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MOTION SICKNESS INDEXES IN AUGMENTED REALITY ENVIRONMENT

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Abstract. *AR market is in an early stage of market formation and technological development after the success of VR. The use of AR is increasing day by day with the development of new AR devices. Research related to the side effects of using AR devices such as motion sickness is lacking. Currently, there is a lack of motion sickness measuring tools for an AR environment. This study aims to analyze motion sickness in augmented reality (AR) using a simulator sickness questionnaire (SSQ) and a virtual reality sickness questionnaire (VRSQ). This study found a consistency in the results of two sickness measuring indexes. Additionally, this study found the size of the object and focal distance as significant factors that affect motion sickness in the AR environment. It is recommended to use buttons with at least a 3° 50′ field of view and a focal distance of 80 cm from the eye. This study can be referred to during designing AR interfaces and it also encourages researchers to develop a sickness measuring index for the AR environment.*
Keywords: Augmented reality, Motion sickness, SSQ, VRSQ, Interface design

1. **Introduction.** Augmented reality is a combined experience of the real world with computer-generated information and objects. The essential characteristics of AR are virtual environment, real-time interaction and 3D view [1]. AR is now one of the emerging trends in various industries with increasing application. Several head-up displays, holographic devices, smart glasses and handheld devices are now available to experience an augmented reality environment.

Research is conducting on different aspects of AR and VR including interface design, interaction methods and usability of AR devices [2-6]. Sickness while using AR devices is one of the areas of interest for researchers. Motion sickness is a sensory conflict that occurs between vestibular, somatosensory and visual systems due to the difference between real and virtual motion [7]. In 1965, the Pensacola motion sickness questionnaire (MSQ), consisting of 25 to 30 symptoms, was developed to measure motion sickness [8]. The motion sickness symptoms include pallor, sweating, vomiting, drowsiness, salivation, postural changes, ataxia, dizziness, nausea, general discomfort, headaches, stomach awareness, apathy, dejection, disorientation, weakness, fatigue, lack of appetite, the desire for fresh air, confusion and occasionally incapacitation.

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With the development of different simulators with less severity of motion sickness, a 16 items simulator sickness questionnaire (SSQ) was developed as an updated measurement index [8]. It consists of three components: nausea, oculomotor and disorientation. SSQ is now widely used to measure simulator sickness in different simulators and devices [9-13]. SSQ was also used to analyze the difference in motion sickness due to changing field of view and image delay of head-up-displays (HUDs) [9,10,14]. The sickness in virtual reality (VR) environments initially with advancement in VR devices was also assessed using SSQ [13,15] due to the lack of any VR motion sickness measuring tool. Apart from traditional simulators, many other devices with 2D and 3D views are now common and widely used. Some of them are virtual reality (VR) and augmented reality (AR) devices. The simulations in these devices are widely different from each other, resulting in the difference in the severity of motion sickness symptoms. According to some studies, a significant difference in SSQ scores and total sickness was found between traditional simulators and VR systems [16,17]. Considering this difference, Kim et al. [12] developed a virtual reality sickness questionnaire (VRSQ) to evaluate motion sickness in the virtual environment. The 9 items VRSQ consisting of two components: oculomotor and disorientation was developed by modifying SSQ. The symptoms of VRSQ consist of general discomfort, fatigue, eyestrain, difficulty focusing, headache, the fullness of head, blurred vision, dizzy (eyes closed), and vertigo.

There is a clear difference between VR and AR in terms of immersive experience. VR is complete exposure to virtual immersion, while AR adds virtual objects to the real environment. AR is expected to have less sickness than VR. There is no particular sickness measuring tool for the AR environment, so researchers are using VRSQ to measure sickness [18]. This study aims to analyze motion sickness in an AR environment with both SSQ and VRSQ. Additionally, the effects of different object sizes and focal distances on motion sickness were also analyzed with both SSQ and VRSQ indexes. After comparing the results of SSQ and VRSQ, this study suggested a potential need to develop a motion sickness measuring index for the AR environment. This study investigated the consistency among SSQ and VRSQ for an AR environment and suggested a new motion sickness measuring index for an AR environment. Considering the results of this study, we are planning to develop ARSQ for augmented reality environments. In Section 2, the procedure, tasks and analysis are elaborated while Section 3 shows the results for SSQ and VRSQ. In Section 4, the results are discussed and compared to recommend a need for developing an ARSQ. Section 5 concludes the whole study.

2. Method.

2.1. Participants.

Fourteen male and ten young female students participated in this experiment. Eleven participants were using glasses, whereas thirteen had normal vision. All participants were physically fit. All participants performed the experiment with their right hands. The incentive was provided to encourage their participation in the experiment.

2.2. Apparatus.

The AR device used in this experiment was Microsoft HoloLens Development Edition. It was comfortable to wear and interact with hand and clicker. In this study, target selection tasks were performed with HoloLens to measure AR sickness. The prototype was made in Unity 3D using C# scripting. The black background was used to control the background effect during the experiment.

2.3. Tasks.

The prototype consists of nine square buttons (3 $\times$ 3 array). The task of button selection was conducted in different conditions (2 sizes and 3 focal distances). The two sizes were termed small buttons and large buttons. Three focal distances (40, 80, and 120 cm) from the eye to the buttons were used as treatment conditions (Figure 1). The

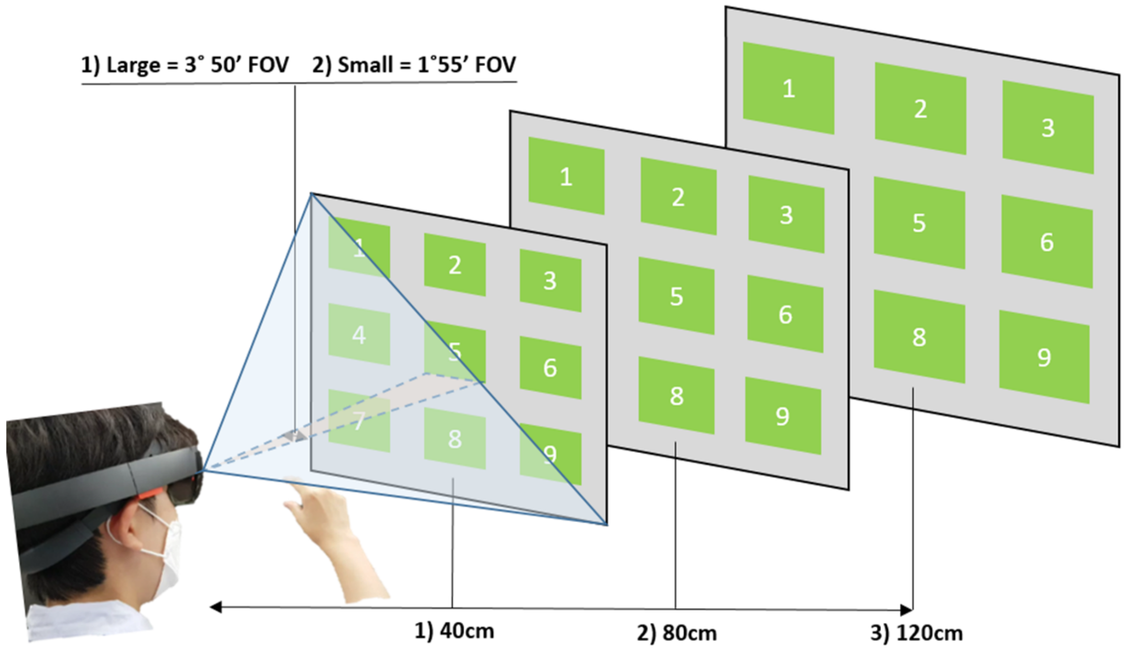

FIGURE 1. An example of experimental target buttons

experiment was within-subject designed. The task was to select a randomly highlighted button and rate the sickness symptoms using the simulator sickness questionnaire (SSQ). The 16 item SSQ is a self-report checklist rated by participant on a Likert type scale from 0-3 (0 = none, 1 = slight, 2 = moderate, 3 = severe).

2.4. **Procedure.** Before starting the actual tasks, all participants attended a practice session to get familiarized themselves with the interactive AR objects. They used the default applications in HoloLens for practicing with both hand and clicker. HoloLens was calibrated for each participant before their task. There were 6 experimental conditions (2 button sizes $\times$ 3 focal distances) in the experiment with a rest time of 2 min between each condition. The participants rated the sickness with the simulator sickness questionnaire (SSQ) according to the severity of symptoms after each condition. Each condition consists of ten sets (5 sets with each hand clicker) and in each set participants had to select four randomly highlighted buttons. Both hand and clicker interaction methods were used to manage interaction time balance and increase generalization. The experiment took approximately 90 min for each participant. It was a balanced Latin square designed experiment to prevent treatment condition effects among participants.

2.5. **Analysis.** ANOVA was performed to analyze the data for each factor of SSQ and total according to size, and distance. After SSQ, the items of VRSQ were selected and analyzed with ANOVA after applying their computational formulas to finding the scores of each factor and total. SNK test was conducted for both SSQ and VRSQ as a post-hoc test to analyze focal distance further.

3. Results.

3.1. **Simulator sickness questionnaire.** There was a significant difference in scores of oculomotor ($F(2, 46) = 13.229$, $p = 0.001$), disorientation ($F(2, 46) = 8.219$, $p = 0.001$) and total ($F(2, 46) = 13.691$, $p = 0.001$) for focal distance. For size there was also a significant difference in scores of oculomotor ($F(1, 23) = 12.293$, $p = 0.002$), disorientation ($F(1, 23) = 10.962$, $p = 0.003$) and total ($F(1, 23) = 13.461$, $p = 0.001$). For nausea, there was a significant difference among focal distance ($F(2, 46) = 8.581$, $p = 0.001$) but not in button size ($F(1, 23) = 2.315$, $p = 0.142$) (Table 1). Figures 2(a) and 2(b) are showing the

TABLE 1. F and p-values for simulator sickness questionnaire and virtual reality sickness questionnaire

Indexes	Variables	Components	F	p
SSQ	Distance	Oculomotor	13.229	0.001
		Disorientation	8.219	0.001
		Nausea	8.581	0.001
		Total	13.691	0.001
	Size	Oculomotor	12.293	0.002
		Disorientation	10.962	0.003
		Nausea	2.315	0.142
		Total	13.461	0.001
VRSQ	Distance	Oculomotor	10.886	0.001
		Disorientation	3.357	0.044
		Total	11.351	0.001
	Size	Oculomotor	13.337	0.001
		Disorientation	5.021	0.035
		Total	12.808	0.002

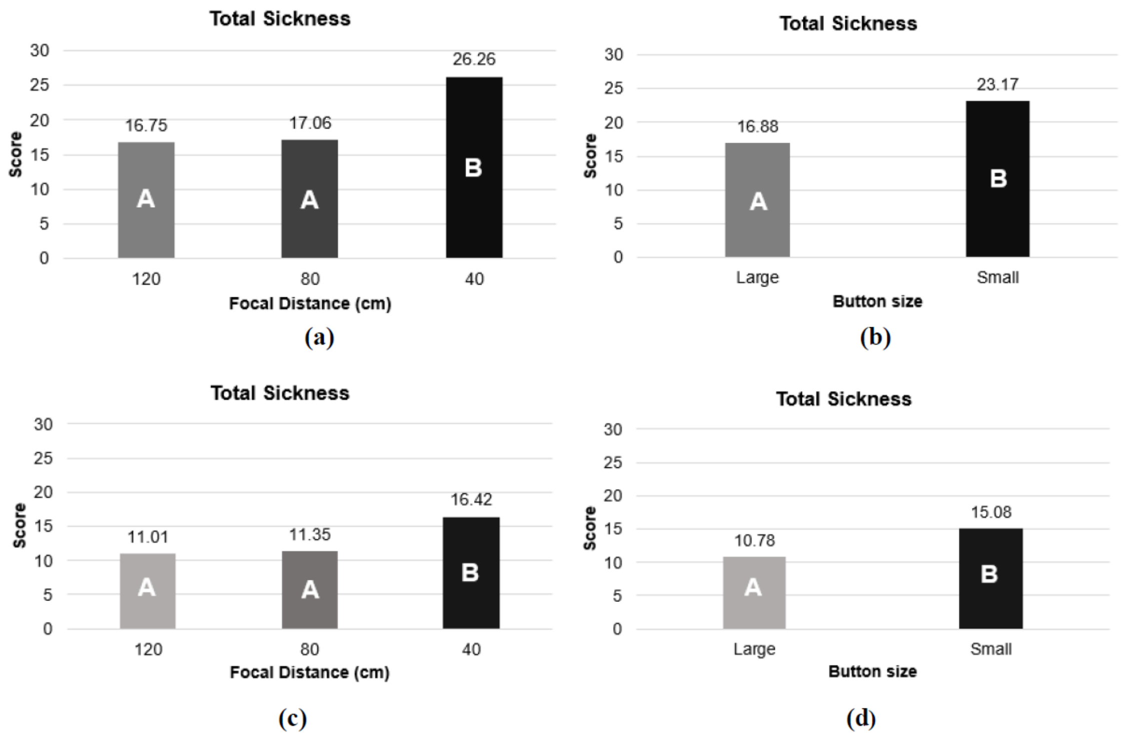

FIGURE 2. Total sickness with SSQ ((a): focal distance, (b): button size) and VRSQ ((c): focal distance, (d): button size). Different alphabets indicate significant difference.

results for total sickness for both focal distance and size according to SSQ respectively. Post hoc result revealed that there was a significant difference in the scores of nausea, oculomotor, disorientation and total between 40 cm and 80 cm and between 40 cm and 120 cm, but there was no significant difference between 80 cm and 120 cm.

3.2. **Virtual reality sickness questionnaire.** For VRSQ, there was a significant difference in scores of oculomotor ($F(2,46) = 10.886$, $p = 0.001$), disorientation ($F(2,46) = 3.357$, $p = 0.044$) and total ($F(2,46) = 11.351$, $p = 0.001$) for focal distance. For size there was also a significant difference in scores of oculomotor ($F(1,23) = 13.337$, $p = 0.001$), disorientation ($F(1,23) = 5.021$, $p = 0.035$) and total ($F(1,23) = 12.808$, $p = 0.002$) (Table 1). Figures 2(c) and 2(d) are showing the results for total sickness for both focal distance and size according to VRSQ respectively. According to the post hoc result, there was a significant difference in the scores of oculomotor and total between 40 cm and 80 cm and between 40 cm and 120 cm, but there was no statistically significant difference in scores of disorientation among focal distances.

4. **Discussion.** In this study, motion sickness in an AR environment is measured with SSQ and analyzed with both SSQ and VRSQ. The impact of button size and focal distance to the button from the human eye were analyzed using the button selection task. The results of both SSQ and VRSQ showed that the two factors (size and focal distance) affect the overall motion sickness in the AR environment. According to the results, both SSQ and VRSQ scores for button size showed that a small button size can cause high motion sickness compared with a large button size. There is a significant difference between both sizes according to both measurement indexes. For the focal distance, both SSQ and VRSQ confirmed that the distance 40 cm has the highest sickness scores among all three focal distances and it was statistically significantly different from 80 and 120 cm. There was no significant difference between the total sickness scores of 80 and 120 cm distances. The results for button size and focal distance were consistent between SSQ and VRSQ. Hence, we can use VRSQ as an alternate to SSQ in virtual and augmented environments.

Initially, SSQ was developed to measure motion sickness in traditional simulators. With time it has been used in various types of simulators and devices. Virtual reality was different from traditional simulators, so Kim et al. [12] developed VRSQ to measure motion sickness in a VR environment. The results were generally consistent for total sickness with both SSQ and VRSQ according to the AR environment. Also, VRSQ contains fewer questionnaire items than SSQ, which makes it faster and efficient to assess sickness in an AR environment. The number of components was reduced to two (oculomotor and disorientation) from three (nausea, oculomotor and disorientation). The simulations and devices for augmented reality are more refined and better in quality in terms of sickness effects than traditional simulators. Some items of SSQ may not be applicable for augmented reality environments due to the less severity of sickness symptoms. There is a possibility of a reduction of more items, similar to the VRSQ, for the AR environment. In an AR environment, the focal distance also affects the total sickness as indicated in the results section. According to Arefin et al. [19], focal distance switching significantly affects eye fatigue. Focal distance switching is still one of the major issues in AR interface design. Currently, there is no motion sickness measuring tool or index for AR. SSQ and VRSQ can be replaced with a new AR sickness measuring index which can also address different environmental issues such as sickness effects due to changing focal distances. The clusters of items were different in VRSQ than SSQ, but they are still using the name of components as oculomotor and disorientation. It is expected that, for an AR environment, the items may change results by making different clusters. Researchers need to rename the factors according to the new combination of symptoms for each factor. It can help researchers and practitioners to understand and relate the most affected part of the human body due to motion sickness in AR. It may more simplify the motion sickness measurement method for augmented reality devices and applications.

5. **Conclusion.** This study used traditional SSQ and VRSQ to measure motion sickness in the AR environment to confirm the consistency among both indexes according to the augmented environment. In this study, both SSQ and VRSQ scores showed that small button size and 40 cm of distances has high motion sickness score. It is recommended to use VRSQ over SSQ for the AR environment as the existing SSQ includes items not related to the AR environment. The number of items in VRSQ is less than SSQ which

can increase its efficiency and effectiveness. There is a potential need to develop a motion sickness measuring index specifically for AR environments in the future.

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