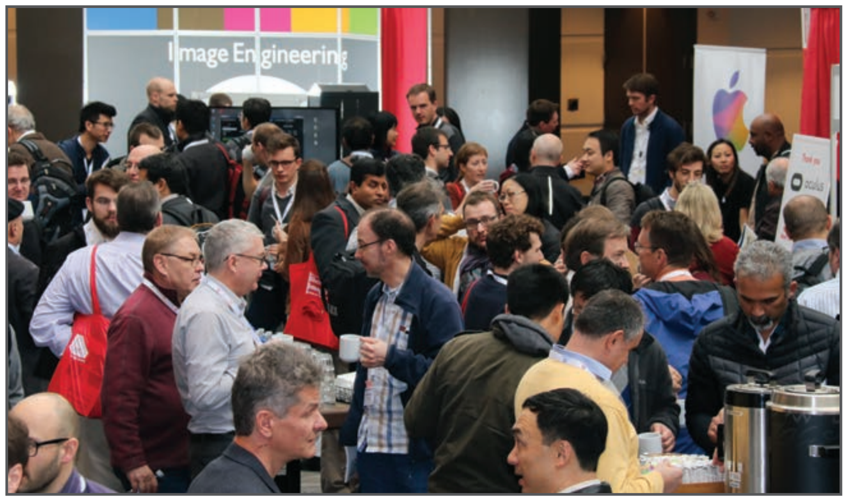

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