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RESEARCH ARTICLE

# Analysis of the Virtual Reality User Experience Improvement Through Human Vision Adjustment Using Diopter Dial

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**ABSTRACT** The head-mounted display (HMD) form factor is an essential element that influences the various emotions users experience during their virtual reality (VR) sessions. In particular, it has been announced that the VR experience highly depends on the user's field of vision because it blocks the user's view of the real world and transmits information exclusively in the virtual world. Users with eye diseases wore vision aids to experience VR environments or used them without sufficient vision. Furthermore, this problem led to factors that reduced the user's sense of immersion and ease of use. In this paper, we analyzed how providing users with adjusted human vision via diopter dial affects the improvement of VR user experiences. The experimental procedure consisted of 2D video and 360-degree video as audiovisual content, as well as sitting mode games and room-scale mode games as playable content. We measured the immersion and sickness of the experimental environment using each verified questionnaire on the 5-point Likert scale and the discomfort score for each experimental content to measure the degree of discomfort. The experimental environment is Phase 1, where users experienced VR while wearing vision aids, and Phase 2, where users experience VR with human vision adjustment using a diopter dial without vision aids. The difference between the evaluation results of both experimental environments was 1.56 for immersion, 2.35 for sickness, and 3.85 for discomfort. Additionally, user feedback was gathered through in-depth interviews to enhance the reliability of the statistical analysis. Through these results, we confirmed that human vision adjustment using the diopter dial provides users with an improved form factor, reduces discomfort and sickness, and enhances the immersive feeling of the VR environment through improved display visibility.

**INDEX TERMS** Virtual reality (VR), head-mounted displays (HMD), immersion, user experience, vision aids, human vision adjustment.

## I. INTRODUCTION

ICT technology has brought about many changes in various fields due to user experience. With the development of Head-mounted display (HMD), multi-sensory devices, software, and hardware, immersive technology is rapidly developing, including virtual reality (VR), augmented reality (AR), and mixed reality (MR) technologies [1], [2]. A typical feature of immersive technology is the ability to implement situations in virtual environments that are difficult to implement due to real-world costs and spatiotemporal limitations. In addition, the virtual environment has the advantage of high user immersion due to three-dimensional representation, interaction with objects in the virtual environment, and realistic behavior by tracking the user's physical data.

These features suggest new ways of leveraging immersive technology to improve efficiency and positive feedback in various fields. The unique feeling that a virtual environment

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provides depends on the immersion, presence, location, variety, low latency, economy, and virtual space provided by the environment [3], [4]. Among them, immersion is the most essential factor to improve the experience of virtual reality technology [5], [6], [7].

Immersion is typically described as a technical quality that allows the user to feel the virtual environment delivered via hardware [8], [9]. Immersion in a virtual environment is influenced by display parameters, visual effects, sound, touch, physical representation, and engagement of the avatar within the virtual environment, with the potential for increased user immersion as technical quality improves [10]. Recently, factors that may affect the sense of immersion in a virtual environment depending on the development direction of immersive technology include tracking level, stereoscopic vision, image quality, field of view, sound quality, update rate, and user perspective [11].

Recent studies have proposed a human vision enhancement system for users to clearly see the virtual images output from VR HMD systems to improve immersion within the virtual environment [12], [13], [14], [15], [16], [17], [18], [19], [20], [21]. These systems were primarily ways of transforming the physical structure of the display and collimating lenses installed within the HMD to improve the human visual system. For example, they used a digitally switchable multifocal lens to adjust the focus to match the human vision, and installed an actuator to dynamically adjust the optical path through which the image is transmitted from the display to the user's eye [20]. Moreover, these studies showed some improvements in the main parameters of HMD display performance, such as spatial resolution in the virtual image, depth, focus signal accuracy, and adjustable response error, but additionally noted that further should be made [12], [21]. However, most of these studies were implemented as prototypes in a benchtop environment and experimented in a relatively confined environment. In addition, these studies showed the results of clarity comparison using user-evaluated captured images for sharpness and software analysis using optical images to prove the proposed method [16], [17], [18], [19], [20]. However, these studies have provided only limited results, and real-world virtual reality content consists of dynamic forms of content, such as videos and games, rather than simple images and laser points. Therefore, an evaluation is required using the content that will actually be used.

This paper conducted an experiment to confirm the user's sense of immersion and experience by improving human vision using the visual dial, targeting users who need to wear vision aids due to eye diseases. In this experiment, after conducting a virtual human vision test to see if focus adjustment was performed generally with the diopter dial, participants participated in a questionnaire after experiencing four different experimental contents, from 2D video to room-scale mode game. Through experimentation, we interpret user immersion and experience in relation to VR environments and form factors, human vision, visual fidelity, optical flow of content, and more. We expect that an adjusted human visual system utilizing diopter dial can achieve increased immersion and improved experience for experimental participants.

Section II describes how the human visual system behaves according to the usage environment of VR HMDs, the relationship between immersion and user experience due to hardware form factors, and research methods and limitations of previous studies. Section III explains the experimental configuration for measuring immersion and user experience designed in this paper, the Snellen chart-based human vision test for measuring user visual acuity, and the overall experimental procedure. Section IV analyses the differences in immersion and user experience in different usage environments based on measured experimental data. Finally, Section V includes the study's conclusions.

## II. LITERATURE

### A. HUMAN-VISION ADJUSTMENT FOR THE HEAD-MOUNTED DISPLAY

VR HMD is configured to block out the real world while transmitting a virtual image generated through a display in front of the device to the user's eyes through collimating lenses. In this structure, it was announced that the display and collimating lens characteristics determine the image quality [22]. The proper optical imaging system is ideal for the VR HMD to deliver a high-resolution virtual image. For this reason, various companies leading the commercialization of VR HMDs have worked to provide users with higher resolutions and larger fields of view (FOV) [23]. The displays used in VR HMDs have achieved higher display per inch (DPI), brightness contrast ratio, and faster refresh rates through the evolution from liquid crystal display (LCD) to organic light emitting display (OLED) and microdisplays [24]. The collimating lens used in VR HMD provides users with a higher immersive feeling through higher FOV and further reduction of form factor while utilizing a simple convex lens, single/dual fresnel lens, and multiple microlens array [25].

The virtual images provided by VR HMDs apply the performance parameters of the human visual system [26]. The monocular FOV of the human eye is 160 degrees horizontally and 130 degrees vertically, and the combined binocular FOV overlaps by 200 degrees horizontally, 130 degrees vertically, and 120 degrees horizontally. Concerning display design, there is a precise balance between resolution density and FOV in that the total number of display pixels is fixed. For VR HMDs, a wide FOV covering the range of the human visual system can be achieved by designing eyepieces with sufficiently low apertures. Furthermore, the current VR HMD researches achieving 100-degree FOV and 60 pixels per degree (PPD) resolution density based on 20/20 vision to deliver virtual images that match the viewing angle of 120 degrees, which is the superimposed viewing angle of both eyes. For MR HMDs, 0.3 arcminutes for the entire FOV are based on 20/20 vision so that virtual images generated via digital holograms can be experienced at the exact resolution as the real world seen in transparent optics [27]. VR HMD, the

binocular parallax that appears to the eye as a stereo display, represents the visual depth signal [28]. That is, VR HMD operates based on fixed-focus retinal parallax stereo vision. Stereo disparity induces eye-distance depth signals, and the haptic visual system is triggered by eye convergence and acceptance in binocular stereo displays [29]. Convergence time for a single eye is approximately 200ms, while accommodation time is longer at approximately 300ms. Various human vision augmentation systems have been proposed to enable users to clearly see virtual images output from VR HMD systems [30]. The first method is physically adjusting the distance between the HMD and the collimating lens. This method is similar to finding the optimal sweet spot by adjusting the distance between two collimating lenses to solve the inter-pupillary distance (IPD) mismatch problem of HMD.

Padmanaban et al. implemented a display mode that adapts to human vision via computational optics to reproduce the focus changes accompanying natural human vision. They noted that the core of HMDs is that the limitations of existing optical structures cause many problems. Therefore, they proposed an adjustable-focus lens and a mechanically-operated eye-tracking technology to provide all users with a natural visual signal and a comfortable user experience. This method corrects for refractive errors in the display rays and can dynamically update the system based on where the user views the virtual image. To verify this study, they configured the liquid crystal display and the optics of each eye on a breadboard with a camera, and after dynamically positioning the lenses at all distances interleaved by four diopters, the relative sharpness was measured. The result was a significant increase in sharpness at all distances and improved recognition of the virtual image [13].

Hasnain et al. defined vergence-accommodation conflict (VAC) as the cause of visual discomfort in HMDs and proposed a lens as an actuator that can dynamically adjust the focal plane. This method applied a method to track the user's gaze through eye tracking and determine the virtual object the user observes. They implemented a prototype that could have a wide optical range adjustable for each eye via the proposed method. By providing a consistent depth signal for all viewing distances of the user, this method can reduce eye fatigue and enable observability of objects at all distances provided within the virtual environment [14].

Wilson and Hua proposed a method of adding a freely laterally movable Alvarez lens between the optical transfer structures of the HMD to eliminate VAC. They provided the 0-to-3D movement with a 150Hz refresh rate via a freestyle Alvarez lens paired with a piezo linear actuator. To validate this study, they set up a microdisplay and optics for virtual image delivery in a benchtop environment. They found that the images were clearly visible after positioning the near and far images. Through the proposed method, they designed an optical structure that can achieve significant focus while maintaining good image quality of HMD, and variable focus technology is the simplest and most effective way to solve the VAC problem of HMD [15].

There are many other ways to solve the VAC problem of HMD, such as deformable membrane mirror devices (DMMD), electrowetting lenses, elastomer-membrane fluidic lenses and liquid crystal lenses, and digitally switchable multi-focal lenses [16], [17], [18], [19]. Moreover, these studies show some improvements in the main parameters of the display performance of HMDs, such as spatial resolution in the virtual image, depth, accuracy of the focus signal, and adjustable response error, and further tradeoffs can be made. Most previous studies reported that the focus adjustment method improved the overall human vision system, including image sharpness and clarity. In order to prove the proposed method, the results of sharpness comparison using user-evaluated photographed images and software analysis using optical images were presented. However, these studies have provided only limited results, and real-world virtual reality content consists of dynamic forms of content, such as videos and games, rather than simple images and laser points. Therefore, evaluating the content that will actually be used is necessary. In addition, although it has been reported that it can improve the user's VR experience, no research has been published that has actually evaluated the features such as immersion and presence of the VR experience for users. Therefore, we will focus on the two major issues not considered in previous studies and compare the improvement of VR user experience.

### B. RELATIONSHIP BETWEEN VIRTUAL REALITY USER EXPERIENCE AND HEAD-MOUNTED DISPLAY FORM FACTOR

Immersive technology is a new social form, creating education, industry, and cultural change. In particular, the development of VR technology has improved the user's sense of immersion in virtual reality. It is announced that such a phenomenon can effectively improve the user's experience, playability, and enjoyment of participation [31]. VR technology can provide users with various emotional effects, two of which are evaluated as representative emotions: immersion and presence [32].

Immersion describes the extent to which a display can provide the user's senses with a comprehensive, pervasive, peripheral, and vivid virtual environment that resembles reality [33]. Immersion, in turn, relates to the degree of body matching in the virtual world, the degree to which the user can act, and the self-contained plot with autonomous reactions. Immersion mainly divides into four detail feelings: inclusive, extensive, surrounding, and vivid. Inclusive means the extent to which the real world is blocked by the physical environment that provides the virtual environment. Extensive means the range of sensitivity modalities acceptable to users. Surrounding means that the virtual reality is not limited to a narrow area but is output to a wide area corresponding to the user's field of view and resembles a panorama. Vivid means various elements such as display resolution and color representation used within the specific parameters of an HMD. Furthermore, this feeling is related to the richness,

information content, resolution, and quality of the display. Based on these factors, immersion can describe the environment provided by the HMD as an objective and quantifiable number.

Presence is a state of psychological awareness that can accompany immersion and is associated with the user's feeling of being present in the environment provided by virtual reality. Through presence, users should experience the virtual environment more engagingly than the real world and perceive the environment displayed in the form of space rather than simple images. Presence also incorporates aspects of autonomous responses and users' various high-level behaviors within virtual reality. A user's behavior in the virtual environment should match what is done in the real world.

The essential hardware for immersive technology is an HMD that blocks the view of the real world to allow immersive participation [34]. Moreover, the level of immersion in virtual reality content does not depend on general VR characteristics such as stereoscopic perspective or user movement tracking but instead on the quality of the virtual environment used and the technical characteristics of the HMD used. Furthermore, previous research has indicated that providing users with a more effective immersive experience is necessary to enhance their visual experience [35], [36].

Laha et al. presented that more realistic high-performance displays increase the objective sensory fidelity provided by virtual environments, providing greater immersion to users. They also observed that several components determine the level of immersion, and the components of visual immersion include field of view, display projection size, resolution, stereoscope, and virtual image realism [37].

The impact of immersion on a user's emotional immersion can also be defined in several different ways by researchers [38]. Some researchers found an increase in more immersive emotional responses compared to less immersive systems, while others found that immersion values did not affect emotional immersion [39], [40]. From another point of view, the effects of emotional immersion can be altered by the nature of the emotion under study [41], [42]. Negative feedback, such as fear and anxiety, which strongly stimulated emotions, occurred more strongly in the more immersive virtual environments [43]. In contrast, positive feedback, such as well-being, rest, and comfort, was reported to have much less effect on the technique used [44], [45].

Typical negative feedback that users feel in virtual reality environments is physical sickness, such as motion sickness and dizziness [46]. In particular, it has been announced that the sickness that may occur in the process of users experiencing virtual reality using HMDs will be more significant than in environments using other digital devices. The sickness that occurs in an environment using an HMD is caused by different factors from motion sickness experienced in daily life or on public transportation. As a typical cause, the user's movement in contact with the virtual environment and the user's experience of the content presented in the virtual environment differ from previously experienced sensory memory, which is referred to as a discrepancy in sensation. According to IEEE 3079 standard, the characteristics of devices that provide virtual reality content, the audiovisual characteristics of virtual reality content itself, the physical and empirical perspectives of users experiencing virtual reality content, and environmental components participating in virtual reality content can be considered [47].

Due to these factors, it was announced that users would experience fatigue and motion sickness that may occur while experiencing virtual reality content. In addition, previous research has shown that technologies such as high resolution and hyper-realistic rendering for the corresponding scene of the content from the viewpoint of visual fidelity affect the body sensitivity of virtual reality motion sickness.

Research to improve user immersion is presented as a way to address the factors associated with improved sickness. Among the most researched themes were display-related improvement factors [48].

Lubeck et al. researched that humans feel dizzier when viewing moving visual content than static content in a virtual environment. They announced that moving stimuli produced an optical flow of virtual reality content, allowing a person to experience phantom self-movement and reduced dizziness to the extent that the optical flow was extensive and rapid within the virtual reality content [49].

Keshavarz and Hecht. confirmed that rotational motion of the visual field caused significant vertigo when there was rotational motion in one or more axes rather than in a single axis. Their research found that the level of user sickness occurrence in virtual reality is closely related to content vection [50]. They experimented with changing the quality of virtual reality content and changing the user's cognitive level to analyze the impact of graphic realism on user immersion, not just optical flow.

Moreover, it was confirmed that users have higher visual fidelity when experiencing virtual reality content than when they experience the real world. It was also confirmed that the more similar the visual stimulus was to reality, the more the user was immersed in the virtual reality and expected the vestibular input related to the visual stimulus [51], [52].

Based on previous research, we determined that the user's usage experience and sense of immersion significantly affect the device environment that delivers virtual reality, as the user's human visual system reliance increases within virtual reality. In this study, we interpret how the proposed method affected the human visual system to improve user experience and sense of immersion.

## III. IMPLEMENTATION

We designed an experiment to ascertain the user's experience with human vision enhancement utilizing the diopter dial. We used the HTC XR Elite product for the experiment, which adjusts human vision to match the user's vision through the built-in diopter dial. In addition, this product provides clearer images in all FOVs corresponding to each eye through IPD adjustment. Figure 1 shows the experimental setup used to




**FIGURE 1.** Using contents in experiment (a) 2D video (source: Top Gun: Maverick), (b) 360-degree video (source: youtube @Vrgorilla1, (c) sitting mode game (source: Last labyrinth), (d) room-scale game mode (source: Ninja legends))

measure user immersion and experience in this paper. The contents used in the experiment are roughly divided into four categories: 2D video, 360-degree video, sitting mode game, and room-scale mode game. The virtual reality content provided by the VR HMD system is used as the primary performance parameter of the human visual system, so it is strong relevant to the user's experience and sense of immersion. As such, the user experiences greater visual fidelity in a virtual reality environment. Also, the elements related to the audiovisual characteristics of the virtual reality content provided by the device are connected to the characteristics of the user's personal physical and experiential viewpoints. Previous studies have confirmed that providing users with moving vision through an optical flow within virtual reality generates more substantial positive and negative feedback.

2D video offers the lowest optical flow among the contents used in the experiments. In this environment, the user sees only images displayed at a fixed position within the virtual reality environment and is provided with a limited optical flow at the fixed head position. 360-degree video outputs images in all spaces within virtual reality, thus providing a wider area of optical flow compared to 2D video. In addition, the head position moves fluidly according to the viewing angle so that the user can view the video from a desired viewpoint. The two types of audiovisual images mentioned above provide users with an audiovisual experience.

However, virtual reality content offers more than just audiovisual content; it also includes controllers and gesture-based interaction. For this reason, 2d video and 360-degree video are classified as audiovisual content, and two more operable content types are set. Of the content used in the experiment, the sitting mode game offers user interaction via controllers but no physical position movement. In this content, users can walk around a specific space within a virtual reality environment via the controller's joystick, interacting with various virtual avatars and 3D objects present in the environment.

However, although this content provides all the in-space images of virtual reality, it does not provide users with physical position switching, so it does not significantly induce much immersion and sickness.

Finally, the room-scale mode game allows the user to freely move within the virtual reality environment in any physical space and interact with various virtual avatars and 3D objects present in the environment via controllers. This content creates an environment that provides users with the strongest immersion through audiovisual sensations provided within the virtual reality environment and enables the same movements as in the real world through virtual avatars.

As shown in Figure 2, we implemented a vision test leveraging the snellen eye chart within virtual reality to ensure a clear fit of the user's focus within virtual reality. A vision test measures a user's vision. In the real world, vision tests are measured at a distance of 20 feet, and the standard visibility scale is set to 20/20 vision. In order to replicate the test in the virtual reality world, a process is required to correlate the distances in the real world to the virtual environment. For this reason, we leveraged the ''distance display'' software development kit (SDK) within the Unity software to map the camera at a distance of 20ft. Before the experiment, the 20/20 vision line optypes had to be read out to ensure that the user's viewpoint achieved adjusted human vision [53].

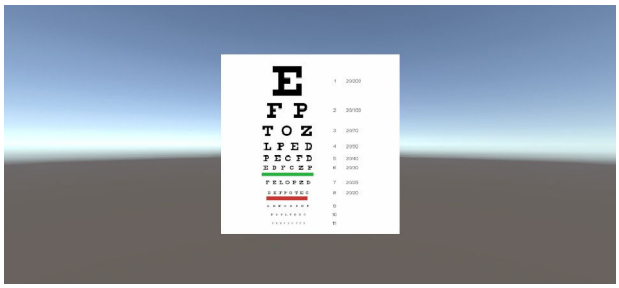


**FIGURE 2.** Human vision test using virtual snellen test in virtual environment.

As shown in Table 1, we used the 31-item immersion experience questionnaire (IEQ) on the 5-point Likert scale to measure user immersion. IEQ combines five factors to measure immersion: challenges, dissociation of the real world through loss of awareness of the surrounding real environment, emotional involvement, including attachment to virtual reality content, and cognitive involvement indicating the degree of effort and concentration.

Factors related to user experience used two questionnaire methods. As shown in Table 2, We used a 15-item simulator sickness questionnaire (SSQ) on a 5-point Likert scale for quantitative analysis. SSQ measures factors that can cause symptoms such as nausea, dizziness, and headache, a form of motion sickness that can occur while experiencing a virtual reality environment. We analyzed the degree of sickness in each experimental environment based on Knight and Baber's comfort rating scales (CRS). Additionally, the periodic discomfort test (PDT) was used to rate participants' degree of discomfort for each content as a score out of 10 points. We analyzed these questionnaires based on three questionnaires that measured the user's experience and emotions felt during the virtual reality experience.

**TABLE 1.** Immersion experience questionnaire (IEQ) items FOR evaluating proposed VR learning module.

| Item | Questionnaire |
|---|---|
| IEQ1 | To what extent did the VR contents hold your attention? |
| IEQ2 | To what extent did you feel you were focused on the VR contents? |
| IEQ3 | How much effort did you put into playing the VR contents? |
| IEQ4 | Did you feel that you were trying you best? |
| IEQ5 | To what extent did you lose track of time? |
| IEQ6 | To what extent did you feel consciously aware of being in the real world whilst playing? |
| IEQ7 | To what extent did you forget about your everyday concerns? |
| IEQ8 | To what extent were you aware of yourself in your surroundings? |
| IEQ9 | To what extent did you notice events taking place around you? |
| IEQ10 | Did you feel the urge at any point to stop playing and see what was happening around you? |
| IEQ11 | To what extent did you feel that you were interacting with the game environment? |
| IEQ12 | To what extent did you feel as though you were separated from your real-world environment? |
| IEQ13 | To what extent did you feel that the VR contents was something you were experiencing, rather than something you were just doing? |
| IEQ14 | To what extent was your sense of being in the VR contents environment stronger than your sense of being in the real world? |
| IEQ15 | At any point did you find yourself become so involved that you were unaware you were even using controls? |
| IEQ16 | To what extent did you feel as though you were moving through the VR contents according to you own will? |
| IEQ17 | To what extent did you find the VR contents challenging? |
| IEQ18 | Were there any times during the VR contents in which you just wanted to give up? |
| IEQ19 | To what extent did you feel motivated while playing? |
| IEQ20 | To what extent did you find the VR contents easy? |
| IEQ21 | To what extent did you feel like you were making progress towards the end of the VR contents? |
| IEQ22 | How well do you think you performed in the VR contents? |
| IEQ23 | To what extent did you feel emotionally attached to the VR contents? |
| IEQ24 | To what extent were you interested in seeing how the VR contents' events would progress? |
| IEQ25 | How much did you want to reward the VR contents? |
| IEQ26 | Were you in suspense about whether or not you would win or lose the VR contents? |
| IEQ27 | At any point did you find yourself become so involved that you wanted to speak to the VR contents directly? |
| IEQ28 | To what extent did you enjoy the graphics and the imagery? |
| IEQ29 | How much would you say you enjoyed playing the VR contents? |
| IEQ30 | When interrupted, were you disappointed that the VR contents was over? |
| IEQ31 | Would you like to play the VR contents again? |

**TABLE 2.** Simulator sickness questionnaire (SSQ) items for evaluating proposed VR learning module.

| Item | Questionnaire |
|---|---|
| SSQ1 | I was worried about how I look when I use this device. |
| SSQ2 | I felt tense or on edge because I was using the device. |
| SSQ3 | I could feel the device on my body. |
| SSQ4 | I could feel the device moving. |
| SSQ5 | The device was causing me some harm. |
| SSQ6 | I felt strange using the device. |
| SSQ7 | I felt bulky when I use the device. |
| SSQ8 | The device affected the way I move. |
| SSQ9 | The device inhibited or restricted my movement. |
| SSQ10 | I did not feel safe using the device. |
| SSQ11 | I was not able to move as usual. |
| SSQ12 | I felt the device was too heavy. |
| SSQ13 | The attachment of the device was too tight. |
| SSQ14 | The attachment of the device was too loose. |
| SSQ15 | I felt that I did not have the device properly attached. |

This experiment was designed for users with existing vision issues who experienced wearing glasses or lenses to provide a VR experience or for users who did not have sufficient eyesight. All 25 participants had to wear glasses due to their vision loss, and all had experienced VR at least once before the experiment. They selected the eye diseases they were experiencing before starting the experiment, with 7 users suffering from myopia, 11 users suffering from hyperopia, and 20 participants suffering from astigmatism. The Institutional Review Board (IRB) of POSTECH approved this study.

Figure 3 shows the overall experimental sequence. The experiment phase was divided into two categories and proceeded for lasted about 80 minutes. In Phase 1, the user

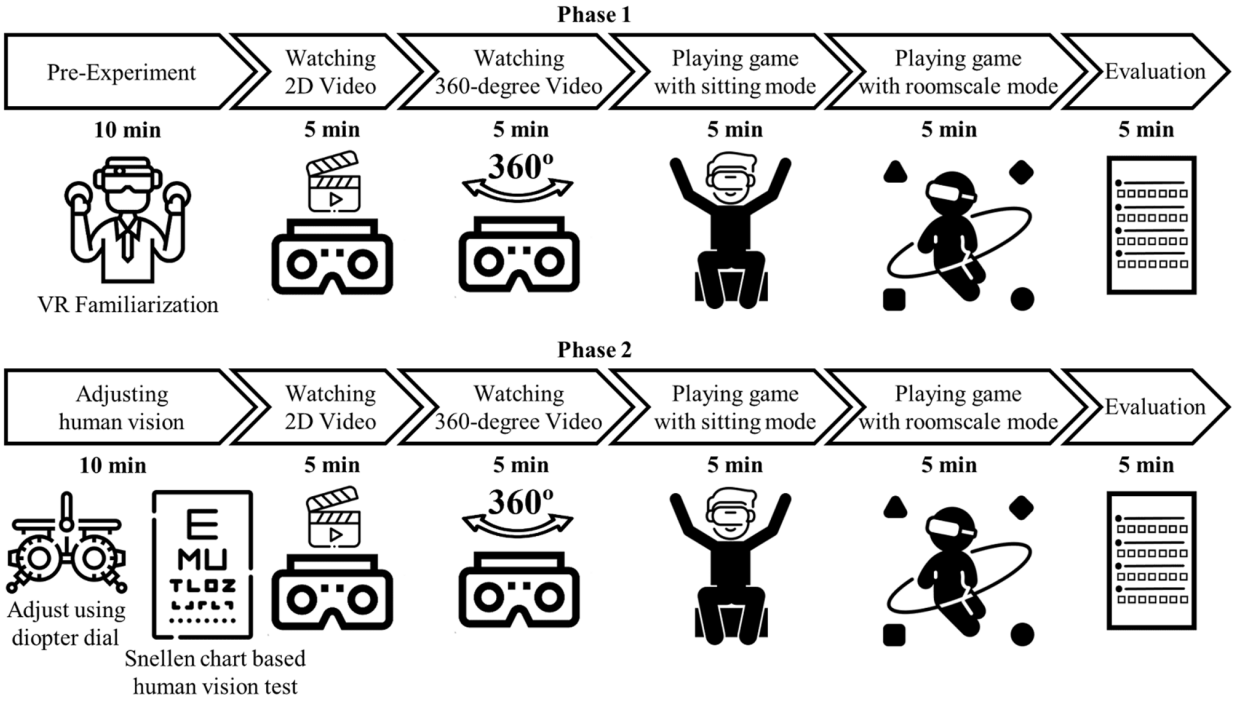



**FIGURE 3.** Human vision test using virtual snellen test in virtual environment.

conducted with the experiment while wearing glasses. Prior to the start of the experiment, participants went through a familiarization process and were able to follow the flow of the experiment smoothly. After completing the pre-experiment process, the participants experienced a given scenario from a 2D video to a room-scale mode game and rated their degree of discomfort within 10 points after each content was completed. The experimental procedure was designed to gradually increase the optical flow and physical movement provided by the content, increasing the user's sense of immersion, physical fatigue, and sickness. After experiencing all the content, users took a break after completing the questionnaire evaluation.

When Phase 2 begins, the user takes off the glasses and then adjusts human vision using the diopter dial according to the given guidelines. During this process, the user goes through a vision test and adjusts their vision to read all the 20/20 vision line optypes of the snellen chart installed in the virtual space. After that, the user re-experienced the four contents tested in Phase 1 according to the given scenario and rated their degree of discomfort within 10 points after finishing each content. Finally, after experiencing all the content, users provide additional feedback for each user experience after completing the questionnaire evaluations. In this experiment, the hypothesis of this paper is as follows: we hypothesize that the diopter dial focusing process can achieve not only an improvement in human vision but also an improvement in the form factor of the environment in which the HMD is used. Additionally, these improvements will increase immersion and user experience.

H1. Due to improved human vision and improved form factor, the immersion score of the Phase 2 environment will be higher than that of the Phase 1 environment.

H2. SSQ scores in Phase 2 environments are lower than in Phase 1 environments due to improved human vision and form factor.

H3. PDT scores in Phase 2 environments are lower than in Phase 1 environments due to improved human vision and form factor.

## IV. RESULTS AND DISCUSSION

### A. STATISTICAL ANALYSIS

Table 3 summarizes the responses to the IEQ items, and Figure 4 visualizes the Q-Q plot of the questionnaire results based on each of the two phases. The mean difference between Phase 2 and Phase 1 is 2.35, and the standard error of the difference is 0.0841, confirming that adjusting human vision through the diopter dial can give the user a greater sense of immersion (Phase 1 = 2.99 (Mean), 2.81/3.18 (95% CI mean lower/upper), 0.456 (Standard deviation), Phase 2 = 4.55 (Mean), 4.44/4.65 (95% CI mean lower/upper), 0.25 (Standard deviation)). The item with the highest average value difference was '(IEQ20) To what extent did you find the VR contents easy?' (Mean difference = 2.36), followed by IEQ24 (Mean difference = 2.04), IEQ23, IEQ19, IEQ31 (Mean difference = 1.92), and so on. The items with the lowest mean difference were '(IEQ11) To what extent did you feel that you were interacting with the game environment?' (Mean difference = 1) and '(IEQ12) To what extent

**TABLE 3.** Mean difference of the IEQ items between phase 1 and phase 2.

| Item | Phase 1 | | | | Phase 2 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | M | 95% CI mean lower/upper bound | | SD | M | 95% CI mean lower/upper bound | | SD | MD | SE | p-value |
| IEQ1 | 3.16 | 2.88 | 3.44 | 0.688 | 4.48 | 4.27 | 4.69 | 0.51 | 1.32 | 0.125 | < .001 |
| IEQ2 | 3.16 | 2.9 | 3.42 | 0.624 | 4.6 | 4.39 | 4.81 | 0.5 | 1.44 | 0.117 | < .001 |
| IEQ3 | 3.32 | 3.04 | 3.6 | 0.69 | 4.68 | 4.48 | 4.88 | 0.476 | 1.36 | 0.114 | < .001 |
| IEQ4 | 3.16 | 2.85 | 3.47 | 0.746 | 4.52 | 4.28 | 4.76 | 0.586 | 1.36 | 0.128 | < .001 |
| IEQ5 | 2.88 | 2.56 | 3.2 | 0.781 | 4.56 | 4.32 | 4.8 | 0.583 | 1.68 | 0.138 | < .001 |
| IEQ6 | 3.16 | 2.85 | 3.47 | 0.746 | 4.6 | 4.39 | 4.81 | 0.5 | 1.44 | 0.117 | < .001 |
| IEQ7 | 2.32 | 1.93 | 2.71 | 0.945 | 4.04 | 3.74 | 4.34 | 0.735 | 1.72 | 0.212 | < .001 |
| IEQ8 | 3.76 | 3.51 | 4.01 | 0.597 | 4.84 | 4.69 | 4.99 | 0.374 | 1.08 | 0.14 | < .001 |
| IEQ9 | 3.64 | 3.41 | 3.87 | 0.569 | 5 | 5 | 5 | 0 | 1.36 | 0.114 | < .001 |
| IEQ10 | 2.96 | 2.66 | 3.26 | 0.735 | 4.44 | 4.23 | 4.65 | 0.507 | 1.48 | 0.184 | < .001 |
| IEQ11 | 3.92 | 3.68 | 4.16 | 0.572 | 4.92 | 4.81 | 5.03 | 0.277 | 1 | 0.141 | < .001 |
| IEQ12 | 3.96 | 3.74 | 4.18 | 0.539 | 4.96 | 4.88 | 5.04 | 0.2 | 1 | 0.115 | < .001 |
| IEQ13 | 2.92 | 2.63 | 3.21 | 0.702 | 4.28 | 4.03 | 4.53 | 0.614 | 1.36 | 0.172 | < .001 |
| IEQ14 | 3.24 | 2.99 | 3.49 | 0.597 | 4.68 | 4.48 | 4.88 | 0.476 | 1.44 | 0.154 | < .001 |
| IEQ15 | 2.88 | 2.61 | 3.15 | 0.666 | 4.36 | 4.07 | 4.65 | 0.7 | 1.48 | 0.154 | < .001 |
| IEQ16 | 2.88 | 2.63 | 3.13 | 0.6 | 4.64 | 4.41 | 4.87 | 0.569 | 1.76 | 0.119 | < .001 |
| IEQ17 | 2.84 | 2.61 | 3.07 | 0.554 | 4.08 | 3.84 | 4.32 | 0.572 | 1.24 | 0.119 | < .001 |
| IEQ18 | 2.88 | 2.58 | 3.18 | 0.726 | 4.44 | 4.2 | 4.68 | 0.583 | 1.56 | 0.164 | < .001 |
| IEQ19 | 2.72 | 2.39 | 3.05 | 0.792 | 4.64 | 4.44 | 4.84 | 0.49 | 1.92 | 0.182 | < .001 |
| IEQ20 | 2.32 | 1.97 | 2.67 | 0.852 | 4.68 | 4.48 | 4.88 | 0.476 | 2.36 | 0.181 | < .001 |
| IEQ21 | 2.88 | 2.58 | 3.18 | 0.726 | 4.48 | 4.27 | 4.69 | 0.51 | 1.6 | 0.183 | < .001 |
| IEQ22 | 3.2 | 2.86 | 3.54 | 0.816 | 4.72 | 4.53 | 4.91 | 0.458 | 1.52 | 0.184 | < .001 |
| IEQ23 | 2.8 | 2.51 | 3.09 | 0.707 | 4.72 | 4.53 | 4.91 | 0.458 | 1.92 | 0.14 | < .001 |
| IEQ24 | 2.64 | 2.38 | 2.9 | 0.638 | 4.68 | 4.45 | 4.91 | 0.557 | 2.04 | 0.158 | < .001 |
| IEQ25 | 2.28 | 2.06 | 2.5 | 0.542 | 3.88 | 3.66 | 4.1 | 0.526 | 1.6 | 0.129 | < .001 |
| IEQ26 | 2.28 | 2.03 | 2.53 | 0.614 | 3.84 | 3.58 | 4.1 | 0.624 | 1.56 | 0.164 | < .001 |
| IEQ27 | 2.84 | 2.56 | 3.12 | 0.688 | 4.6 | 4.39 | 4.81 | 0.5 | 1.76 | 0.156 | < .001 |
| IEQ28 | 3.56 | 3.27 | 3.85 | 0.712 | 5 | 5 | 5 | 0 | 1.44 | 0.142 | < .001 |
| IEQ29 | 2.92 | 2.61 | 3.23 | 0.759 | 4.8 | 4.63 | 4.97 | 0.408 | 1.88 | 0.156 | < .001 |
| IEQ30 | 2.6 | 2.33 | 2.87 | 0.645 | 4.12 | 3.94 | 4.3 | 0.44 | 1.52 | 0.131 | < .001 |
| IEQ31 | 2.72 | 2.39 | 3.05 | 0.792 | 4.64 | 4.44 | 4.84 | 0.49 | 1.92 | 0.152 | < .001 |
| Total | 2.99 | 2.81 | 3.18 | 0.456 | 4.55 | 4.44 | 4.65 | 0.25 | 1.56 | 0.084 | < .001 |

did you feel as though you were separated from your real world environment?' (Mean difference = 1). Then there was IEQ8 (Mean difference = 1.08), IEQ17 (Mean difference = 1.24), IEQ1 (Mean difference = 1.32) and so on. The Shapiro-Wilk test result (W) for normality evaluation was 0.938, and the p-value was 0.136, satisfying the normality assumption, and the p-value values of all questionnaire items were within 0.001. For this reason, we adopt hypothesis H1 'Due to improved human vision and improved form factor, the immersion score of the Phase 2 environment will be higher than that of the Phase 1 environment'.

Table 4 summarizes the responses to the 15 SSQ, and Figure 5 visualizes the Q-Q plot of the questionnaire results based on each of the two phases. The mean difference between Phase 2 and Phase 1 is 2.35, and the standard error of the difference is 0.0761, confirming that adjusting human vision through the diopter dial can improve the various sicknesses that users can experience in the virtual environment (Phase 1 = 3.85 (Mean), 3.69/4.02 (95% CI mean lower/upper), 0.394 (Standard deviation), Phase 2 = 1.5 (Mean), 1.38/1.62 (95% CI mean lower/upper), 0.289 (Standard deviation)). The item with the highest mean difference was '(Q4) I could feel the device moving.' (Mean difference = 3.12), and the items with the lowest were '(Q2) I felt tense or on edge because I was using the device. (Mean difference = 2) and '(Q12) I felt the device was too heavy.' (Mean difference = 2). The Shapiro-Wilk test result (W) for normality evaluation was 0.948, and the p-value was 0.222, satisfying the normality assumption, and the p-value values of all questionnaire items were within 0.001. For this reason,

**TABLE 4.** Mean difference of the SSQ items between phase 1 and phase 2.

| Item | Phase 1 | | | | Phase 2 | | | | MD | SE | p-value |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | M | 95% CI mean lower/upper bound | | SD | M | 95% CI mean lower/upper bound | | SD | | | |
| SSQ1 | 3.96 | 3.77 | 4.15 | 0.455 | 1.92 | 1.75 | 2.09 | 0.4 | 2.04 | 0.0909 | < .001 |
| SSQ2 | 3.92 | 3.66 | 4.18 | 0.64 | 1.92 | 1.72 | 2.12 | 0.493 | 2 | 0.1528 | < .001 |
| SSQ3 | 4.08 | 3.74 | 4.42 | 0.812 | 1.68 | 1.42 | 1.94 | 0.627 | 2.4 | 0.1826 | < .001 |
| SSQ4 | 4.56 | 4.35 | 4.77 | 0.507 | 1.44 | 1.2 | 1.68 | 0.583 | 3.12 | 0.1665 | < .001 |
| SSQ5 | 4.2 | 3.93 | 4.47 | 0.645 | 1.64 | 1.44 | 1.84 | 0.49 | 2.56 | 0.1536 | < .001 |
| SSQ6 | 4 | 3.76 | 4.24 | 0.577 | 1.6 | 1.36 | 1.84 | 0.577 | 2.4 | 0.1732 | < .001 |
| SSQ7 | 4.6 | 4.36 | 4.84 | 0.577 | 1.52 | 1.28 | 1.76 | 0.586 | 3.08 | 0.1519 | < .001 |
| SSQ8 | 4.36 | 4.16 | 4.56 | 0.49 | 1.64 | 1.38 | 1.9 | 0.638 | 2.72 | 0.1227 | < .001 |
| SSQ9 | 4.48 | 4.27 | 4.69 | 0.51 | 1.64 | 1.41 | 1.87 | 0.569 | 2.84 | 0.1376 | < .001 |
| SSQ10 | 4.16 | 3.88 | 4.44 | 0.688 | 1.68 | 1.48 | 1.88 | 0.476 | 2.48 | 0.1541 | < .001 |
| SSQ11 | 4.28 | 4.09 | 4.47 | 0.458 | 1.52 | 1.31 | 1.73 | 0.51 | 2.76 | 0.1046 | < .001 |
| SSQ12 | 3.72 | 3.42 | 4.02 | 0.737 | 1.72 | 1.44 | 2 | 0.678 | 2 | 0.2082 | < .001 |
| SSQ13 | 3.88 | 3.58 | 4.18 | 0.726 | 1.4 | 1.16 | 1.64 | 0.577 | 2.48 | 0.1306 | < .001 |
| SSQ14 | 3.88 | 3.61 | 4.15 | 0.666 | 1.44 | 1.23 | 1.65 | 0.507 | 2.44 | 0.1301 | < .001 |
| SSQ15 | 3.6 | 3.24 | 3.96 | 0.866 | 1.24 | 1.02 | 1.46 | 0.523 | 2.36 | 0.172 | < .001 |
| Total | 3.85 | 3.69 | 4.02 | 0.394 | 1.5 | 1.38 | 1.62 | 0.289 | 2.35 | 0.0761 | < .001 |

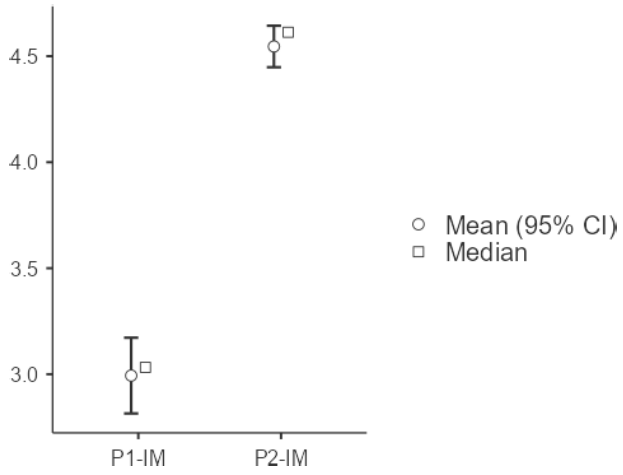



**FIGURE 4.** Q-Q plot of IEQ items between Phase 1(P1) and Phase 2(P2).

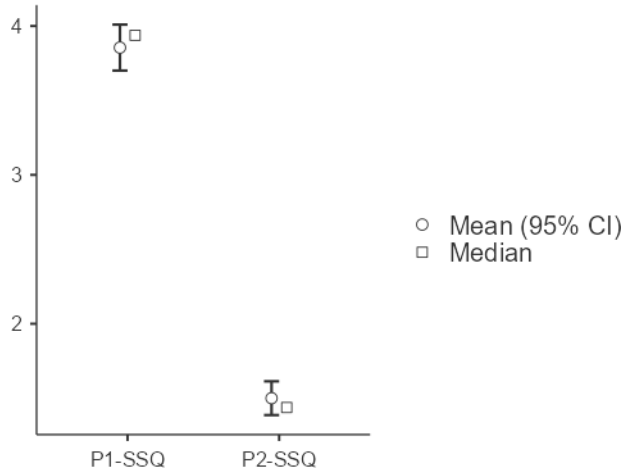



**FIGURE 5.** Q-Q plot of SSQ items between Phase 1(P1) and Phase 2(P2).

we adopt hypothesis H2 'SSQ scores in Phase 2 environments are lower than in Phase 1 environments due to improved human vision and form factor'.

Table 5 summarizes responses to PDT scores, and Figure 6 visualizes the Q-Q plot and graph of the questionnaire results based on each of the two phases for the four experimental contents. The Mean difference value between Phase 2 and Phase 1 is 3.85, and the standard error of the difference is 0.208. We confirmed that adjusting human vision through the diopter dial can improve the discomfort experienced by the user in the virtual environment (Phase 1 = 6.1 (Mean), 5.59/6.61 (95% CI mean lower/upper), 1.24 (Standard deviation), Phase 2 = 2.25 (Mean), 1.98/2.52 (95% CI mean lower/upper), 0.665 (Standard deviation)). The content with the highest mean difference was room-scale mode game (Mean difference = 5.12) and the item with the lowest mean difference was 2D Video (Mean difference = 2.36). Moreover, as the experimental sequence progressed, the difference between the average value and the average value for each phase increased (Phase 1 Mean: 2D video = 3.68, 360-degree video = 5, Sitting mode game = 7, Room-scale mode game = 8.72, Phase 2 Mean: 1) 2D video = 1.32, 360-degree video = 1.6, Sitting-mode game = 2.48, Room-scale mode game = 3.6, Mean difference: 2D video = 2.36, 360-degree video = 3.4, Sitting mode game = 4.52, Room-scale mode game = 5.12). The Shapiro-Wilk test result (W) for normality evaluation was 0.941, and the p-value was 0.16, satisfying the

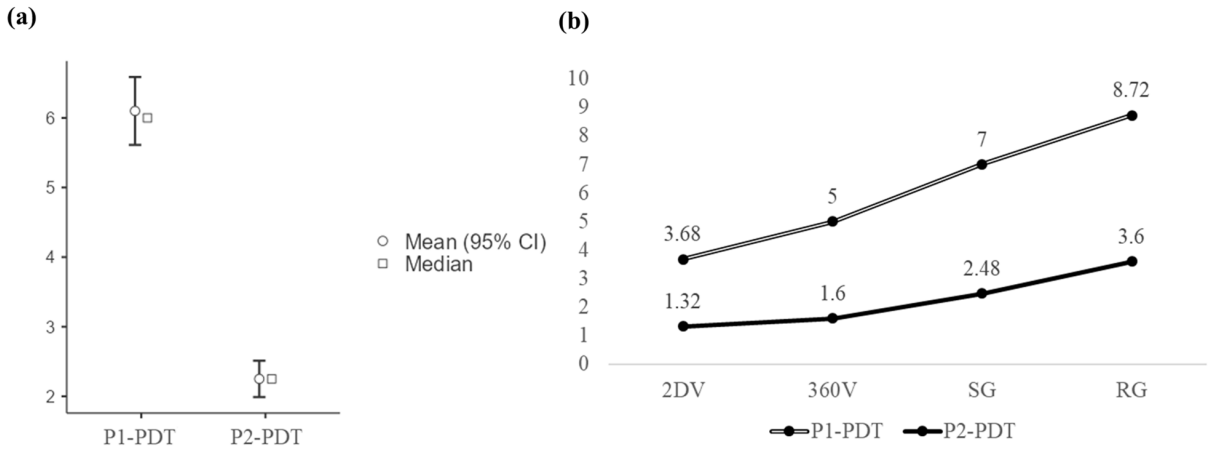



**FIGURE 6.** (a) Q-Q plot and (b) graph of the between Phase 1(P1) and phase 2(P2) (2D = 2D video, 360D = 360-degree video, SG = sitting mode game, RG = room-scale mode game)Figure 1 Q-Q plot of SSQ items between phase 1(P1) and phase 2(P2).

**TABLE 5.** Mean difference of the PDT between phase 1 and phase 2.

| Item | Phase 1 | | | | Phase 2 | | | | MD | SE | p-value |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | M | 95% CI mean lower/upper bound | | SD | M | 95% CI mean lower/upper bound | | SD | | | |
| 2D | 3.68 | 3.11 | 4.25 | 1.38 | 1.32 | 1.12 | 1.52 | 0.476 | 2.36 | 0.276 | < .001 |
| 360D | 5 | 4.37 | 5.63 | 1.53 | 1.6 | 1.33 | 1.87 | 0.645 | 3.4 | 0.271 | < .001 |
| SG | 7 | 6.4 | 7.6 | 1.44 | 2.48 | 2.1 | 2.86 | 0.918 | 4.52 | 0.259 | < .001 |
| RG | 8.72 | 8.27 | 9.17 | 1.1 | 3.6 | 3.15 | 4.05 | 1.08 | 5.12 | 0.226 | < .001 |
| Total | 6.1 | 5.59 | 6.61 | 1.24 | 2.25 | 1.98 | 2.52 | 0.665 | 3.85 | 0.208 | <. 001 |

normality assumption, and the p-value values of all questionnaire items were within 0.001. For this reason, we adopt hypothesis H3 'PDT scores in Phase 2 environments are lower than in Phase 1 environments due to improved human vision and form factor'.

Table 6 summarizes the content of in-depth interview with the experimental participants after all experiments were completed, with response rate of 80%. The participants answered with a focus on the sense of immersion, experience of use, and comfort generated by adjusted human vision using the diopter dial. Most experimental participants experienced a gradual increase in discomfort and sickness following an experimental sequence designed to increase optical flow, in a trend similar to the quantitative analysis results. They also noted that the issues as mentioned above were primarily ameliorated in the Phase 2 environment and that trial participants experienced a better user experience. Additionally, they said that the Phase 2 experience improvements were felt more with playable content than with audiovisual content.

### B. DISCUSSION

Through the results of questionnaires and the content of in-depth interviews, we organized the relationship between human vision adjustment using the diopter dial and human factors, immersion, and sickness.

First, this concerns the display form factor. We mentioned the following before the discussion. The collision and inconsistency between the human visual system and the vestibular system results in the loss of understanding of the brain and the generation of Sickness, which can directly affect immersion in the virtual environment by creating distractions and discomfort that break the feeling of being present in the virtual environment. The reaction time required for tasks performed in the virtual environment can be slowed, and the performance can deteriorate [54], [55], [56], [57], [58]. Inadequately calibrated vision can cause sickness, and the immersive experience can diminish due to discomfort and disorientation [59]. Physical, cognitive, and psychological competencies are essential considerations for Sickness sensitivity, and this discomfort can break the immersive experience. This can also be seen as a concept involving ergonomic design [60], [61]. In addition, in terms of experimental design. When categorized into low-immersive, semi-immersive, and fully-immersive content, the stronger the immersive content, the stronger the cybersickness experience, and this feeling breaks the presence and immersion, potentially causing users to leave the virtual environment, and the more pronounced the sensory conflict between visual input and physical feedback, the stronger the sickness that can occur.

In addition, the experimental results confirmed that the 360-degree video environment mentioned in other

**TABLE 6.** Excerpts from in-depth interviews for participants.

| No. | Excerpts |
|---|---|
| P3 | I was positive that I could receive clean VR content without glasses through human vision adjustment. This has been a new experience for me and seems to have had a positive impact on the VR experience. |
| P4 | The feeling I experienced through Phase 2 was very new. In particular, adjusted vision made the environment where you can experience VR very comfortable. I think this technology is enough to increase interest in VR. |
| P5 | The improvements applied in Phase 2 had a significant impact on the user's experience improvement and completely changed the overall perception and immersion of the VR experience. |
| P6 | In the meantime, visual aids such as glasses that must be worn due to astigmatism have forced very narrow viewing angles and limited movements in the process of experiencing VR experiences. However, diopter dial has solved almost all of the aforementioned physical limitations. Through this system, I completely improved my preconceptions about the existing VR experience. |
| P7 | Visual improvement completely improved the experience and immersion in VR. Improved vision was able to focus more on the VR environment and content and interact with objects. |
| P8 | After adjusting the vision using diopter dial, I felt comfortable as if I were not wearing a VR HMD. |
| P9 | In the process of experiencing VR before, I had to suffer from a lot of immersion and discomfort due to the hardware structure of glasses and VR HMD. However, the visual control function solved this inconvenience and I was able to fully immerse myself in the VR environment. |
| P10 | The biggest feeling I felt when I experienced VR through the visual control system without glasses is mobility. In Phase 1, when experiencing mobile content, the range of the image was low due to the inconvenience of the form factor due to glasses and the lens mismatch between the glasses and HMD. However, this inconvenience was completely resolved by moving on to Phase 2. Through this experiment, I thought that the user's convenience was the factor that had the greatest influence on the immersion of the VR environment in my standards. |
| P11 | The difference in experience between the two experimental environments was significant. I think Phase 2 was definitely easy to use, so it was a good environment to experience VR content. |
| P12 | I usually have a lot of experience using other VR devices, and wearing glasses when using HMD was a very uncomfortable experience, so I wore contact lenses every time I used it. However, the improvement of human vision using diopter dial could have completely improved this use experience. In particular, I felt a stronger improvement when I experienced playable contents rather than just audio-visual content. And I think this improvement in user inconvenience can convey the contents and emotions that the VR environment provides so that they can be delivered well. |
| P13 | I think the biggest difference between the two experimental environments was Movement. The environment in Phase 2 was so comfortable. |
| P15 | I was impressed by the change in experience and immersion as the VR environment itself became more comfortable |
| P16 | The long VR experience through Phase 1 was very uncomfortable. When I first saw the audio-visual content, there was no big inconvenience, but from the time I experienced the game content, I felt uncomfortable because I felt that the experimental environment was bulky in earnest. The human vision adjusted in Phase 2 solved this inconvenient part very much, and the immersion and user experience were sufficiently improved. |
| P17 | I was able to immerse myself in the content as the VR HMD environment became more comfortable |
| P18 | The experiment time of Phase 1 was too long, so I felt more uncomfortable. |
| P21 | Compared to other hardware, in an environment that limits a user's view, such as VR technology, the sense of using the hardware to use the technology was considered important. |
| P22 | During the experimental process of Phase 1, I felt very uncomfortable when I experienced the game. I should have moved my head to make frequent viewpoint changes during the game. However, during this process, various inconveniences occurred, such as repeatedly colliding lenses and glasses or re-positioning HMD due to out of focus, and mobility was very limited. This was mostly improved when diopter dial was used to provide adjustment time, especially in playable contents such as games rather than audio-visual content, and the immersion and convenience were greatly improved. |
| P23 | There was no major inconvenience when Phase 1 was just started, but as the usage time increased, the inconvenience increased, and there were many restrictions when experiencing room-scale games. However, in the Phase 2 process, restrictions were resolved through coordinated vision, so that they could only immerse themselves in the VR environment. |
| P24 | I think the usability improvement has made a lot of differences in emotional aspects. |
| P25 | It was so hard to experience VR content while wearing glasses for a long time and I couldn't concentrate well. However, when diopter dial was used to control human vision, some of the feelings of wearing HMD were felt, but it was so comfortable that I felt as if I were looking at the real world as it was. And these comfortable emotions induced people to fully immerse themselves in VR content and feel interested. |

references negatively impacted conventional VR-based content, including interaction [62], [63]. Among all IEQ items, the item that showed the most significant mean difference was '(IEQ20) To what extent did you find the VR contents easy?' (Mean difference = 2.36). All questionnaires were aimed at users who already had VR experience, and the questions were

rated based on the experimental environment rather than the content used in the experiment.

In addition, items such as SSQ2, SSQ9, SSQ11, and SSQ8 showed significant differences in order, including '(SSQ4) I could feel the device moving.' (Mean difference = 3.12), which was the item that showed the most significant difference in average values among all the questionnaire contents of SSQ. Furthermore, many participants responded through in-depth interviews that the method of using them without vision aids such as glasses made the environment for experiencing VR dramatically more comfortable (P6, P9, P10, P12, P22, P25). This questionnaire focused on the movement of the user while wearing the HMD. Moreover, users answered that resolving visual constraints through the sequences given in the experiment, such as diopter dial and IPD adjustments, significantly impacted the improvement of movement. From these results, we confirmed that human visual adjustment using the diopter dial positively impacted the user's comfort through improved movement.

Second, visibility is a crucial part of the display. Among the IEQ questions, the question on visibility was IEQ28 (Mean difference = 1.44) and IEQ2 (Mean difference = 1.44). Moreover, many participants said that experiencing the whole VR experience without vision aids impacted their increased immersion (P3, P4, P7, P16, P21). Furthermore, since the improved sense of immersion is accompanied by an increased sense of presence, participants can experience the virtual environment more engagingly than the real world. As a result, we saw significant improvements in questions IEQ7 (Mean difference = 1.72) and IEQ5 (Mean difference = 1.68), which assess user concentration, and IEQ24 (Mean difference = 2.04), IEQ23 (Mean difference = 1.92), IEQ19 (Mean difference = 1.92), and IEQ29 (Mean difference = 1.92), which assess motivation and interest. There was no direct question about visibility in the SSQ, but it is known from previous research that improving sickness improves the user's sense of immersion. Furthermore, we expected the low SSQ scores in Phase 2 to influence all IEQ questions. Through these results, we confirmed that human vision adjustment using diopter dial could directly improve the sense of intense immersion related to the visibility of the display and visual sensory modalities among the four detailed senses of immersion.

In addition, although Phase 2 showed higher Phase 1 immersion scores for all items, the items that showed the smallest differences among IEQs were IEQ11 (Mean difference = 1), IEQ12 (Mean difference = 1), and IEQ8 (Mean difference = 1.08). And, these items were linked to environmental factors. The sense of detail that is related to the environmental elements within the sense of immersion is inclusivity and surrounding. Questions IEQ11 and IEQ12 implied a separation between the real world and the virtual environment, but both experimental environments used the same virtual reality content. We speculate that the virtual environment itself completely blocks the user's view of the real world and only conveys virtual reality information, so it did not cause a dramatic change.

The new academic points arising from this study are as follows. Prior research shows that failure to control or mitigate Sickness properly can lead to bias in experimental results, undermine the reliability of VR studies, compromise the effectiveness of VR applications in the context of research and training, and while providing high-resolution visual information can reduce visual nausea, technical improvements such as high resolution cannot wholly alleviate Sickness symptoms [64], [65]. Through our study, we can see that many participants in the study in various VR-based engineering studies can control the experimental environment by receiving improved visual information beyond a certain threshold, which could soon be ways to strengthen the reliability of the study further.

### C. LIMITATIONS AND FUTURE WORKS

This study focuses on evaluating the immersion and user experience improvements of human visual adjustments utilizing diopter dial. Before concluding the experiment, we would like to acknowledge some experimental limitations. Our experiment consisted of 25 experimental participants to evaluate immersion and user experience, and this small sample limits its effectiveness verification [66]. Experiments comparing the principles of each experimental guideline require hundreds of experimental participants to constitute groups for statistical validation by quantitative analysis. These issues suggest that our research value may be somewhat limiting [67]. To complement these issues, we provided in-depth commentary and received detailed feedback from experimental participants to ensure statistical reliability across questionnaires such as the IEQ and SSQ. From the experimental results, we supplemented the reliability of the research through qualitative studies. We confirmed that the results of the quantitative analysis and the results of the in-depth interviews were closely related. Recent research attempts to quantify user experiences such as immersion and sickness with biometric data such as electroencephalography (EEG) and electrocardiogram (ECG). In the future, we plan to use EEG signals to quantify user factors such as the user's sense of immersion and sickness and compare them with the questionnaire results. This study will ensure the reliability of the methodology and provide more detailed guidelines through diversifying experimental environments.

## V. CONCLUSION

In this paper, we proposed to improve human vision using diopter dial to improve immersion and user experience in the VR environment. To verify the validity, we implemented the Phase 1 experimental environment in which VR is experienced while wearing vision aids such as glasses and the Phase 2 experimental environment in which human visual improvement using diopter dial is provided without vision aids. The experiment sequence consisted of 2D video, 360-degree video, playable content, sitting mode game, and room-scale mode game, and applied a method of increasing the user's physical and empirical feedback by increasing the

optical flow in the content and the user's movement of avatars in the physical and virtual environment. We conducted an IEQ questionnaire to measure immersion in each experimental environment, an SSQ questionnaire to measure sickness using a 5-point Likert scale, and measured the PDT score for each experimental content to measure discomfort. The average difference between the two experimental environments was 1.56 for immersion, 2.35 for sickness, and 3.85 for PDT. In addition, we collected user feedback through in-depth interviews and ensured the reliability of statistical analysis by similarity to questionnaire results. We confirmed that human vision adjustment using the diopter dial could provide users with an improved form factor, reduce discomfort and sickness, and even improve overall immersion through improved display visibility. In the future, through EEG signal-based biometric data, we will quantify user factors such as immersion and sickness, ensure the reliability of the methodology, and present more detailed guidelines through diversification of the experimental environment.

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