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Verification of the effect of horizontal virtual frame on VR sickness reduction by SSQ and cerebral blood flow measurement

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Abstract: *This study investigates the effectiveness of the virtual frame in reducing VR sickness. Using SSQ and cerebral blood flow as measures, the study shows that the virtual horizontal frame effectively suppresses VR motion sickness, as evidenced by a decrease in SSQ scores and oxy-Hb levels during VR experiences. The visual field limited horizontal sense frame was also found to be effective in reducing VR sickness and more practical in terms of immersion. Future research may explore the use of AI technology to dynamically adjust the shape and depth of the frame to further reduce the impact of VR sickness.*

Keywords*: VR sickness, field of view , SSQ, cerebral blood flow*

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I. INTRODUCTION

Virtual reality (VR) is gaining popularity in various fields such as real estate previews, rehabilitation, education, entertainment, and advertising. However, the disadvantages of VR have also begun to appear, including symptoms similar to motion sickness, collectively referred to as "VR sickness" which can include discomfort, nausea, dizziness, headache, and other symptoms. The severity and type of disease symptoms vary from person to person.

Previous research has focused on reducing VR sickness using only visual means, without the use of other devices or tools outside of VR. To suppress the movement and confusion of the spatial recognition function, which is one of the causes of VR sickness, a virtual horizontal frame was developed that "covers the peripheral vision" and "visualizes the actual horizontal position and the inclination of one's own field of vision." Post-experimental results showed that disease scores were reduced in all subjects wearing the virtual horizontal frame, and it was especially effective in subjects with high disease scores without the horizontal frame.

However, previous studies have been limited to testing the content of virtual horizontal frames for roller coaster simulations. In addition, the impact of the frame on content that enables arbitrary movement in 3D space through controller manipulation or body movement, as well as content that does not exist in reality, such as shooters, was measured. Additionally, a framework that only covers peripheral vision was developed and verified that the horizon has the effect of suppressing VR sickness. In this study, the effectiveness of different frames, including the virtual horizontal frame in previous studies and the virtual horizontal frame developed in this study, was measured to determine whether the position of the horizon or the peripheral visual field coverage are the main contributors to the suppression of VR sickness. In a previous study, the effect of the developed framework was verified through the SSQ questionnaire survey, while in this study, the effect was further verified by the measurement of cerebral blood flow.

As the concept of VR has grown to include the concept of "virtual worlds" or "metaverse," where users can interact with each other in a virtual space, addressing VR sickness is becoming increasingly important to provide users with a seamless and enjoyable experience.

II. PURPOSE OF RESEARCH

The purpose of this article is to highlight the research objectives of evaluating the effectiveness of the virtual frame in reducing VR sickness. To achieve this objective, previous research has utilized the Simulator Sickness Questionnaire (SSQ) as an index to quantify sickness by measuring various symptoms experienced by subjects, including discomfort, nausea, and dizziness. The subjects were asked to complete the SSQ after viewing the VR content in a relaxed state without using the virtual frame, and then again after viewing the content with the virtual frame. This approach confirmed the effectiveness of the virtual frame in reducing VR sickness.

However, to further substantiate the effect of the virtual frame, this study has additionally incorporated a cerebral blood flow meter to measure the physiological response of the subjects under the same conditions. This not only provides a subjective evaluation but also an objective measurement of the effect of the virtual frame on reducing VR sickness.

Furthermore, unlike previous research that only experimented with one VR content, this study aims to confirm the effectiveness of the virtual frame for a wide range of VR contents. A variety of VR contents that allowed for arbitrary movement in 3D space through controller manipulation or body movement, as well as contents that did not exist in reality, such as shooters, were employed in this study. The effectiveness of the virtual frame in reducing VR sickness was thus confirmed for a wider range of VR content.

III. VR SICKNESS

The cause of VR sickness, which is similar in symptoms to motion sickness, is thought to be related to the same mechanism as motion sickness [1][2]. One of the causes of motion sickness is the theory of sensory contradiction, where the information received by the human semicircular canals responsible for balance contradicts the visual information received by the eyes, resulting in the accumulation of conflicting signals in the brain [3][4][5].

As the cause of VR sickness is related to that of motion sickness, it is necessary to explore the effectiveness of existing methods for reducing motion sickness symptoms in the context of VR to alleviate VR sickness. VR sickness is attributed to the discrepancy between sensory and visual information from the vestibule and somatosensory systems, and one of the causes of VR sickness is visually induced self-motion sensation, also known as vection [1].

Suppressing vection, which occurs when using VR content, can alleviate VR sickness. In order to do so, it is necessary to eliminate the discrepancy between visual information and spatial information obtained from the vestibule and somatosensory systems. There are two primary methods for eliminating vection.

One method to avoid vection in virtual reality (VR) is to make the VR environment and the natural environment identical. This is achieved by using a machine to transmit visual information from the VR environment as motion information to the vestibular and somatosensory systems, matching the spatial information from the VR environment to that of the natural environment. Alternatively, spatial information can be matched by completely replicating the natural environment in the VR environment. For example, a study reported a significant reduction in VR sickness by creating a motorcycle in a VR environment and synchronizing the engine sound and vibration with the image. [6]

However, there are several challenges associated with introducing a machine that reproduces motion in VR. First, using such a machine requires a place with sufficient space for movement, limiting the usability of VR. Additionally, the cost of implementing such a solution can be prohibitively high, making it difficult to adopt as a casual measure against VR sickness. Moreover, if the natural environment is replicated in the VR environment, the range of content that can be experienced may be limited.

Another method to suppress vection is by blocking or adjusting the equilibrium and peripheral visual field information related to spatial recognition [7]. The human eye has a field of view of approximately 200° horizontally and 125° vertically when facing forward. Within this field, there are several visual fields, including the discriminative visual field, which is the central region with excellent visual acuity and color discrimination (about 5°); the effective visual field, which is instantly receptive by eye movement (horizontal about 30°, vertical within about 20°); the stable gaze field, which is the area where effective information reception is possible with comfortable eyeball/head movement (horizontal 60° to 90°, vertical 45° to 70°); the guided visual field, which has low discriminating ability but affects the spatial coordinate system (horizontal 30° to 100°, vertical 20° to 85°); and the auxiliary visual field (peripheral visual field), where the presence of stimuli can be seen (horizontal 100° to 200°, vertical 85° to 130°) [7].

Research has shown that the peripheral visual field is deeply related to the occurrence of vection and that adding a mask area that covers the peripheral visual field can make it difficult for vection to occur [8]. The central visual field is better at identifying given information such as color and shape, while the peripheral visual field is more attuned to sensing changes in position and shape and performs motion perception [9].

Overall, these two approaches offer different strategies to combat vection in VR environments, and may be applied depending on the specific situation and desired outcome.

IV. DEVELOPMENT OF VIRTUAL HORIZONTAL FRAME

4.1 Creating a coaster

In our previous study, we utilized Unity's asset Animated Steel Coaster to develop a VR roller coaster content aimed at inducing VR sickness. Specifically, we created a roller coaster, which we will refer to as coaster α, that simulated yaw, pitch, and roll movements in the VR environment to create inconsistencies between visual and somatosensory spatial information, thereby amplifying the potential for VR sickness.

Fig.1. coasterα

We determined that a roller coaster, which combines high-speed linear motion and rotational motion, is the most appropriate content for inducing effective spins in the participant.

Furthermore, since the roller coaster features multiple rotations along the roll, pitch, and yaw axes, we anticipated the occurrence of vection. Additionally, realistic snow mountain objects were strategically placed to maintain the participant's sense of orientation. To create the roller coaster track, we utilized Unity's Track_and_Rails asset and developed a course that lasts approximately 1 minute and 30 seconds per lap. This content will be referred to as coaster β moving forward.

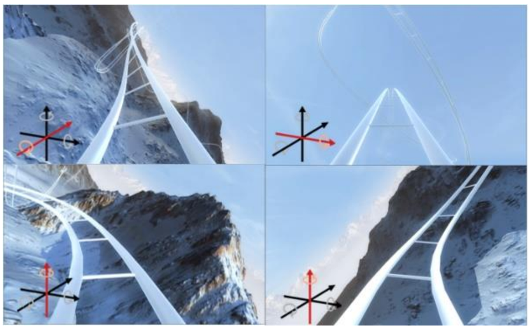

Fig.2. Yaw, pitch, and roll axis course

We determined that a roller coaster, which combines fast linear and rotational motion, is the most effective content for inducing sickness. However, since the viewpoint movement is constant in a roller coaster, we decided to increase the viewpoint movement by placing targets along the course and creating a simple shooting game. By incorporating these elements, we aimed to induce sickness more effectively than a roller coaster alone. Using Unity's Tracks and Rails assets, we created a shooting course that takes about 1 minute per lap and developed an original shooting game. Additionally, by keeping track of scores after three laps, we increased competitiveness and created a way to enhance concentration on the game.

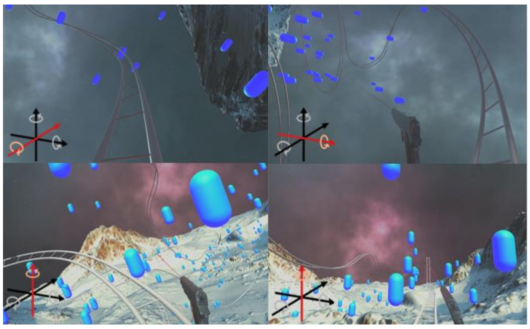

Fig.3. shooting coaster

We realized that in order to induce more VR sickness, it would be beneficial to have content where the player could control the movement. Therefore, we created a game using slide movement as the method of locomotion in VR. By allowing the player to operate the avatar and experience both linear and rotational motion, we could induce vection more effectively. The objective of the game is to collect items scattered throughout the map while controlling the avatar with the controller. To enhance the game experience, we added crouching, jumping, and dashing buttons, which are common elements found in many games. These elements were designed to induce sickness when the actions were performed. We used the map of RPG/FPS Game Assets for PC/Mobile of Unity assets to create an original game.

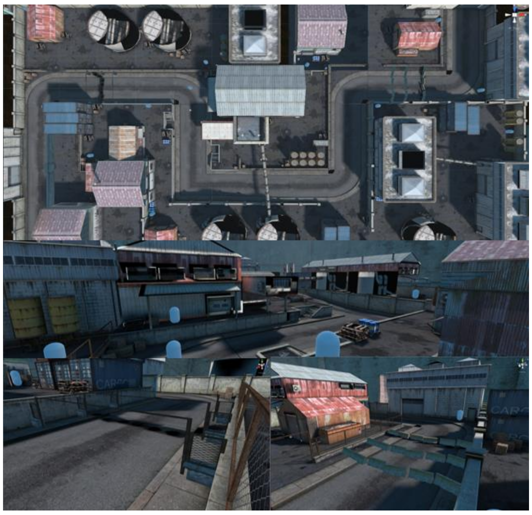

Fig.4. Action game

4.2 Virtual horizontal frame

In previous research, we developed a frame to easily perceive the horizon angle of view. The horizon section remains fixed on the screen and is not affected by head movements, enabling users to always perceive their horizontal field of view. The ring section rotates with camera movements and slowly returns to the horizon, visually representing users' horizontal position and angle of inclination, and reducing spatial recognition gaps. The ring section also hides peripheral vision and helps to suppress vection. However, displaying the virtual horizontal frame may obstruct the view of VR content. To avoid this, we used broken lines for both the horizontal line and the ring, expanding the range in which VR content can be viewed and preserving the immersive experience. This frame is referred to as Frame 1.

Fig.5. Virtual horizontal frame

4.3 Omnidirectional virtual frame

To compare the effectiveness of the virtual horizontal frame in suppressing VR sickness, we created a second virtual frame that differs in design from the first. This frame obscures the peripheral visual field and provides a fixed gaze point. This design was chosen because previous research has shown that a fixed gaze point can reduce the occurrence of VR sickness by providing a stable reference point for the eyes. By comparing the effects of these two frames on reducing VR sickness, we can better understand the specific features of the virtual horizontal frame that contribute to its effectiveness.

Fig.6. Omnidirectional virtual frame

4.4 Horizontal sensation retention frame with limited visual field

We have developed an updated version of the virtual horizontal frame, building upon the design of the previous frame. The new frame retains the rotation function of the horizon and ring of frame 1, while also improving the design to enhance the immersive feeling. The horizon has been simplified to minimize interference with the content, and the ring has been redesigned as a complete circle to cover the peripheral visual field more effectively and suppress vection. To create the horizontal line of the ring, the gradation of the upper half of the circle has been adjusted, and the boundary line of the lower half has been utilized as a new horizontal line. This new design is referred to as frame 2.

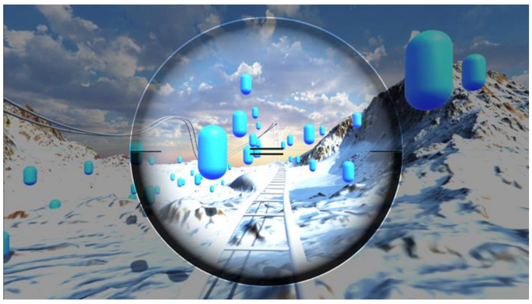

Fig.7. Horizontal sensation retention frame with limited visual field

The horizon part has been replaced with a black circle to provide a gaze point that does not interfere with the immersive feeling of VR content. This makes it difficult to grasp the horizontal position of the field of view, but its role as a gazing point does not change. Therefore, the effect of suppressing VR sickness on the horizon can be verified by comparing it with the virtual horizontal frame. In addition, by removing the rotation function of the ring part and changing from a broken line to a solid line, the frame is made to only cover the peripheral visual field. This makes it possible to verify how effective the rotation of the ring in the peripheral vision is in suppressing VR sickness. Hereinafter, this frame is referred to as frame 3.

V. EXPERIMENT

5.1. Experimental method

To evaluate VR sickness in this study, both subjective and physiological measures are used. The Simulator Sickness Questionnaire (SSQ) is used as a subjective evaluation, while cerebral blood flow is measured as a physiological index. The decision to use cerebral blood flow as a physiological indicator was based on the findings of Graybiel et al., who did not find a significant correlation between the onset of motion sickness and other physiological indicators [10]. However, Seraglia et al. showed that cerebral blood flow can be accurately measured during VR experiences using a combination of VR and cerebral blood flow meter (NIRS) measurement [11]. Therefore, this study uses cerebral blood flow as a physiological measure to evaluate VR sickness.

In this study, 20 male and female subjects were recruited and assigned to experience each of the four contents with and without different virtual frames. Specifically, 5 subjects were assigned to each content, and the subjects were asked to experience the content in each of the four conditions (no frame, frame 1, frame 2, and frame 3). The severity of VR sickness was then evaluated using the SSQ questionnaire, which the subjects completed after each experience. Additionally, to measure changes in cerebral blood flow, a cerebral blood flow meter was attached to the subjects when they were experiencing VR. The measurement was conducted in a controlled environment with a room temperature of 25 degrees on a sunny day with at least 2 hours after eating to ensure consistency across all measurements.

5.2 SSQ and cerebral blood flow measurement

In this study, SSQ (Simulator Sickness Questionnaire) was used as one of the indicators of VR sickness. SSQ is a subjective evaluation method used to diagnose VR sickness, and it was developed by Kennedy et al. in the United States. The questionnaire consists of 16 items, which were determined to be effective for simulator sickness by factor analysis of subjective evaluation results obtained from a large number of simulator users. The items are rated on a scale of 0 to 3, with 0 indicating no symptoms and 3 indicating severe symptoms. The items that correspond to nausea (N), eyestrain (O), and disorientation (D) are marked with 1, and those that do not correspond are marked with 0. The total value for each item is calculated by Equation (1), and the total score for nausea, eyestrain, and disorientation is calculated by Equation (2). [12] [13] Table 1 shows the 16 subjective evaluation items included in the SSQ questionnaire.

i) Signs and symptoms of sickness	Evaluation value $x_i(0\sim3)$	Degree of discomfort N_i	Degree of eye fatigue O_i	Degree of dizziness D_i
1) General discomfort		1	1	0
2) Feeling tired		0	1	0
3) Headache degree		0	1	0
4) Eyestrain		0	1	0
5) The degree of difficulty in eye focusing		0	1	1
6) Increased saliva		1	0	0
7) Amount of sweating		1	0	0
8) Degree of nausea		1	0	1
9) The degree of inattention		1	1	0
10) The degree of light-headedness		0	0	1
11) Blurred eyes		0	1	1
12) Dizziness (eye open)		0	0	1
13) Dizziness (eye closed)		0	0	1
14) Degree of loss of balance		0	0	1
15) Stomach discomfort		1	0	0
16) Belching		1	0	0

Table 1. Subjective evaluation items of SSQ

(1)N = 9.54 × (rating of 1+ rating of 6+ rating of 7+ rating of 8 + rating of 9 + rating of 15 + rating of 16)
O = 7.58 × (rating of 1+ rating of 2+ rating of 3+ rating of 4 + rating of 5 + rating of 9 + rating of 11)
D = 13.92 × (rating of 5+ rating of 8+ rating of 10+ rating of 11+ rating of 12 + rating of 13+ rating of 14)
(2) TS = 3.74 × (total of 16 ratings of N, O, D)

In this study, cerebral blood flow is used as a physiological index of VR sickness, and a cerebral blood flow meter (NIRS) is used to measure it. NIRS is a non-invasive device that measures blood volume in the brain and visualizes changes in blood volume in the frontal lobe. Hemoglobin, a blood component, scatters light, and the degree of scattering changes when oxygen is bound to it. Light absorption in the near-infrared wavelength range is caused by oxy-Hb and deoxy-Hb, which have different absorption spectra. By measuring the change in absorbance at two or more wavelengths and using the molar extinction coefficient of oxy-Hb and deoxy-Hb, the concentration change of oxy-Hb and deoxy-Hb can be calculated. The software can display a graph of cerebral hemoglobin in real-time [14].

Seraglia et al. demonstrated that cerebral blood flow can be accurately measured even during VR experiences using a cerebral blood flow meter (NIRS). They also found that changes in oxy-Hb can be used as parameters that reflect brain activity, as oxy-Hb increases during actively self-driven movements, but changes in oxy-Hb due to external factors are not observable. [11] [15]

Previous studies have already demonstrated the effectiveness of using frames to reduce VR sickness. However, in this study, we aim to further verify this effect by measuring changes in cerebral blood flow.

In this study, cerebral blood flow was used as a physiological indicator of VR sickness, and a cerebral blood flow meter (NIRS) was used for measurement. NIRS is a non-invasive device that measures blood volume in the brain and visualizes changes in the frontal lobe. Hemoglobin, a blood component, scatters light, and when oxygen binds to it, the degree of scattering changes. The absorption of light in the near-infrared wavelength range is caused by oxy-Hb and deoxy-Hb, which have different absorption spectra. By measuring the change in absorbance at two or more wavelengths, the concentration change of oxy-Hb and deoxy-Hb can be calculated if the molar extinction coefficient of each is known. A graph of cerebral hemoglobin can be displayed by the software in real-time. [14] Seraglia et al. utilized a combination of VR and NIRS measurements to assess brain activity (in the parietal and occipital lobes) during VR tasks, and demonstrated that cerebral blood flow can be accurately measured even during VR experience. [16] Additionally, oxy-Hb levels increase during actively performed exercise, such as voluntary movement, but not during exercise that is not related to intention due to external factors. [15][16] Based on these findings, changes in oxy-Hb can be used as a parameter to reflect brain activity.

Because the data from the previous SSQ test showed that Frame 3 performed better than Frame 2, we decided to use Frame 3 as a superior alternative to Frame 2 when measuring cerebral blood flow.

The subjects were measured three times in both a relaxed state and during VR experience, and the data was taken as one set. The average graph of oxy-Hb was obtained while experiencing VR content with and without wearing Frame 1 and Frame 3. It was observed that wearing a frame can suppress the increase in oxy-Hb and reduce its changes, indicating that the subject is in a relaxed state while experiencing VR content. This also suggests that using a virtual horizontal frame causes minimal disturbance to the autonomic nerves and reduces the likelihood of motion sickness. Moreover, when comparing Frame 1 and Frame 3, the oxy-Hb waveform was smaller in Frame 1, indicating that frames with horizontal lines and rings were most effective in suppressing VR sickness.

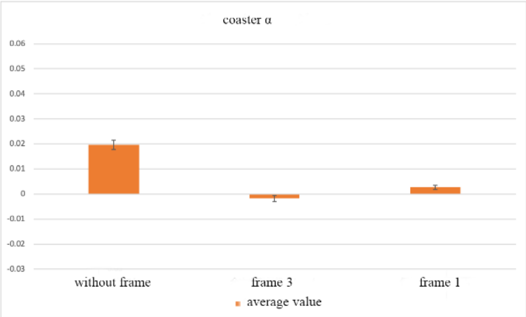

Fig.8. [Coaster α] Average value of oxy-Hb

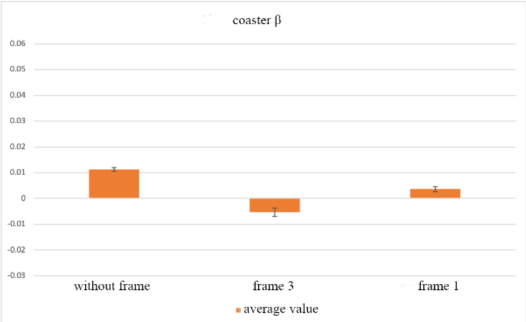

Fig.9. [Coaster β] Average value of oxy-Hb

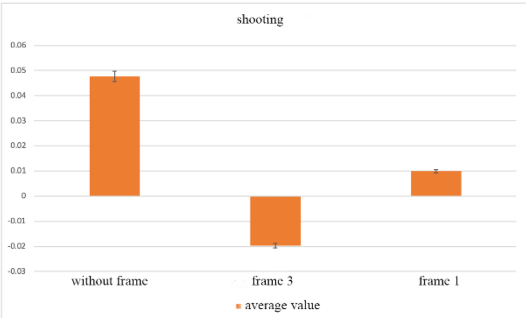

Fig.10. [shooting game] Average value of oxy-Hb

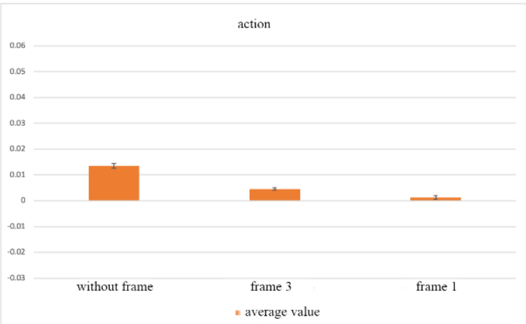

Fig.11. [Action game] Average value of oxy-Hb

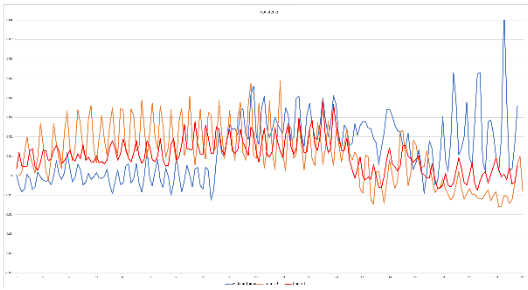

Fig.12. [Coaster α] measurement of oxy-Hb

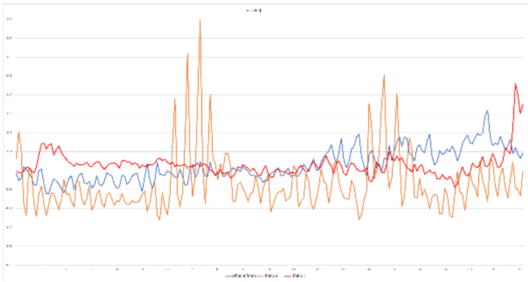

Fig.13. [Coaster β] measurement of oxy-Hb

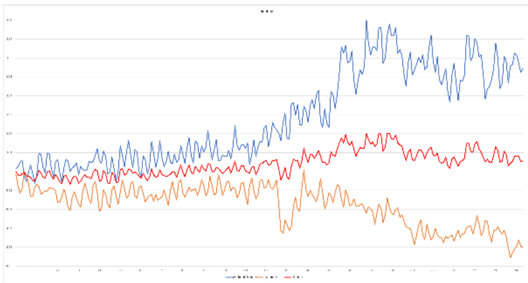

Fig.14. [shooting game] measurement of oxy-Hb

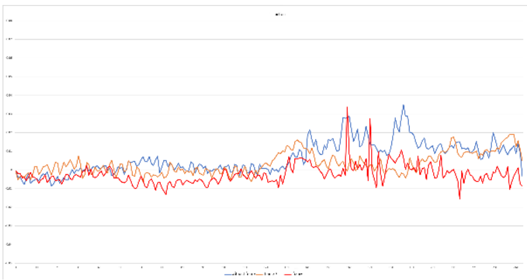

Fig.15. [Action game] measurement of oxy-Hb

The blue line above represents without frame, the orange represents frame3, and the red represents frame1

VI. CONCLUSIONS

In this study, we improved the virtual horizontal frame developed in previous studies and created a sensory-preserving horizontal frame with limited visual field. As a result, we were able to suppress VR motion sickness and provide a more immersive VR experience. Our experiments using an omnidirectional virtual frame developed midway through the project showed that simply masking peripheral vision was not as effective in suppressing VR motion sickness as a virtual horizontal frame. This suggests that the horizontal lines and rings of the virtual horizontal frame play a significant role in suppressing VR motion sickness. Furthermore, in experiments using VR content, users remained stationary and moved arbitrarily in 3D space by manipulating controllers or moving their bodies, and we observed a decrease in SSQ scores after experiencing each content when a virtual frame was displayed. This indicates that VR vertigo can be suppressed by using a virtual frame. Subsequent detection of cerebral blood flow further confirmed this effect.

When comparing the effect of the virtual horizontal frame and the sensory-preserving horizontal frame with limited visual field in inhibiting VR motion sickness, both frames significantly inhibited motion sickness, but there was no significant overall difference. However, the newly designed frame that does not hinder the sense of immersion had the same effect of suppressing VR motion sickness as the virtual horizontal frame and is more practical than other frames.

As AI technology continues to rapidly develop, AI painting and AI 3D modeling have already taken shape. Future research will attempt to use AI to dynamically adjust the shape and depth of the frame to fit the VR content, in order to further reduce the effect of VR sickness.

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