Factors Affecting Motion Sickness in an Augmented Reality Environment

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Abstract—**This study aims to evaluate the factors affecting motion sickness in the Augmented Reality (AR) environment. Motion sickness is due to a difference between actual and expected motion. When people use Virtual Reality (VR), they experience symptoms of motion sickness due to the inconsistency in vision and body movements. To measure the motion sickness, a VR Sickness Questionnaire (VRSQ) measurement index is used. The experiment was conducted with the following settings. The study group consisted of 12 female and 12 male participants with no health problems. They performed the task of repeatedly selecting specific buttons. It consisted of a total of 240 button selections (12 treatment (two methods of selection × two button sizes × three distances) × 4 choices × 5 sets = 240 tasks). The Latin Square design was used to minimize the effect of order. Then, a questionnaire was conducted after each treatment. ANOVA (ANalysis Of VAriance) was performed to check if there were differences in Oculomotor, Disorientation, and VRSQ total score. There was a significant difference in selection method and distance of VRSQ Oculomotor. It is recommended to use physical buttons and to have a distance of 100 cm from the target to reduce the motion sickness in AR environment.**

Keywords-Augmented reality; simulator sickness questionnaire; virtual reality sickness questionnaire.

I. INTRODUCTION

Over the past decades, Augmented Reality (AR) technology is developed and used in many fields. AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world [1]. There are many cases of motion sickness in Virtual Reality (VR) environment. There are many kinds of factors that cause motion sickness. Studies show that motion sickness varies depending on age. Older participants had a greater likelihood of simulator sickness than younger participants [2][6]. It is also related to the amount of time exposed to VR environments. VR sickness is also affected by visual stimulation locomotion and exposure times [6]. The longer the exposure time, the more pronounced the motion sickness symptoms [3].

However, there are not many studies dealing with motion sickness in AR environments. As a method to measure the degree of motion sickness of AR, a VR Sickness Questionnaire (VRSQ), which was developed according to the VR environment, is utilized. The goal of this study is to check the factors affecting motion sickness in the AR environment.

Section II introduces VRSQ measurement, Section III introduces how the user test was conducted, Section IV explains the limitation of the study, and Section V concludes this paper.

II. VRSQ

A typical tool for measuring motion sickness in a cyber simulator is SSQ (Simulator Sickness Questionnaire). SSQ includes 16 symptoms that are divided into three components [4]. In this study, VRSQ tools were selected to measure motion sickness in the AR environment. VRSQ is a motion sickness measurement specialized for VR environments [5]. VRSQ consists of nine symptoms (General discomfort, Fatigue, Eyestrain, Difficulty focusing, Headache, Fullness of head, Blurred vision, Dizzy (eyes closed), Vertigo), which are divided into two factors (Oculomotor, Disorientation) (Table 1). In this study, one index was used per nine symptoms. VRSQ scores can be calculated using the following formula (Table 2).

TABLE I. COMPUTATION SCORE OF VRSQ

VRSQ symptom	Oculomotor	Disorientation
1. General discomfort	O	
2. Fatigue	O	
3. Eyestrain	O	
4. Difficulty focusing	O	
5. Headache		O
6. Fullness of head		O
7. Blurred vision		O
8. Dizzy (eyes closed)		O
9. Vertigo		O
Total	[1]	[2]

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TABLE II.

Components	Computation
Oculomotor	([1]/12)*100
Disorientation	([2]/15)*100
Total	(Oculomotor + Disorientation score)/2

III. CASE STUDY

A. Experimental design

1) Participants

The study group consisted of 12 female and 12 male participants with a corrected vision of 0.6 or higher, with no physical or visual health problems (average age: 21.2 years old, standard deviation: 1.26 years old). Since there may be differences between genders, 12 female and 12 male were chosen in consideration of gender balance. The participants were all Korean and had no experience in using AR devices. We recruited the university students who are thought to be interested in AR devices. There were 11 people who had experience using VR devices. Twenty-two of them were right-handed and two were left-handed. All of them conducted the experiment with their own hands.

2) Apparatus

The AR environment was configured using Microsoft Hololens (1st generation) developer edition. Its Holographic resolution 2HD 16:9 light engines producing 2.3M total light points. There are two ways to perform a task (Figure 1). The first thing is to use finger gestures. 1) Gaze at the hologram which want to select. 2) Point the index finger straight up toward the ceiling. 3) Air tap: lower the finger, quickly raise it. The second is to use a clicker. To select a hologram, button, or other element, gaze at it, then click.

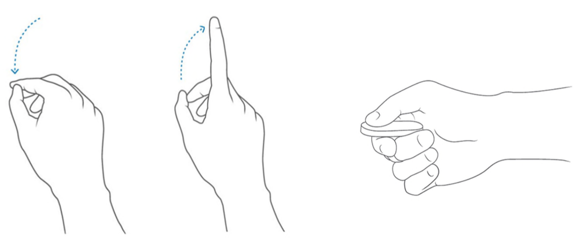

Figure 1. Finger gesture and clicker

3) Tasks

After wearing the Hololens HMD, finger gestures and clickers were used to perform the task of repeatedly selecting specific buttons. Nine buttons are marked in an array of 3×3. Buttons consist of two sizes and three distances (Table 3).

TABLE III. SETTINGS OF BUTTONS

FOV	Distance (cm)	Size of button (cm)
3°49"48'	60	3.68
	80	4.90
	100	6.14
1°55″4′	60	2.00
	80	2.68
	100	3.35

The small button was set to a 1°55'4" field of view based on the length of the large side of the mobile phone's 3×4 keyboard. The large button is set to twice the size of the small button and its field of view is 3°49'48" (Figure 2).

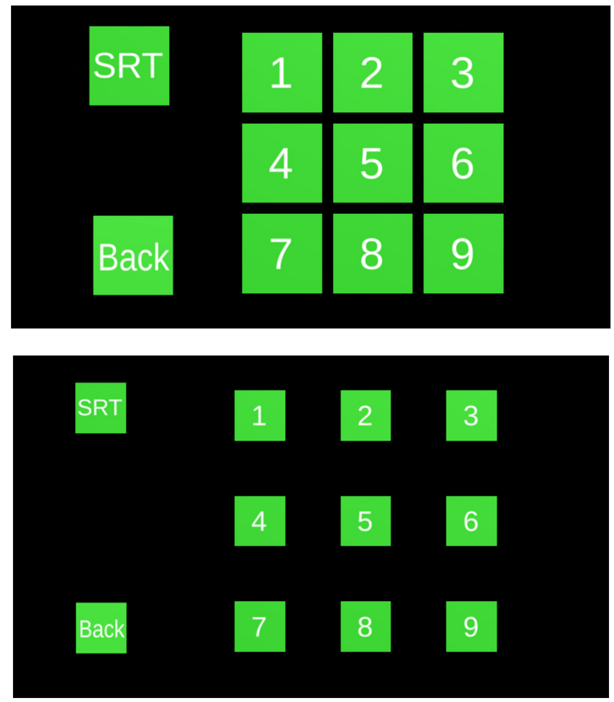

Figure 2. An example of target buttons (up: large buttons, down: small buttons)

4) Procedure

Participants were asked to perform tasks consisting of two selection methods (finger gestures, clickers), two button sizes, and three distances (60 cm, 80 cm, 100 cm) and respond to SSQ. The manufactured application was run through Hololens. The experiment lasted about 90 minutes, including break time.

First, the purpose and contents of the experiment were introduced. They were also explained that if participants feel severe motion sickness, they can rest and stop at any time. And It is evaluating the device, not the ability of the participants. Before starting the experiment, the subjects had a chance to practice until they got used to the device (Figure 3).

Second, participants performed a task consisting of 12 treatments (two methods of selection × two button sizes × three distances = 12 treatments). Each treatment consisted of five sets and one set was to select four randomly highlighted buttons. Thus, it consisted of a total of 240 button selections (12 treatment × 4 choices × 5 sets = 240 tasks). The Latin Square design was used to minimize the effect of order.

Finally, a questionnaire was conducted after each treatment. Motion sickness levels were assessed through the difficulty level and SSQ of performing the task. The score was based on a five-point recurve scale (1 = not at all, 2 = slightly, 3 = normal, 4 = moderately, 5 = very).

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Figure 3. A person wearing the HMD equipment and clicking the buttons

B. Result

1) ANOVA with VRSQ

Analysis of variance (ANOVA) was performed to check if there were differences in Oculomotor, Disorientation, and VRSQ total score depending on the method of selection, the size of the buttons, and the distance. As a result of the analysis of variance, items with a P value of 0.05 or less were analyzed Tukey post-analysis (Table 4).

TABLE IV. EFFECT TESTING BETWEEN SELECTION METHOD, SIZE, DISTANCE

	VRSQ		VRSQ-Oculomotor		VRSQ-Disorientation	
	F	P	F	P	F	P
Selection (A)	2.97	0.09	5.62	0.02	0.11	0.75
Size (B)	1.90	0.17	2.66	0.10	0.45	0.51
Distance (C)	3.95	0.05	5.91	0.02	0.71	0.40
(A)×(B)	0.94	0.33	1.10	0.30	0.40	0.53
(A)×(C)	0.05	0.82	0.16	0.69	0.10	0.93
(B)×(C)	0.79	0.38	1.00	0.32	0.26	0.61
(A)×(B)×(C)	0.00	0.95	0.13	0.72	0.18	0.67

Differences were found in Oculomotor depending on the method of selection and the distance (Figure 4). In Oculomotor, the P value of Selection was 0.0185 ($p<0.05$), and there was a significant difference in the use of finger gesture and clicker as a result of post-analysis. The VRSQ Oculomotor score of finger gesture selection is 74.02 and the score of clicker is 65.1.

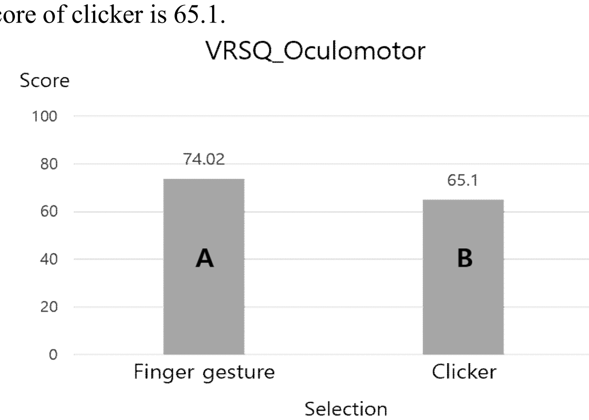

Figure 4. VRSQ_Oculomotor scores for Selection methods (Different letters indicate a statistically significant difference).

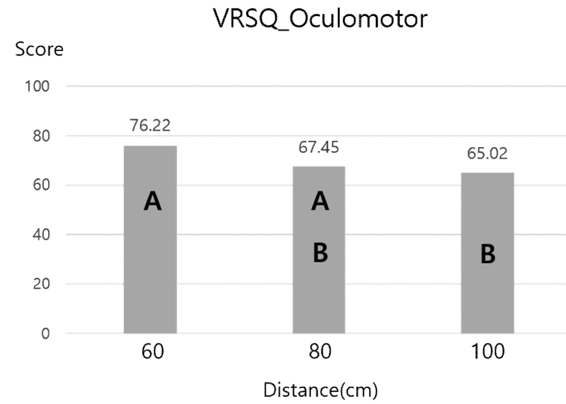

Figure 5. VRSQ_Oculomotor scores for Distance (Different letters indicate a statistically significant difference).

In addition, the P value of Distance was 0.0157($p<0.05$) and there was a significant difference between 60 cm and 100 cm (Figure 5). The VRSQ Oculomotor score of distance 60 cm is 76.22, and the score of 100 cm is 65.02. There were no significant differences in the disorientation score and VRSQ total score according to the selection methods, button sizes, and distances.

IV. DISCUSSION

As a result of the data analysis, two methods of selecting buttons indicated significant differences.

There was a study that measured motion sickness in two ways to select a target: direct selection to select a target with physical buttons and automatic target selection to stare and select for a certain period of time [5]. In this study, both SSQ and VRSQ scores for the choice method using physical buttons were significantly lower. The study also showed that the physical button, the clipper method, had a low motion sickness score.

There was a significant difference between 60 cm and 100 cm in the distance between the target and the subject. The 60 cm VRSQ Oculomotor score was 76.22 and the 100 cm score was 65.02 points. The button at a distance of 100 cm caused less motion sickness. Therefore, when producing contents of AR environment, it is recommended to use physical buttons and to have a distance of 100 cm from the target.

In the case of finger gesture, the finger must be within the camera radius to be recognized. So, the experiment was carried out with the arms stretched forward, and the fingers were in the field of view. Depending on the movement of the eyes, the hands had to move together and the subjects had to pay attention to it. However, the clicker was connected by Bluetooth, so it could be operated comfortably without raising its arms. Due to these differences, eye movements would have varied depending on how buttons were selected, so the degree of motion sickness must have been different.

The experiment was carried out standing in place, facing one direction. Although the position of the buttons changed slightly depending on the view, body movements were

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generally not required. This may have affected directional loss scores.

This study did not identify differences in the effects of motion sickness by gender. Gender differences need to be checked in further studies.

V. CONCLUSION

SSQ uses a 4-point Likert scale (0=not at all, 1=slightly, 2=moderately, and 3=very). However, in this study, there were limitations in converting to scores using 1-5 scales. Because the numbers on the scales were different, it was difficult to apply the SSQ calculation method.

24 subjects cannot represent all populations. Furthermore, the age of 24 participants was early 20s. So, it could not confirm previous research that there was a difference in the degree of motion sickness depending on age. It is necessary to recruit subjects of various ages for further research.

The task of selecting buttons in an AR environment was carried out and the motion sickness was measured using the VRSQ tool. Twenty-four participants carried out a task consisting of nine buttons, two button selection methods, two button sizes and three distances. VRSQ, which has increased efficiency in VR environment compared to the previous SSQ, is utilized.

This study revealed that Oculomotor among motion sicknesses in AR environment is related to the method and distance of button selection. To provide better usability, motion sickness in the AR environment needs to be improved. This study can suggest the possible user interface element of AR environment to reduce motion sickness.

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