Intuition, Accuracy, and Immersiveness Analysis of 3D Visualization Methods for Haptic Virtual Reality

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***Abstract*—The purpose of this study is to analyze the usefulness of 3D immersive stereoscopic virtual reality technology in applications that provide tactile sensations. Diverse experiments show that the haptic 3D visualization method presented in a 3D stereoscopic space using headsets is more intuitive, accurate and immersive than the haptic 3D visualization method displayed in 3D flat displays. In particular, the intuitiveness has been significantly improved in a stereoscopic 3D visualization rather than flat 3D visualization. In spite of the general superiority of the stereoscopic 3D visualization, it is mentionable that the precise operation performance has not been greatly improved in the elaborate object movements. It means that users can recognize and manipulate the position of objects more quickly in 3D stereoscopic immersive VR environments, however, the precise operation does not benefit greatly in the 3D stereoscopic visualization. Note that the degree of game immersion is remarkably augmented in the case of using 3D stereoscopic visualization.**

***Keywords*—3D; stereoscopic; haptic; intuition; immersiveness; recognize; simulation; virtual reality; visualization**

I. Introduction

The development of virtual reality (VR) and stereographic visualization technology has made a great impact in the field of education. Furthermore, the advancement of head-mounted display (HMD) technology has led to the creation of many immersive simulations using VR HMDs for education and training purposes. It is noted that immersive technology with VR HMDs is advantageous for acquiring cognitive skills related to remembering and understanding spatial and visual information. It is also useful for psychomotor skills related to the movement of one’s head, such as visual scanning or observational skills [1]. Haptic interfaces can enhance the immersion of VR simulations by enabling users to “touch” and “feel” objects in virtual environments. Virtual haptic simulations can be implemented with both the two-dimensional (2D) graphics and the three-dimensional (3D) graphics. 3D graphics are divided into 2D flat visualization and 3D visualization.

In this study, the authors only consider methods to visualize virtual haptic simulations implemented in 3D graphics. 3D visualization generally presents stereoscopic images using binocular parallax. There are stereoscopic display and volumetric displays, which are classified according to whether wearing glasses or not. The currently commercialized binoculars are a way to assess the stereoscopic effect by using shutter glasses or polarized glasses. The images taken with two lenses are combined into one image from the brain through two eyeballs again. The resulting binocular disparity can be reconfigured in the brain to give a sense of depth.

Another common 3D graphics visualization method is to use a stereoscopic head-mounted display like Oculus Rift or HTC Vive. This method allows stereoscopic images to be synthesized in the brain by inputting binocular images directly into two eyes. Combined with the head tracking equipment, it has the advantage of providing a constant immersion feeling even when the viewpoint is changed by turning the head. Various previous studies and methods for visualizing 3D stereoscopic images have been suggested. Table I summarizes the diverse visualization methods. This study adopts a 3D visualization method using a head-mounted display due to the easiness of implementation and its efficiency.

TABLE. I. VARIOUS 3D STEROSCOPIC VISUALIZATION METHODS

3D Visualization Method	Visualization Equipment	Summary
Anaglyph Stereoscopy	Color glasses	Two differently filtered colored images are viewed through the "color-coded" "anaglyph glasses", one for each eye.
Film Patterned Retarder	Polarized 3D glasses	The optical element controlling the polarization direction of the light called the Patterned Retarder (PR) is attached to the display front side and the light of the different polarization characteristics comes out from even and odd number line of the horizontal direction.
Shutter Glasses Method	3D active shutter glasses	Two screens separating are shown in order on the display. At the same time, when a screen for the right appears in synchronized shutter glasses, the left closes and the right closes when a screen for the left appears.
Head-Mounted Display	VR Headsets	A 3D rendered virtual environment is shown through one or two small displays with lenses and translucent mirrors embedded in headsets, visors or helmets.
Parallax Barrier	No device	The vertical shield is properly placed in front of the screen, and the image using this shield is only reached by the left eye and the other by the right eye.
Volumetric Display	No device	The light is shot in the real space and the flow of the cubic light is made.

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Recently, many studies have been conducted applying 3D stereoscopic visualization methods to various fields. The 3D visualization method using a VR headset is expected to produce superior results in user experience than the 3D visualization method using a flat monitor which is commonly used. If the expected results are actually proven by experiments, it will be a good basis for applying 3D visualization methods in wider and diverse fields.

This study is to analyze through experiments the efficiency of 3D haptic VR technology that provides virtual simulations with 3D stereoscopic images as well as tactile sensations. In order to conduct experiments, the authors developed haptic VR simulations that perform various experiments. These simulations allow for experimenting the object recognition, accuracy of operation, and immersiveness in virtual environments. the authors intend to analyze the effectiveness of 3D visualization methods through three experiments using haptics and virtual reality technology.

The researchers also wish to demonstrate the improvements of the accuracy and the speed of virtual operations by means of various experiments using stereoscopic 3D visualization (3D graphics to visualize on the VR stereoscopic headset) rather than the flat 3D visualization (3D graphics to visualize on a 2D flat display) for virtual simulations.

The rest of this paper proceeds with a short survey of related works. Then, a brief description of virtual simulations used for experiments and some technical considerations are presented. Next, the methods of experiments are briefly explained. Then the results of the experiments are elaborated. Lastly, a comprehensive analysis of our experiments is described. followed on by our conclusion and future work.

II. Related Works

Various core technologies for effective haptic virtual reality simulations are being studied in order to provide training systems for practicing before actual operations. Among many studies, there is a case where a simulation developed to perform elaborate work using a haptic device. This study developed an educational program for the telemanipulation of carbon nanotubes using haptic feedback and a 3D display [2]. Another study proposes a method to evaluate usability and acceptance in the virtual learning environment [3]. There is also a study that reports the development of an interactive immersion environment for educating nanotechnology [4]. And there is a study that the effect of the VR system on academic achievement was evaluated for engineering students. The results of this study showed that academic achievement was significantly higher when the VR system was used [5]. As a result of utilizing a cost-effective smartphone-based VR system for classroom teaching, it is suggested to use VR for leading immersion and realistic learning [6]. An example of an evaluation study is a review of the author's work of 20 years ago that confirmed that achieving experience through VR has a positive impact on worker performance [7].

In the field of medicine, diverse haptic virtual reality surgery simulations are being studied in order to provide medical students and surgeons practicing before the actual surgery. One of the remarkable early studies for surgery training simulators using haptic devices and virtual reality technology can be found in 2007. It is a simulation-based training in minimally invasive surgery (MIS) which allows the trainee touch, feel, and manipulate virtual tissues and organs while viewing images of tool-tissue interactions on a monitor as in real laparoscopic procedures [8]. Also, a dental anesthesia training simulation is developed based on anatomical data [9]. In this study, haptic technology is used for dental treatment technology education. Another example of using haptic equipment and the VR environment can be found in the case of the construction of an online database from the suturing procedures of surgeons [10]. In addition, relevant to cognitive science, a study on the HVDT (haptic visual discriminant test) [11] using haptic virtual reality technology can be noted [12]. This paper presents a possible integration of vision and haptic perception of physically or mentally disabled children.

Another study analyzes the relationship between the 3D position of a three-dimensionally rendered object and the point that touches on the surface [13]. This study demonstrates that users can recognize accurately when touching objects presented in 3D stereoscopic environments then 2D flat environments. There is also a study that addressed the problems that arise when 3D touch applied in a stereoscopic display environment like the flat-screen in a 3D movie theater. This study evaluates the effect of visual conflicts such as vergence/accommodation mismatches and double vision for mid-air 3D selection performance [14]. We can also note a case study for the exploration and information retrieval of scientific articles [15].

Pre-operative training through surgical simulation can have a great effect. However, even if presenting and dealing with 3D objects in a virtual environment represented by a flat monitor, the position of the object on the flat monitor can be much different from what actually seen. The reasons are that there can be distortion on the flat-screen or a lack of perspective. Because of this problem, there is a limit to recognizing the position of objects through a simple 2D plane monitor. In order to practice the operation of the correct movement, intuitive, and precise awareness of the operation position is needed.

III. Virtual Simulations

This study measures how quickly and realistic a user feels if stereoscopic VR is applied to a virtual reality application. In addition, it demonstrates that the factors such as user's immersion, presence, and fun vary depending on the visualization method of 3D VR games. This section describes the implementation issues of the experimental environment and simulations.

A. Implementation Environment

The virtual simulation developed in this study is implemented using a 3D VR head-mounted headset such as Oculus Rift or HTC Vive for 3D visualization. For tactile senses, haptic devices such as PHANToM OMNI[1], PHANToM Desktop[2] , or Novint Falcon[3] are used.

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Basically, this experimental system is implemented C++ language software development environment, in addition to open software tools, such as UNITY Engine[4], CHAI3D[5], OpenGL[6], and OpenHaptics Toolkit[7]. UNITY Engine is a cross-platform game engine for producing content such as 3D video games, architectural visualization, and real-time 3D animation, and it provides functions that are easy to produce for Oculus Rift device programs. CHAI3D is an open-source framework of C ++ library for real-time simulation of computer touch, visualization, and commercialization. CHAI3D is simple in structure, so it can be easily used by beginners with haptic equipment. CHAI3D has the advantage of supporting the same interface regardless of the haptic device. Graphics are based on OpenGL. OpenHaptics Toolkit is also an open-source framework for real-time simulations such as CHAI3D. However, OpenHaptics Toolkit has the advantage of being easy to apply to a 3D engine because it has separate functions based on OpenGL or DirectX.

B. *Simulation Implementation*

There are two perspectives in 3D VR: the first-person perspective and the third-person perspective. In fact, VR in the first-person perspective with haptic feedback increases immersion and intuition than VR in third-person perspective. Meanwhile, in the experiment using HMD, there is a work that shows the result of increasing the efficiency of operation by improving accuracy and work speed [16].

The following three experiments are designed for examining whether the flat visualization or the stereoscopic visualization appear more efficient, accurate, and intuitive when performing them using haptic devices and VR headsets:

1) Intuitive Object Movement
2) Precise Manipulation
3) Immersiveness for Horror Games

For the first two experiments, the researchers developed two virtual simulations in the first-person perspective with haptic feedback. The third experiment is undertaken using a commercial 3D VR game Outlast 2 (Outlast by Red Barrels). Some considerations such as free perspective and collision detection should be resolved for implementing simulations using 3D haptic VR technology.

1) Free perspective: In order to implement simulations for experiments, it is necessary to link a haptic camera with a real camera. Existing OpenHaptics library has limitations in setting the point of view of the haptic camera. However, by using VR, simulations can be conducted from a free perspective. The authors solved the point limit of the haptic camera by adding an attribute value of the VR camera. The UNITY game engine is linked to the CHAI3D library to efficiently manipulate haptic devices and the Oculus Rift DK2.

2) Collision detection: A series of object moving processes need to place objects to the target point. However, to prevent the progress of abnormal experiments due to the phenomenon of unrealistic penetration of rigid objects during the movement process, all of the objects must be set up to be a “collision object”. In addition, the application of our “haptic collision detection method using subdivision surface and sphere clustering” will provide more precise haptic rendering [17], [18]. This way allows you to touch objects with a haptic device and enable collision interactions between objects, thereby preventing impossible movements in reality.

IV. Experimental Design

This section explains the procedure of three experiments. Each experiment has different purposes. The purpose of the first experiment is to examine the degree of intuitiveness for object recognition in a stereoscopic 3D environment. On the second experiment, the accuracy and efficiency of precise operation is the main measurement of the experiment. The last experiment is about the relationship between immersiveness and stereoscopic vision.

A. *Intuitive Object Movement*

Define intuitive recognition of objects can influence the operational performance in 3D VR environments. The first experiment places various objects into the corresponding containers of their own shape. In this experiment, examinees move a cube to the open box, a soccer ball to the trash can, and a block of Jenga from the tower of Jenga blocks. Those objects are paired together for moving operations. The experiment compares the time until the first haptic pointer touches the object and the finish time when all objects are located at the given position. Fig. 1 and Fig. 2 show the simulation and a screenshot for the first experiment, respectively.

B. *Precise Manipulation*

Surgery training, such as vascular sutures, requires a high degree of precision using the appropriate medical instruments. The second experiment is to interconnect two blood vessels for vascular suture experience. The examinees move blood vessel objects on the right using the haptic device. The left blood vessel cannot be moved, and it is for connecting the right part of the blood vessel. Only the right blood vessel can be operated to be connected. This experiment compares the time until the haptic pointer touches the right object first and the final time until the right blood vessel reaches the appropriate position of the left blood vessel. Fig. 3 and Fig. 4 presents the simulation and a screen capture of simulation for the second experiment.

C. *Immersiveness for Horror Games*

According to a study on the immersion in digital games, immersion is a confluence of different psychological faculties such as attention, planning, and perception that, when unified in a game, lead to a focused state of mind [18]. However, the authors intend to quantitatively measure the immersiveness. In clinical studies, heart rate variability (HRV) is used as one of

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the evaluation methods for autonomic nervous system change [19].

The third experiment observes the differences in human emotional responses when playing a horror game equipped with or without a VR headset. The game used in this experiment is Outlast 2, and it is tested twice for each examinee. The first is to play without a VR headset and the second is to play with a VR headset. It takes about 15 minutes after the start of the game including the introductory tutorial. In this experiment, the fear felt by users is measured by the number of blood pulses. the authors capture the change of the users' heart rate to evaluate their emotional immersiveness. The minimum, maximum, and average pulse rates are compared between the two trials.

Fig. 1. Performing Intuitive Object Movement Simulation.

Fig. 2. Screenshot of the Simulation of Intuitive Object Movement.

Fig. 3. Performing Precise Manipulation Simulation.

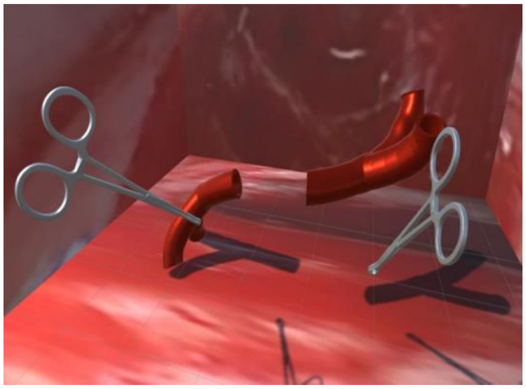

Fig. 4. Screenshot of the Simulation of Precise Manipulation.

V. Experimental Results

The examinees are divided into two experimental groups; Novice and Expert. This grouping is based on their intimacy with 3D environments. Before the actual experiment, the examinees are given a preliminary explanation of the process of experiments. After the experiments are pre-practiced, the actual experiments are repeated three times for each examinee. Then the average value was measured to reduce the effect of the operational errors.

A. Intuition for Object Movement

The measurement data for the first experiment are as follows:

- The time for positioning the haptic pointer to the target object to move.
- The time for positioning the target object to be moved to the exact target point after detection of the starting point.

This experiment is to analyze the operational efficiency by measuring the duration for intuitively recognizing an object, and then moving an object to the target point. The chart in Fig. 5 calculates the average value of the flat 3D and the stereoscopic 3D experimental results. The starting point search time shows that 23.27% (2.76 seconds) in the Novice group, 25.95% (1.98 seconds) in the Expert group, and the average search time in stereoscopic 3D is reduced by 24.33% (2.37 seconds) compared to the flat 3D.

In object movement time, the results of stereoscopic 3D experiments were reduced in all experimental groups. The manipulation time reduction rate was about 13.83% (0.65 seconds) in the Novice group, 19.31% (0.62 seconds) in the Expert group, and 16.16% (0.64 seconds) on average. Note that the average reduction rate of the Novice group is 14.17% (2.32 seconds), while the average reduction rate of the Expert group was 28.02% (3.61 seconds), much higher than the average reduction for the Novice group. In addition, the total experimental time shows an average reduction rate of 20.24% (2.96 seconds).

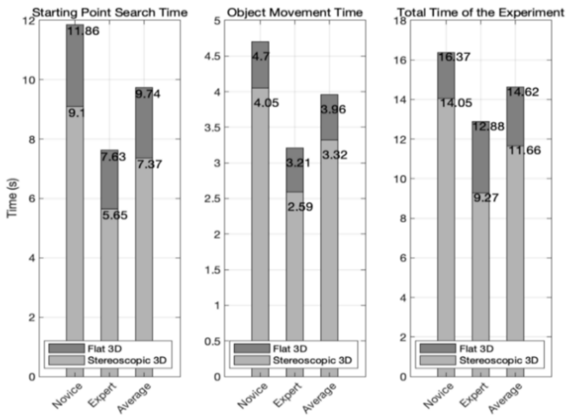

Fig. 5. The Starting Point Search Time, Object Movement Time, and Total Time of Intuitive Object Movement Experiment for Novices and Experts based on their Intimacy with 3D Environments.

The results of the first experiment above show that starting point search time is clearly better in the stereoscopic 3D than the flat 3D. It shows that users can recognize the position of the object more quickly in the stereoscopic 3D VR visualization. However, the time duration of reaching the target point after recognizing the position of the object does not differ greatly. The reason is that object manipulation time differs according to the examinees' ability to search rather than the dimension of visualization.

In this first experiment, the Expert group shows a higher reduction rate than the Novice group. It means that the more familiar the examinee is with the stereoscopic 3D environment, the more intuitive the perception can be.

B. *Precise Operation of Blood Vessels*

The followings are measurement data of the second experiment:

- The time for positioning the haptic pointer to the right blood vessel to move.
- The time for placing the right blood vessel to reach the junction of the left blood vessel.

Experiments measured the accuracy of the simulations to be required for surgery. In addition, the operational efficiency is also examined through the experiment of moving the object to the target point after recognizing the object.

In the second experiment, the starting point search time is faster in a stereoscopic 3D environment on average. That is, the starting point search time has decreased by 19.17% (1.98 seconds) in the Novice group, 19.97% (1.52 seconds) in the Expert group, and 19.6% (1.76 seconds) on average. In addition, the object movement time showed a reduced rate of 5.87% (0.24 seconds) in the Novice, 12.46% (0.35 seconds) in the Expert group, and 8.7% (0.295 seconds) on average. The average reduction rate has appeared at 18.02 % (1.88 seconds) in the Expert group and 15.33% (2.21 seconds) in the Novice group. The total duration of the operation in the stereoscopic 3D visualization showed an average reduction rate of 16.57% (2.06 seconds) compared to the flat 3D visualization as presented in Fig. 6.

The first indicator shows improvement of intuition in 3D stereoscopic visualization compared to that of flat 3D visualization. From the second indicator, the authors can understand that the time to recognize an object and manipulate the haptic device for moving it in a stereoscopic 3D environment is higher than that of a flat 3D environment. Nevertheless, the absolute value of the time shows a small reduction of less than just one second on average. It means that the stereoscopic 3D visualization does not give a significant improvement in accuracy compared to the flat 3D visualization. This can lead us to conclude that the 3D stereoscopic visualization has a higher improvement in the intuition of recognizing the object than the flat 3D visualization. However, in the process of performing the precise work, stereoscopic 3D visualization does not show significant improvement than the flat 3D visualization.

In the second experiment, the Expert group had a slightly higher value of the reduction rate of time than the Novice group. The actual value of the absolute time decrement was larger in the Novice experiment group. This result shows that there is no correlation between the degree of intimacy and the degree of improvement of accuracy in the 3D environment when the precise work is performed.

C. *Immersiveness for Horror Games*

In the previous two experiments, data are recorded in units of time to analyze the accuracy of object recognition. The third experiment checks the following data to analyze immersion:

- The average heart rate of examinees at the simulation being performed
- The heart rate in three emotionally sensitive sections of the most fearful parts

The examinees are divided into the following two groups:

- Wearing a VR headset initially
- Wearing a VR headset subsequently

In the third experiment, the heart rates of the examinees are used as the major indicator, unlike the previous two experiments, and recorded in beats per minute (bpm). The reason behind dividing the experiment groups in terms of wearing a VR headset initially or subsequently in the third experiment is to normalize the variability of the heart rate that may possibly arise from being immersed in a virtual environment with or without the prior knowledge of the content.

In Fig. 7, the authors can recognize that the overall heart rate of the group that wore a VR headset initially is generally low in a flat 3D environment compared to the stereoscopic 3D environment. The Novice group showed a reduced rate of 5.34% (4.44 bpm) and the Expert group showed a 9.08% (6.74 bpm) increased. The heart rate was increased by 11.49% (8.75 bpm) on average. For emotionally sensitive sections, the heart rate of the Novice group decreased by 7.55% (6.5 bpm) and that of the Expert group also increased by 13.05% (9.93 bpm). On average, it was increased by 13.3% (10.3 bpm) in emotionally sensitive sections.

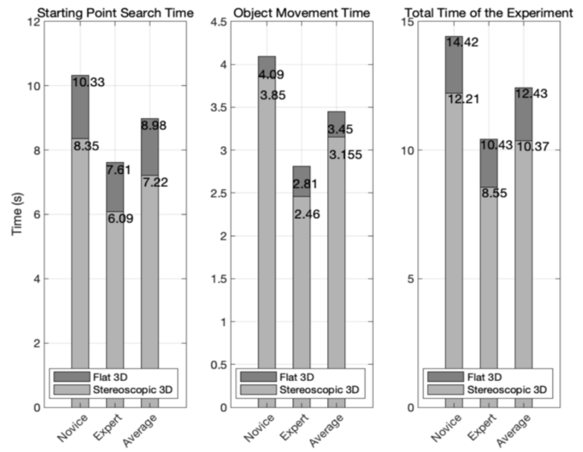

Fig. 6. The Starting Point Search Time, Object Movement Time, and Total Time of Precise Manipulation Experiment for Novices and Experts based on their Intimacy with 3D Environments.

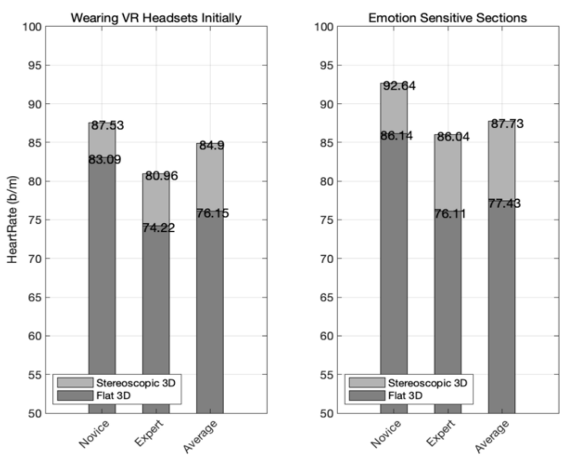

Fig. 7. Results for Heart Rates of the Group Wearing a VR Headset Initially.

As summarized in Fig. 8, the experiment in the experimental group that used a VR headset subsequently, the heart rate of the Novice group increased by 7.95% (6.48 bpm) and that of the Expert group increased by 4.85% (3.6 bpm). The result also showed a 6.74% (5.23 bpm) cardiac rate reduction on average compared to the stereoscopic 3D environment in the flat 3D environment. In addition, the heart rate in the emotion sensitive sections also showed a reduction of 7.74% (6.58 bpm) in the Novice group and a reduction of 4.83% (3.75 bpm) in the Expert group. The heart rate increased by 7.4% (5.9 bpm) on average. Overall, regardless order of wearing headsets, the average heart rate of wearing a VR headset was 83.28bpm and the average heart rate of using a flat monitor was 77.81bpm totally increased by 7.03% (5.47 bpm). And in the emotionally sensitive section, the average heart rate of wearing a VR headset was 87.65bpm and the average heart rate if using a flat monitor was 80.71bpm totally increased by 8.60% (6.94 bpm).

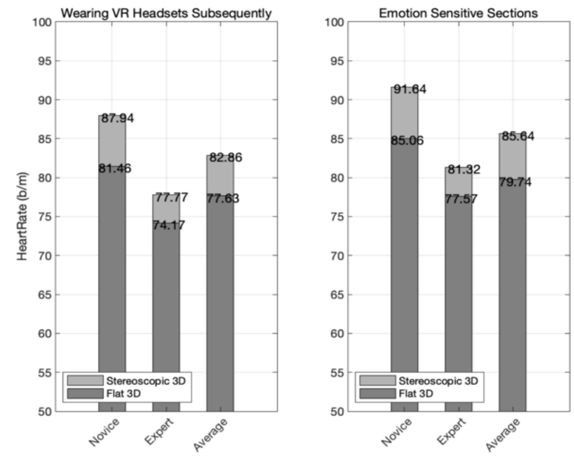

Fig. 8. Results for Heart Rates of the Group Wearing a VR Headset Subsequently.

TABLE. II. AVERAGE OF HEART RATE REDUCTION RATE ACCORDING TO THE ORDER OF WEARING A VR HEADSET

Experiment	Average of the Entire Operation	Average of the Emotion Sensitive Sections
Wearing a VR headset Initially	11.49% (8.75bpm)	13.3% (10.3bpm)
Wearing a VR headset subsequently	6.74% (5.23bpm)	7.4% (5.9bpm)

The results of the third experiment were summarized in Table II. Both experimental groups showed a higher heart rate in a stereoscopic 3D environment. There is a difference in the reduction rate between the groups. The group that used a VR headset initially showed a greater difference in heart rate in immersion than the group that used VR headset subsequently. In the group with VR headset subsequently, it can be confirmed that the prior experience of the experiment in the flat 3D environment influenced the experiment in the stereoscopic 3D environment.

Based on the above experiment, the authors noticed that the VR immersion in the stereoscopic 3D visualization is stronger than the VR in the flat 3D visualization. In addition, it was confirmed that the degree of heart rate in the stereoscopic 3D visualization is much higher than the flat 3D visualization even in the emotionally sensitive sections.

VI. COMPREHENSIVE ANALYSIS

The three experiments above lead us to conclude that it is more efficient and intuitive to identify the three-dimensional position of a virtual object in stereoscopic 3D visualization rather than the flat 3D visualization in general. However, the authors could not find a consistent reduction rate difference between Novice and Expert groups. This implies that the intimacy of the stereoscopic 3D environment does not significantly influence the difference of immersion in the virtual environment. Table III is a comprehensive summary of the experimental results. In all three experiments, stereoscopic 3D visualization showed excellent overall results. However, in the precision manipulation experiment, the improvement of stereoscopic 3D visualization was relatively insignificant.

TABLE. III. EXPERIMENTAL RESULTS OUTLINE

Experiment	1st Experiment Intuitive Object Movement	2nd Experiment Precise Manipulation	3rd Experiment Immersiveness for Horror Game
Data Acquisition	Starting point search time (second) Object movement time (second)	Starting point search time (second) Object movement time (second)	Heart rate (bpm)
Intuition	The overall average shows a 24.3% reduction of the total operation time in the stereoscopic 3D environment.	The reduction of the total operation time by 19.6% is obtained in the stereoscopic 3D environment.	• Comprehensive evaluations in both groups (with a VR headset initially or subsequently) resulted in a 6.56% increase in heart rate in the 3D stereoscopic environment. • In the 3D stereoscopic environment, an increase in heart rate of 7.92% occurred in three emotionally sensitive sections.

What we need to discuss through the experimental results is that operations in 3D stereoscopic environments can give a similar experience of operations in the real world. This allows us to experience difficult, expensive, or dangerous operations in the real-world with the help of 3D stereoscopic simulations in VR. However, VR has different control variables compared to the real world. For example, VR has not yet such control variables as temperature or noise compared to the real world.

The stereoscopic environment using VR headsets has diverse influencing factors including immersiveness, intuition, and accuracy that studied in this paper. However, there are several other factors that influence users in 3D stereoscopic environments. In future work, the research on the measurement of other influencing factors is needed.

VII. CONCLUSION

In this study, the authors analyzed the improvement of efficiency, accuracy, and immersiveness of stereoscopic 3D visualization through diverse experiments. The plane 2D monitors can be used to represent 3D graphics objects in virtual environments, however, the location of virtual objects that users perceive may be different from the actual location of the virtual object. The degree of distortion, perspective, and immersion make these differences. By presenting a virtual environment as a stereoscopic 3D objects using a VR headset, the intuitive operation performance has been improved and especially operational accuracy has been greatly enhanced.

The results of three experiments conducted in this work showed that the first experiment improved the intuitiveness of the examinees wearing a VR headset. However, the second experiment showed that the accuracy of the examinees who wear a VR headset does not improve meaningfully in the elaborate work requiring accuracy. In the third experiment, the results of the improvement of immersion were observed in the group who wear a VR headset. This study leads us to conclude that the intuition and the immersiveness are outperformed in the case of the stereoscopic 3D visualization using a VR headset. It is also expected that the training effect will be maximized when performing in stereoscopic environments equipped with a VR headset for intuitive and cognitive training using haptic technology.

In this study, the authors experimented only with simple simulations that experience the movement of objects and game simulation. In future work, the authors will examine whether the authors can experience the same effect even if it is applied to complex and collaborative simulations, such as wargame simulation. Meanwhile, some examinees complained of cybersickness in the experiment using a VR headset. Future studies will endeavor to solve the cybersickness that may arise in the stereoscopic visualization method using the HMD.

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