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Correction of Depth Perception in Virtual Environment Using Spatial Compnents and Perceptual Clues

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공간 구성요소 및 지각단서를 활용한 가상환경 내 깊이지각 보정

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Abstract As the education and training is such a virtual environment is applied to various fields, its usability is endless. However, there is an underestimation of the depth of perception in the training environment. In order to solve this problem, we tried to solve the problem by applying the top-down correction method. However, it is difficult to classify the result as a learning effect or perception change. In this study, it was confirmed that the proportion of spatial components of urine had a significant effect on the depth perception, and it was confirmed that the size perception were corrected together. In this study, we propose a correction method using spatial component and depth perception to improve the accuracy of depth perception.

Key Words : Virtual environment, Depth perception, Spatial components, Top-down correction, Bottom-up correction

요 약 가상환경을 활용한 시뮬레이션과 같은 교육, 훈련 등이 다양한 분야에 적용되고 있는 만큼 그 활용성은 무궁무진하다. 하지만 가상환경에서 훈련을 함에 있어 깊이지각의 과소추정이 존재하며, 이는 향후 훈련의 타당도에 문제가 될 수 있다. 관련 연구에서는 이를 해결하기 위해 하향식 보정방안을 적용하여 문제를 해결하려 하였으나 그 결과가 학습에 의한 효과인지 실제 지각의 변화인지에 대한 구분이 어렵다는 단점이 있다. 이에 본 연구에서는 실험결과를 통하여 공간 구성요수 중 비례가 깊이지각에 유의미한 영향을 끼치는 것을 확인하였으며, 비례와 깊이지각 단서를 함께 보정하여 실험할 경우 깊이지각 중 크기지각이 매우 정확해진다는 것을 확인하였다. 이에 본 연구에서는 깊이지각의 정확도를 높이기 위해 공간 구성요소와 깊이지각을 활용한 보정방안을 제시한다.

주제어 : 가상환경, 깊이지각, 공간 구성요소, 하향식 보정방안, 상향식 보정방안

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1. Introduction

1.1 Virtual Reality Utilization Status

With the advent of 5G and the fourth industrial revolution, virtual reality has been applied and used in various fields. Typically, in the game industry, games utilizing virtual reality are emerging, and the entertainment industry is actively taking advantage of them. In the manufacturing industry, it is possible to design an efficient process by planning and adjusting processes and assembly processes using virtual reality [1].

The reason why virtual reality is attracting attention is that it is possible to simulate situations that are difficult to actually happen or urgent situations, and to learn about repetitive actions and coping methods.

1.2 Depth Perception Problem in Virtual Reality

In a virtual environment, it is important to have experience similar to the actual situation for realistic simulation [2]. However, according to Lécuyer et al., The object size of a virtual space on an HMD (Head Mounted Display) is smaller than the size of an actual object. Also, it is repeatedly verified that there is a tendency to underestimate the distance in virtual reality [3]. Underestimation operates on simulations and creates distortions in distance and size. Distortion is a question of the reliability and validity of results for simulation and user experience.

In this study, we try to find a correction method to have depth perception similar to reality in virtual environment. For this purpose, we identify the major factors affecting the depth perception in the virtual environment, among spatial components and perceptual clue factors, and conduct calibration experiments according to major factors and user characteristics. The purpose of this study is to construct.

2. Background and Related Research

2.1 Virtual Reality and Depth Perception

Virtual reality refers to a user's interaction with a virtual environment based on a virtual environment and feeling 'Presence' as a reality. Virtual reality is a realistic virtual environment. Presence means that it is present in Hear and now, to make it feel like it is here in the virtual environment, and to cause behavior similar to the actual situation. Behavior similar to the actual situation is effective for simulation training through iterative proficiency [4].

Depth perception is the perception of the depth of space. In this study, we focus on the most influential size perception and distance perception. Although there has not been much research on actual size perception, in the real world, research has shown that size-distance invariance theory provides consistent depth perception and distance perception [5].

2.2 Space Component

Space component is a common component that constitutes the sense of space in the fields of interior architecture, environmental psychology, ergonomics, and perception factors [6]. Although it is difficult to define the sense of space as a few factors, we have selected elements that are commonly defined in various fields above. This is shown in Table 1 below.

Table 1. Spatial components

Field	construct	Human psychological behavior	interior architecture
size	○	○	○
proportion	○	○	○
material	○	○	○
light	○	○	○
domain	○	○	
opening	○	○	○
noise		○	○
furniture	○		○

experience	○	○	
Field	ergonomics	Environmental Psychology	Perception element
size	○	○	sight
proportion	○	○	sight
material	○	○	sight, touch
light	○	○	sight
domain		○	sight, mentality
opening		○	sight
noise	○	○	auditory
furniture	○		sight, touch
experience		○	mentality

In this paper, we have selected space elements, space, proportions, materials, lighting, openings, noise, furniture, etc. The size refers to the size of the space, and the proportion refers to the size of the object in proportion to the size. The lighting means the intensity of the brightness, and the opening means the extent of the wall.

2.3 Depth Perception Clue

The world is made up of three dimensions, but the image projected on the retina is a two-dimensional image. The human being interprets the information given in two dimensions and intends to understand it in three dimensions, which is a concept that includes both distance perception and size perception. That is, the distance perception affects the size perception, which is a clue to the fact that the size of the image on the retina does not actually change in size. In order to aid distance perception and consistent size perception through depth perception, various clues are used, and the clues are called depth perception clues [7].

The depth cognitive clue is divided into binocular cocoon and unicorn cocoon. The binocular cocoon refers to perception of depth through physiological intersection due to difference of position of both eyes due to difference of position of both eyes. Unilateral cocoon is controlled by perspective. There are various clues such as motion parallax, linear view, superposition, and so on [8]. These depth perception cues are described in Table 2.

Swan et al. Explained that depth perception is achieved through the integration of several visual cues. Visual features, individual signals and signals are processed by a visual processing system and perceived depth as a way to create a coupled three-dimensional perception world in the brain [9].

Table 2. Depth perception clue

Perceptual Elements	Depth perception clue	Explanation	Bino cular / mono cular
Relative depth perception clue	Relative size	Relativity of size	mono cular
	block	Nearest thing covered away	mono cular
Absolute depth perception clue	Control and convergence	Tension of eye-regulating muscles	Bino cular
	Binomial discrepancy	Differences in images formed on the retina	Bino cular
	Exercise time difference	The closer it appears to move faster	mono cular
	Linear view	A parallel straight line converges towards the vanishing point	mono cular
	Atmospheric view	The farther away the blur looks	mono cular

Research on depth cues has been conducted several times, and it has already been confirmed that more depth cues lead to more accurate depth cues. Therefore, in this study, we want to add insufficient depth perception cues in the generation of depth perception correction model.

2.4 Depth Perception Correction Method in Virtual Environment

Various methods have been tried to correct the depth perception in the virtual environment. There are two ways to overcome underestimation. Top-down and top-down. The bottom-up method modifies the given stimulus to reduce the underestimation, and the top-down method changes the response to the stimulus. For example, feedback or training can be used as a method.

The top-down method was experimented by the method proposed by Richardson and Waller (2005), the blind walking method, and the behavior was corrected by giving feedback on the user's underestimation via computer [10]. In fact, this training has shown better results. However, it was unclear whether the actual perception was different or better, or whether it was merely a training effect.

Bottom-up method was confirmed by Witmer and Sadowski(1998) [11]. The reason for the underestimation is suggested that there are reasons for HMD brightness, graphic quality, field of view (FOV) and so on. Sarah et al.(2015) reported that distance-based assessments were consistently underestimated, regardless of HMD, by comparing costly and low-cost equipment. Therefore, the context of the environment should be considered as an element of the absolute scale in the virtual environment [12].

In this study, we try to establish a correction model by using the bottom - up correction method which corrects the depth perception by modifying the context of the surrounding environment rather than the top - down correction method involving the learning effect.

3. Methodology

3.1 Research Outline

The outline of the experiment is shown in Fig. 1 below. In Experiment I, it is aimed to select valid elements for depth perception in a virtual environment among spatial components. In the previous research, the size and the proportion of the space are selected and designed.

In Experiment Ⅱ, it is divided into two steps. The first step is to check whether there is a difference in depth perception depending on the presence or absence of the depth perception cue. The difference between the first condition in which the depth perception cue is not given and the second condition in which the depth perception cue is given is observed. In the second step, the spatial component selected in Experiment I is used as a calibration model, and the depth perception cues are applied equally to Conditions II and III. Analyze the difference between condition ii and condition iii to verify the validity of the calibration model.

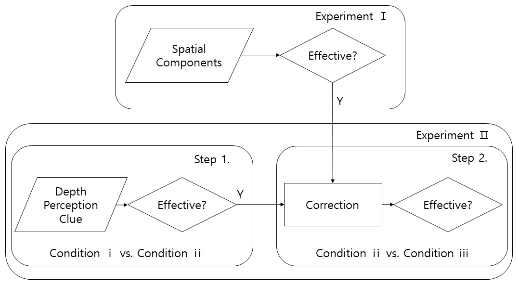


Fig. 1. Outline of experiment

3.2 Experimental Tools

Experimental tools used in this paper consist of virtual environment and output device. The virtual environment stimulus is similar to reality, and it is intended to provide a stimulus that can interact with the virtual environment in order to make it immersive [13]. To do this, we created a virtual environment using Unreal Engine 4, a program with high graphics quality and support for the VR platform [14].

3.3 Data Collection

The information that can be obtained from the virtual environment can be collected by analyzing the information that appears by interacting with the user's movement and the virtual environment. This information is utilized in a user's behavior pattern, usability evaluation, simulation, and the like in a virtual environment, and the technology continues to evolve. There are many ways of analyzing the information that can be obtained from the multifaceted virtual environment, but it is difficult to extract the psychological factors that users feel from the collected data.

In this study, we tried to apply these limitations to the real - time correction work by collecting real - time data of the subjects using the controller. For this purpose, we first analyzed the collected information in real time. Data in the virtual environment is collected over at least 600 ticks per minute, including the tick, the HMD position, the controller position and vector, the distance between the controllers, and the distance between the controller vector and the target box.

In order to find a way to correct the error of the depth perception in the virtual environment through the error value of the perceived position of the cube, Perception variables were set.

In the virtual environment, the tick is set to 0.1 second, and about 600 times per minute is collected to increase the accuracy of the information. It also sets the controller's trigger's T / F so that it can extract values for the size and position that the subject expects. The extracted information was used as mean value for each trial.

In Experiment I, depth perception measurements were measured through a trigger, and analyzed using two-way ANOVA using the size and proportions of space according to each condition.

In Experiment II, we measured the size perception and distance perception using triggers. The condition was carried out under three conditions: condition without the cues, interaction with the cues, but not with the correction effect, interaction with the cues, and correction.

In this experiment, the blind pedestrian performance is the same as the experiment of Interrante (2006), which performed the virtual environment experiment for the depth perception in the virtual environment by covering the eyes and walking to the target position [15].

3.4 Analysis Method

A variety of analytical methods are needed to analyze the data collected in this study. The Levene test was performed to test the equally distributed analysis of the data collected in Experiment I. Levene Test is performed to confirm that the variance among groups is the same.

Two-way ANOVA analysis was performed to determine the influence of spatial components through the data collected in Experiment I. The two-way ANOVA is a statistical analysis for analyzing the data collected in two conditional variables. The two-way ANOVA is a statistical analysis that verifies the degree of influence of one treatment variable on the dependent variable, . & Lt; / RTI & gt;

In Experiment Ⅱ, Bartlett test was performed for equidistant test according to each condition. The Bartlett test used a uniform distribution test for different distributions that are independent of each other.

4. Results

4.1 Experiment Ⅰ : Explore depth perceptual space components

In order to investigate the main factors influencing the depth perception in the virtual space, the virtual environment was set up using the components of the space. As Shin Yoo-jin (2005) confirmed in previous studies, the perceived virtual environment is more accurate than the actual environment, and the depth perception becomes more accurate. However, it is difficult for HMD to output the same resolution as a human eye. Presenting a photograph of a real environment emphasizes a real environment and a gap in interaction in a virtual environment, resulting in an error in depth perception.

4.1.1 Subject

The purpose of this experiment Ⅰ is to search the components of the main space in the depth perception in the virtual environment. Therefore, those who have difficulty in depth perception in the real environment are excluded from the experiment. Were excluded from the experiment. The total number of subjects was 20, and the average age was 27.4 years. The collected data were assumed to be equally distributed through the Levene test.

4.1.2 Virtual Environment and Experimental Design

The virtual space was created using the Unreal Engine, and the system was constructed using Blue print, a visual script function of UE4, to collect data. The virtual environment is constructed as shown in Fig. 2 below.

The size of the virtual space, which is considered to affect the depth perception in the virtual environment, is set to the size of the room and set to three stages: 5m × 5m × 2.3m, 6m × 6m × 2.7m, and 7m × 7m × 3.3m. In addition, the proportion was set as the size of the box for estimating the size, and the experiment was performed by setting the size as 50 cm × 50 cm × 50 cm, 60 cm × 60 cm × 60 cm, and 70 cm × 70 cm × 70 cm.

Fig. 2. Experimental virtual environment

4.1.3 Experimental Procedure

If there is no problem of depth perception, it gives time to familiarize with virtual space and controller by giving one minute to search in space given after wearing HMD. Three exercises were carried out to familiarize you with the measurement method. Each experiment was conducted wirelessly under 9 conditions.

The experiment started with the HMD screen turning off and the subject pulling the trigger. Pulling the trigger turns on the HMD. At this time, the size of the room and the size of the box were set according to the wireless conditions. The subject stood at the origin in the virtual space and stretched both hands and pulled the trigger to gauge the size of the box. After the measurement was completed, the position of the box was checked, the HMD screen was turned off, and at random for at least 10 seconds, the position of the box was pointed with the right hand and the trigger was pulled. The experiment was performed under 9 conditions, and the experiment was repeated 18 times according to the brightness. Depending on the individual differences, the experiment was conducted for about 40 minutes, including breaks if necessary.

4.1.4 Experiment Result

Levene test was performed for each measured value to check whether the measured value for the depth perception assumes equal distribution. As a result of the test, each of the measurements showed a p-value of more than 0.05.

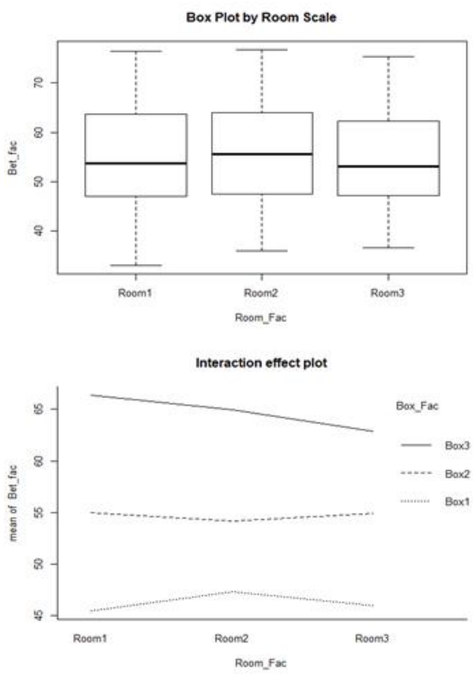
Two-way ANOVA was performed on the estimated box size according to the conditions in the virtual environment in order to investigate whether the change in the size and proportions of the space in the virtual environment affects the depth perception. The results are shown in Table 3.

Table 3. Two-way ANOVA results of box size estimates

	DF	Sum Sq	Mean Sq	F Value	Pr(>F)
Room	2	35	18	0.325	0.723
Box	2	10261	5130	94.816	2e-16 ***
Room :Box	4	130	32	0.598	0.664
Residuals	171	9253	54		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

The result that the change of proportionality according to the condition becomes the condition to distinguish the change of the box size was significant. It can be seen that as the proportion increases in the virtual environment, regardless of the size of the space, the estimate of the box size also increases. This means that size perception and distance perception are independent in size-distance invariance, and is the same as previous Kim Eu-Gene (2003) [6].



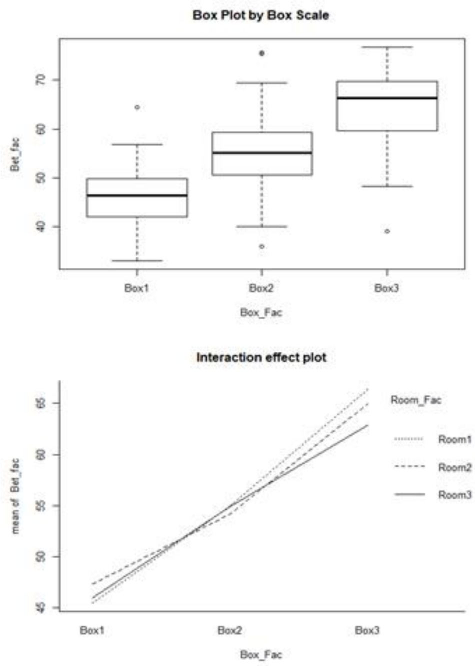


Fig. 3. Two-way ANOVA of box size estimates

The Scheffe test was used to confirm the difference in the mean, which showed that the size of the box was significantly changed, and that the size was significantly underestimated. As a result, it can be seen that the size change of the cube in the virtual environment clearly affects the size perception, and the estimate of the size is underestimated by about 10%. The results are shown in Fig. 4.

```
Study: Box_fac_ Estimate of Box Scale

Scheffe Test for Bet_fac

Mean Square Error  : 54.10972

Box_Fac,  means

      Bet_fac      std  r      Min      Max
Box1 46.25916 5.856400 60 33.02852 64.48652
Box2 54.69723 8.113999 60 35.99651 75.68420
Box3 64.73027 7.712522 60 39.16316 76.75778

Alpha: 0.05 ; DF Error: 171
Critical Value of F: 3.048833

Minimum Significant Difference: 3.316338

Means with the same letter are not significantly different.

      Bet_fac groups
Box3 64.73027      a
Box2 54.69723      b
Box1 46.25916      c
```

Fig. 4. Scheffe Test Results

In this experiment, we tried to select spatial components that affect the depth perception in a virtual environment. This shows that the proportional effect significantly affects the size perception. Also, although it was not significant, it was found that the error of the depth perception tended to increase as the space became larger. As the box size increased, the error of the depth perception decreased. These results are used to correct the depth perception in the virtual environment.

4.2 Experiment Ⅱ : Depth Perception Calibration and Experiment

In Experiment I, the proportion of the spatial components influencing the depth perception in the virtual environment has a significant effect, and the depth perception varies with the spatial extent. In Experiment Ⅱ, two steps were used to find the error of depth perception using individual spatial components and to correct it.

In Experiment II, two conditions were satisfied. In Experiment Ⅱ, we applied the correction using the depth perception cues and the proportions because the expected space size in Experiment I did not have a meaningful result.

We applied unilateral clue to the depth perception clue and applied familiar size, relative size, linear view, exercise parallax, and atmospheric view. As shown in Table 4, it was constructed in a virtual environment according to the distance according to the effect of unidirectional clues.

Table 4. Effects of depth perception cues on distance

Monocular Cues	0~2m	2~30m	30m+
Superposition	O	O	O
Relative Size	O	O	O
Linear perspective	O	O	O
Motion parallax	O	O	-
Atmospheric perspective	-	-	O

In the calibration model, the error value was extracted from the estimated size (k) of a 50 cm × 50 cm × 50 cm cube in the virtual space, and the size of the cube was modified by applying a proportional method. Neceri. A et al. Reported that size estimates could lead to underestimation of up to 20%. [9] The correction value of the underestimation was set to 20% at maximum, and this correction was applied to the proportion of the cube to compensate for the depth perception of the individual.

4.2.1 Subject

The purpose of this experiment Ⅱ is to test the calibration model and exclude those who have difficulty in depth perception in real environment like experiment Ⅰ and recruit them regardless of virtual environment experience. The subjects were 20 persons and did not share groups to perform all conditions.

4.2.2 Virtual Environment and Experimental Design

The clues of depth perception can be classified according to the context of the given environment. To do this, we set the condition Ⅰ and environment that cut off the context of the environment and set the condition iii, which is a combination of interaction - free condition and context - correcting factor. The contents are shown in Table 5 below.

Table 5. Conditional Correction Element

	condition i	condition ii	condition iii
Interaction	○	○	○
Depth perception cues (context of environment)	×	○	○
Calibration of spatial components	×	×	○

The virtual environment was built using the Unreal Engine, and a virtual environment was built according to the conditions. In condition i, the walls were all white, and the bottom was gray for visibility and black for one wall. The size of the room was judged to have little influence on the size of the room as confirmed in Experiment I, and was set to 5m × 5m × 2.3m similar to the room size of the experimental space.

In the case of condition Ⅱ, the same environment was established to provide the context of the environment. However, in order to obtain the correction value obtained in condition ii, it precedes condition iii. In order to limit the learning effect, the interaction time was set within 10 seconds. In order to provide depth cues, we set up an atmospheric sight cue by placing an opening (window) to the outside environment, and set familiar size bookshelves and entrances to provide clues to the familiar size.

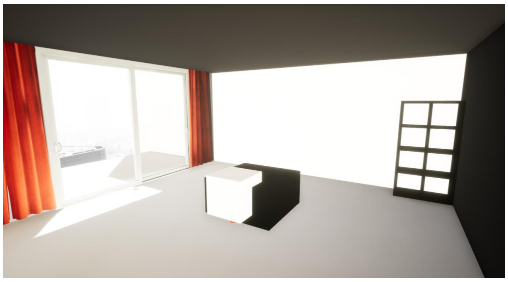


Fig. 5. Condition ii virtual environment

In condition iii, there is no noticeable change in the virtual environment because the conditions such as the context of the virtual environment are the same. However, the proportion of the cube, the target of size estimation and distance estimation, has changed. This is shown in Fig. 6.

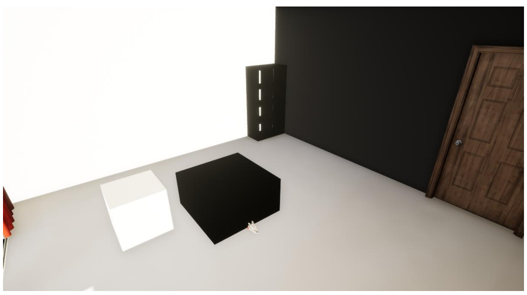


Fig. 6. Condition iii virtual environment

4.2.3 Experimental Procedure

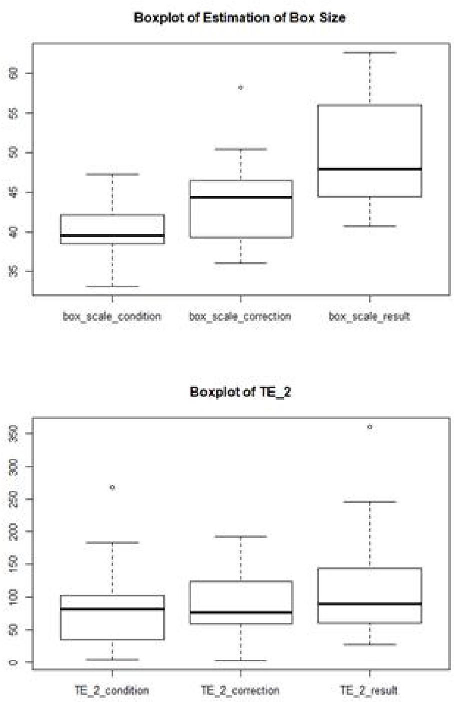
The procedure of Experiment Ⅱ was the same as Experiment Ⅰ, and it was confirmed whether or not the vision test and consent form were written and the depth perception problem. In case of no problem, we conducted the experiment and gave the learning time to get used to virtual space and controller for about 1 minute. Each experiment was classified into treatment condition and non−treatment condition, and condition ii was preceded by condition iii, so that the order of condition i and condition ii was wirelessized.

The experiment started with the HMD screen turning off and the subject pulling the trigger. Pulling the trigger turns on the HMD. At this time, the presence or absence of the depth perception cue was set according to the conditions set by radio. The subject started from the origin in the virtual space. First, both hands were opened and the trigger was pulled to gauge the size of the cube. After the measurement was completed, the position of the box was confirmed, the HMD screen was turned off, and a random movement was performed for at least 10 seconds. Then, the position of the box was pointed with the right hand and the trigger was pulled. In condition Ⅱ, the degree of underestimation of the size of the cube is analyzed in proportion to the size of the cube. The experiment was conducted under three conditions, and depending on the individual difference, the experiment was carried out for about 40 minutes including rest if necessary.

4.2.4 Experiment Result

The design of the experiment was set up in two stages. In step 1, we set the condition with the presence or absence of a depth perception cue to verify the effectiveness of the depth perception cues. As described in previous research, it was expected that the depth perception would be more accurate as the depth perception leads to more, so it was set as a step for excluding the practice condition and the learning effect. At this stage, the difference between condition ⅰ and condition ⅱ was confirmed. In the second step, the difference between the error value of the depth perception of the individual and the depth perception error value of the condition ⅲ using the correction model is tested based on the data collected in the condition ⅱ.

Fig. 7 shows the results of the box plot according to the conditions. The box plot shows the box size of the box predicted by the subject. The Box plot of Estimation of Box Size is the box size predicted by the subject. Finally, in the bottom right corner, 'Box plot of between Camera and Cube' is the distance between the camera and the cube predicted by the user and is the result of the blind press test.



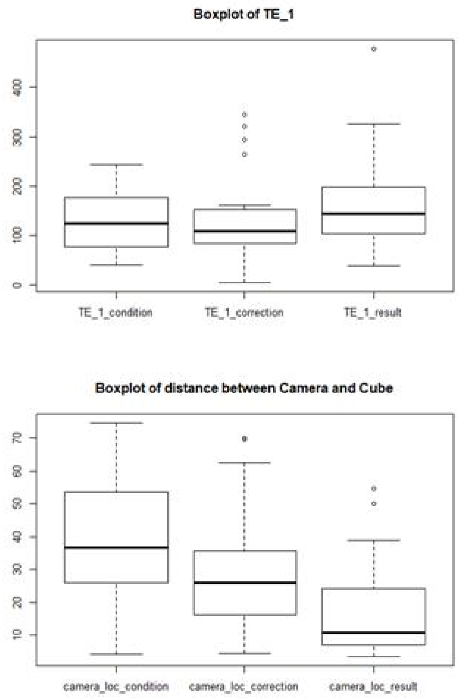


Fig. 7. Box figure of four measurements

Unlike Experiment I, the experiment was divided into two stages. In the first stage, the condition Ⅰ, in which the correction factors such as depth perception element and spatial element were not applied, and the condition ⅱ, in which the depth perception element was applied, Verify the effects of the perceptual clues. As described in previous research, it is necessary to verify the accuracy of depth perception in a virtual environment as the number of depth perception increases, to perform the exercise step to adapt to the virtual environment, and to generate the correction model to be applied in the second step Collect the data.

In the second step, a correction model is created based on the error of the depth perception even though the depth perception cue in the virtual environment is added. Then, the correction model is compared with the previous error to determine whether the error is lowered.

The subjects were recruited through the recruitment of Bartlett test. Fig. 8 below shows the results of the Bartlett test. Each result was assumed to be equally distributed with a p−value greater than 0.05. However, with p−value <0.05 in the box size, it was not possible to assume equidistribution by adopting the null hypothesis.

The T−test was performed to verify the difference of the mean value of the measured values except for the estimated size of the cube, and the Wilcoxon Signed Rank Test, which is a nonparametric test, was performed on the estimated size of the cube. As a first step of Experiment II, we can verify whether the depth perception leads to a significant change in the effect of depth perception in a virtual environment.

```
> bartlett.test(y ~ cls, data = group_box_scale)

        Bartlett test of homogeneity of variances

data:  y by cls
Bartlett's K-squared = 9.0465, df = 2, p-value = 0.0108

> bartlett.test(x ~ cls, data = group_camera)

        Bartlett test of homogeneity of variances

data:  x by cls
Bartlett's K-squared = 0.95136, df = 2, p-value = 0.621

> bartlett.test(TE_1_Vec ~ cls, data = group_TE_1)

        Bartlett test of homogeneity of variances

data:  TE_1_Vec by cls
Bartlett's K-squared = 4.9841, df = 2, p-value = 0.0827

> bartlett.test(TE_2_Vec ~ cls, data = group_TE_2)

        Bartlett test of homogeneity of variances

data:  TE_2_Vec by cls
Bartlett's K-squared = 3.8929, df = 2, p-value = 0.1428
```

Fig. 8. Bartlett Test Results

1) Step 1. Depth Perception Clue Effect

At this stage, we check whether depth perception varies in virtual environment depending on presence or absence of depth perception cues. Also, a correction model is generated according to the depth perception error of the individual through the data collected in this step.

In order to confirm the difference of the mean value as a result of the first step of Experiment II, Wilcoxon Rank Sum Test, which is a nonparametric test method, and t−test, which is assumed to be equally distributed, were performed. Fig. 9 shows this, and the size estimate of the cube, which is a size perception, is significant.

```
> wilcox.test(box_scale_condition, box_scale_correction,
+               alternative = c("less"),
+               paired = TRUE,
+               conf.level = 0.95)

        Wilcoxon signed rank test

data:  box_scale_condition and box_scale_correction
V = 41, p-value = 0.007656
alternative hypothesis: true location shift is less than 0

>
> t.test(df_of_TE_1$TE_1_condition, df_of_TE_1$TE_1_correction,
+         alternative = c("greater"),
+         paired = TRUE,
+         conf.level = 0.05)

        Paired t-test

data:  df_of_TE_1$TE_1_condition and df_of_TE_1$TE_1_correction
t = -0.53941, df = 19, p-value = 0.7021
alternative hypothesis: true difference in means is greater than 0
5 percent confidence interval:
 27.9132     Inf
sample estimates:
mean of the differences
              -12.65559

>
> t.test(df_of_TE_2$TE_2_condition, df_of_TE_2$TE_2_correction,
+         alternative = c("greater"),
+         paired = TRUE,
+         conf.level = 0.05)

        Paired t-test

data:  df_of_TE_2$TE_2_condition and df_of_TE_2$TE_2_correction
t = -0.3703, df = 19, p-value = 0.6424
alternative hypothesis: true difference in means is greater than 0
5 percent confidence interval:
 24.31772      Inf
sample estimates:
mean of the differences
              -6.626874

>
> t.test(df_of_camera_loc$camera_loc_condition, df_of_camera_loc$cam
_loc_correction,
+         alternative = c("greater"),
+         paired = TRUE,
+         conf.level = 0.05)

        Paired t-test

data:  df_of_camera_loc$camera_loc_condition and df_of_camera_loc$ca
a_loc_correction
t = 1.282, df = 19, p-value = 0.1076
alternative hypothesis: true difference in means is greater than 0
5 percent confidence interval:
 18.78793      Inf
sample estimates:
mean of the differences
               7.999125
```

Fig. 9. Wilcoxon Rank sum test and t−test result of condition i and condition ii

The difference in significance according to the above results shows that the size perception is changed when the depth perception cue is added in the virtual environment.

2) Step 2. Depth Perception Correction

At this stage, it is confirmed whether the depth perception error varies depending on the presence or absence of the correction of the proportion. As in the first step, a T−test was performed to verify the difference in the mean of the measured values except for the estimated size of the cube, and the Wilcoxon signed rank test, which is a nonparametric test, was performed on the estimated cube size. As a second step of Experiment II, it can be seen that applying the calibration model actually affected depth perception in the virtual environment. The results of this step analysis are shown in Fig. 10 below.

```
> wilcox.test( box_scale_correction, box_scale_result,
+              alternative = c("less"),
+              paired = TRUE,
+              conf.level = 0.95)

        Wilcoxon signed rank test

data:  box_scale_correction and box_scale_result
V = 28, p-value = 0.001356
alternative hypothesis: true location shift is less than 0

>
> t.test(df_of_TE_1$TE_1_correction, df_of_TE_1$TE_1_result,
+         alternative = c("greater"),
+         paired = TRUE,
+         conf.level = 0.05)

        Paired t-test

data:  df_of_TE_1$TE_1_correction and df_of_TE_1$TE_1_result
t = -1.2862, df = 19, p-value = 0.8931
alternative hypothesis: true difference in means is greater than 0
5 percent confidence interval:
 9.534925      Inf
sample estimates:
mean of the differences
              -27.68688

>
> t.test(df_of_TE_2$TE_2_correction, df_of_TE_2$TE_2_result,
+         alternative = c("greater"),
+         paired = TRUE,
+         conf.level = 0.05)

        Paired t-test

data:  df_of_TE_2$TE_2_correction and df_of_TE_2$TE_2_result
t = -1.4354, df = 19, p-value = 0.9163
alternative hypothesis: true difference in means is greater than 0
5 percent confidence interval:
 4.996784      Inf
sample estimates:
mean of the differences
              -24.41428

>
> t.test(df_of_camera_loc$camera_loc_correction, df_of_camera_loc$cam
era_loc_result,
+         alternative = c("greater"),
+         paired = TRUE,
+         conf.level = 0.05)

        Paired t-test

data:  df_of_camera_loc$camera_loc_correction and df_of_camera_loc$ca
mera_loc_result
t = 3.55, df = 19, p-value = 0.001069
alternative hypothesis: true difference in means is greater than 0
5 percent confidence interval:
 19.313    Inf
sample estimates:
mean of the differences
                12.9872
```

Fig. 10. Wilcoxon Rank sum test and t-test result of condition ii and condition iii

As a result of the analysis, the size perception of the cube showing the size perception significantly changed after applying the correction model, which can be expected to make a meaningful change in the change of the cube size by applying the proportional correction model. On the other hand, the distance between the cube and the camera, which is the result of the blind press test, can be confirmed to be significantly smaller after applying the correction model. According to the above results, when the correction model is applied, it is confirmed that the size perception and distance perception change significantly.

The correction of the proportion was applied to the maximum value of 20% by applying the proportional value of the size perceived by the subject. The corrected values and their average values are shown in Fig. 11 below. This allows us to measure the ratio value of the correction of size perception.

```
> Scale_of_cube
 [1] 0.533198 0.600000 0.548890 0.600000 0.539453 0.585706
 [7] 0.537747 0.581560 0.577183 0.600000 0.543065 0.600000
[13] 0.564490 0.598225 0.598225 0.525000 0.526000 0.525000
[19] 0.600000 0.600000
> mean(Scale_of_cube)/50 *100
[1] 1.138374
```

Fig. 11. Correction value

The difference in depth perception is shown in Fig. 12 below. The average of the estimated size of the cube was 43.86cm and 49.77cm. If we express this as a ratio of estimated value, it can be said that the difference is significant from 87.72% to 99.54%. Also, the distance between the camera and the cube is about 30cm to 17cm.

```
> ########### summary ####################
> summary(df_of_box_scale)
 box_scale_condition box_scale_correction box_scale_result
 Min.   :33.16       Min.   :36.12        Min.   :40.75
 1st Qu.:38.49       1st Qu.:39.50        1st Qu.:44.78
 Median :39.50       Median :44.33        Median :47.97
 Mean   :39.99       Mean   :43.86        Mean   :49.77
 3rd Qu.:42.08       3rd Qu.:46.34        3rd Qu.:55.69
 Max.   :47.30       Max.   :58.16        Max.   :62.60
> summary(df_of_TE_1)
 TE_1_condition    TE_1_correction    TE_1_result
 Min.   : 39.92   Min.   :  4.569   Min.   : 38.51
 1st Qu.: 78.50   1st Qu.: 86.122   1st Qu.:104.23
 Median :124.00   Median :109.034   Median :144.79
 Mean   :125.05   Mean   :137.704   Mean   :165.39
 3rd Qu.:174.03   3rd Qu.:149.616   3rd Qu.:195.43
 Max.   :244.42   Max.   :344.187   Max.   :477.67
> summary(df_of_TE_2)
 TE_2_condition     TE_2_correction     TE_2_result
 Min.   :  4.849   Min.   :  3.017   Min.   : 27.33
 1st Qu.: 36.181   1st Qu.: 60.140   1st Qu.: 60.98
 Median : 81.746   Median : 77.130   Median : 89.05
 Mean   : 84.860   Mean   : 91.487   Mean   :115.90
 3rd Qu.:102.772   3rd Qu.:120.885   3rd Qu.:144.07
 Max.   :267.408   Max.   :192.682   Max.   :360.48
> summary(df_of_camera_loc)
 camera_loc_condition camera_loc_correction camera_loc_resul
 Min.   : 4.151       Min.   : 4.486        Min.   : 3.477
 1st Qu.:27.035       1st Qu.:16.733        1st Qu.: 7.254
 Median :36.758       Median :26.105        Median :10.896
 Mean   :38.265       Mean   :30.265        Mean   :17.278
 3rd Qu.:53.157       3rd Qu.:33.261        3rd Qu.:21.242
 Max.   :74.639       Max.   :70.215        Max.   :54.540
```

Fig. 12. Depth perception estimates and error values

5. Conclusion

In this study, we investigated the factors affecting the depth perception of spatial components in virtual space, and experimented in a virtual environment to search for ways to improve the accuracy of depth perception by combining depth perception elements.

In Experiment I, it is assumed that the estimated size of the cube collected through the Levene Test is $p > 0.05$ in the room size condition and the cube size condition, assuming that the equipartition is assumed, and that all of the experimental results have a standardized variance. The two-way ANOVA showed that the estimated size of the cube is significantly different depending on the condition. We also confirmed that the mean difference is also significant through the Scheffe test. It was confirmed that underestimation in the virtual environment was confirmed, and that it was proportional to the depth perception of spatial components.

In Experiment Ⅱ, Experiment I was used to correct the depth perception by adjusting the proportion that significantly affects depth perception in spatial components. In addition, by using the depth perception cues, the virtual environment is constructed to improve the accuracy of the depth correction in the virtual environment. In Step 1, we can confirm that the depth perception varies depending on the presence or absence of the depth perception cue in the virtual environment. Also, it was confirmed that the difference in size perception was significant. In Step 2, it was confirmed that the correction using the proportion of spatial components caused a significant change in depth perception. The correction value of the proportion is 1.138374, which indicates that the size of weak cube is estimated from 87.72% to 99.54%. This means that the proportional correction and depth perception cues in the virtual environment gave significant changes in depth perception accuracy.

Through this experiment, we have investigated the correction method to improve the accuracy of depth perception in virtual environment. In the absence of the depth perception cues, size perception was judged to be an average of 80% of the target size, 87.72% in the case of only the depth perception cues, and 99.54% when the depth perception cues and proportional correction were applied. this work could make an estimate. It can be confirmed that the correction method used in this experiment is a correction method that can estimate the accuracy of the size perception of the depth perception very high.

On the other hand, distance perception during depth perception was measured using the distance between the camera and the cube collected through blind pedestrian performance. The difference was significant in the absence of the depth perception cue, about 38cm in depth, and about 30cm in the depth perception cue, and about 17cm when the perceptual cue and proportional correction were applied. It can be seen that the depth perception leads to correction of the distance perception and that the correction of the size affects the distance perception. This result shows that the distance perception is mediated by the size perception as a result of opposing the size - distance invariance that size perception is mediated by the distance perception.

The proportional correction proposed in this study shows very significant results in size perception, which can be applied as a correction method of size perception among underestimation of depth perception occurring in virtual environment. This can be utilized as the size correction of the target in the virtual environment simulation, and this can be utilized as a method of maximizing the learning effect of the simulation.

In this experiment, the virtual space can be implemented in an environment similar to the experimental space by using the existing model in implementing the virtual environment. However, in future research, it is expected that it will be necessary to implement the environment of the same size as the experimental space, and to find ways to correct the depth perception by increasing the presence of the subject.

In this study, the correction method of distance perception based on size perception is unclear and it is necessary to search for ways to correct it. In addition, in this study, some biased results may be included by recruiting subjects through convenience recruitment. In this paper, we propose a new method to estimate the depth perception in a virtual environment.

In the experiment, the resolution is 1080 × 1200 in the single resolution due to the limit of the equipment. However, in future research, it will be influential to improve the resolution by using better equipment. Also, it is necessary to increase the accuracy of the depth perception in the virtual environment by projecting the movement of the subject and the movement of the avatar in order to increase the immersion feeling in the virtual environment. In future research, it will be necessary to search for the correction method for the distance perception outside the proposed correction method, and to search the correction method by searching the parameter variable besides the size perception. It is also necessary to increase the number of subjects and to increase the assumptions and reliability.

REFERENCES

[1] J. M Loomis & J. M. Knapp. (2003). Visual perception of egocentric distance in real and virtual environments. *Virtual and adaptive environments, 11,* 21−46.
DOI : 10.1145/2543581.2543590

[2] S. S. Fisher, M. McGreevy, J. Humphries & W. Robinett. (1987). Virtual environment display system. *I3D '86 Proceedings of the 1986 workshop on Interactive 3D graphics, 11* 77−87.
DOI : 10.1145/319120.319127

[3] J. M. Loomis & J. M. Knapp. (2003). Visual perception of egocentric distance in real and virtual environments. *Virtual and adaptive environments, 11,* 21−46.
DOI : 10.1145/2543581.2543590

[4] H. S. Yu, D. H. Shin & S. S. Nam. (2017). User Experience in Virtual Reality Games: the Effect of Presence on Enjoyment. *Korean Telecommunications Policy Review, 24(3),* 85−125.

[5] R. G. Eggleston, W. P. Janson & K. A. Aldrich, (1996). "Virtual reality system effects on size−distance judgements in a virtual environment," *Proceedings of the IEEE 1996 Virtual Reality Annual International Symposium, Santa Clara, CA, USA,* 139−146.
DOI : 10.1109/VRAIS.1996.490521

[6] Y. J. Shin. (2005). A basic study for The sense of real improvement in Virtual Reality *Journal of the Architectural Institute of Korea Planning & Design 7(21),* 11−18.

[7] E. U. Kim (2003). A review on depth and size perception, *Journal of Social Science, 20(1).* 3−27.

[8] A. Naceri, R. Chellali, F. Dionnet & S. Toma. (2010). Depth perception within virtual environments: comparison between two display technologies. *International Journ. on Advances in Intelligent Systems, 3(1)*, 51−64.

[9] J. E. Swan, A. Jones, E. Kolstad, M. A. Livingston & H. S. Smallman.(2007). Egocentric depth judgments in optical, see−through augmented reality. *IEEE transactions on visualization and computer graphics, 13(3)*, 429−442.
DOI : 10.1109/TVCG.2007.1035

[10] A. Richardson. (2004). The Effect Of Feedback Training On Distance Estimation In Virtual Environments. *Applied Cognitive Psychology, 19.* 1089−1108.
DOI : 10.1002/acp.1140

[11] B. G. Witmer & W. J. Sadowski (1998). Nonvisually Guided Locomotion to a Previously Viewed Target in Real and Virtual Environments. *Human Factors, 40(3),* 478-488.
DOI : 10.1518/001872098779591340

[12] S. H. Creem−Regehr, J. K. Stefanucci, W. B. Thompson, N. Nash & M. McCardell (2015). Egocentric distance perception in the oculus rift (dk2). *In Proceedings of the ACM SIGGRAPH Symposium on Applied Perception. ACM, New York, NY, USA,* 47−50.
DOI : 10.1145/2804408.2804422

[13] D. Banakou, R. Groten & M. Slater. (2013). Illusory ownership of a virtual child body causes overestimation of object sizes and implicit attitude changes. *Proceedings of the National Academy of Sciences, 110(31)*, 12846−12851.
DOI : https://doi.org/10.1073/pnas.1306779110

[14] J. Jacobson & M. Lewis. (2005). Game engine virtual reality with CaveUT. *Computer, 38(4)*, 79−82.
DOI : 10.1109/MC.2005.126

[15] V. Interrante, B. Ries & L. Anderson. (2006). Distance Perception in Immersive Virtual Environments, Revisited, *In Proceedings of the IEEE conference on Virtual Reality (VR '06). IEEE Computer Society, Washington, DC, USA,* 3-10.
DOI : 10.1109/VR.2006.52

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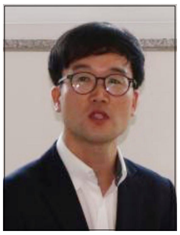

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