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INVESTIGATION OF FACTORS INFLUENCING SIMULATOR SICKNESS AND THE SENSE OF PRESENCE IN FLIGHT SIMULATOR

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Abstract. *Simulator may cause unintended motion sickness because of the discrepancy between visual and motor cue. This study investigated the effect of visual display type and task complexity on the sense of presence and the simulator sickness during flight simulator training. Human subject experiment with 18 participants (average age 22.6) showed that the head-mount display provides high level of sense of presence on sensory and realism factor, but it also generates higher simulator sickness on nausea, oculomotor, disorientation, and motion sickness. The effect of task complexity is not significant on both simulator sickness and sense of presence. The result implies that wide visual angle and binocular depth perception are positively influencing the sense of presence while also increasing simulator sickness. Thus the importance of providing proper motion cue would become more important as the visual reality increases.*
Keywords: Simulator sickness, SSR, Visual display, Head-mount display

1. **Introduction.** Simulation training has continued ever since earlier research showed a positive transfer of training from the simulator to the aircraft [8]. In simulator training, Simulator Sickness (SS) and the sense of presence are representative factors that affect the simulator performance. Sense of presence is that people subjectively perceive themselves as existing in an environment even if they are not physically located in the place. On the other hand, SS is a negative factor in training, which lowers the performance of positive transfer of training from the simulator to the aircraft. It is important to provide a proper visual cue in simulator because SS can be triggered by visual display alone [12]. In addition, the difference in fidelity due to the display type affects SS and sense of presence. However, the effect of display type on the presence and the SS is not clear yet. In particular, further research is required on the direction in which fidelity affects positively or negatively the sense of presence and the SS. This paper empirically investigated whether the presence and SS are affected by differences in display types in the flight simulator environment. Experimental conditions are that the trainee performs different complexity of flight tasks in the immersive HMD (Head-Mounted Display) and the flat-screen display environment.

2. **Literature Review.** Literature research was conducted using a systematic literature review methodology. Through the search engine PubMed, thesis titles, abstracts, and subjects containing ‘Presence’ or ‘Sense of Presence’ and ‘Virtual reality’ and ‘Simulator’ were primarily searched. Then, (((presence OR (sense of presence)) AND virtual reality) AND simulator) was used for the search formula which resulted in 39 papers. By the same search formula with Google Scholar, two additional papers were added. With the same

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way as above, ((simulator sickness) AND measurement) was used for the search formula. Through this, 152 papers were retrieved. Five additional papers were found on Google Scholar.

2.1. **Simulator sickness.** Kolasinski (1995) reported that SS occurs mostly in combination with visual cue, not just only motion cue [6]. According to Kennedy et al. (1993), SS is due to abnormal interaction conditions between the visual display element and the visual-vestibular system. The main symptoms are nausea, oculomotor, and disorientation [4]. Kennedy and Fowlkes (1992) found that there were various symptoms associated with SS and that no single symptom was predominant in some subjects with symptoms (Polysymptomatic). In addition, the cause of SS was not identified as a single cause (Polygenic) [3].

2.2. **Cue conflict theory.** Kennedy et al. (1988) have published a cue conflict theory as the basic theory of SS, including discrepancies in perceived information related to human motion and body orientation [5]. According to Kolasinski (1995), the cue conflict theory is the most generally acknowledged SS theory, and the cue conflict appears as a discrepancy between senses (or within a sense) [6]. In the fixed-base simulator, the human visual system detects movement, but the vestibular system does not detect it. This theory explains the main causes of SS. While the visual cue is provided to the user in the simulator, the motor cue is not provided properly. In this situation, disparity between the senses occurs. In terms of the theory, a countermeasure to prevent SS is to provide a proper cue by matching a motor cue with a visual cue.

2.3. **The sense of presence.** Witmer and Singer (1998) pointed out following 4 factor groups, Control Factor, Sensory Factor, Distraction Factor and Realism Factor, as influencing the presence. The following Table 1 summarizes the factors [13].

2.4. **Hypothesis.** This paper analyzed the effect of the presence and SS due to HMD and flat-screen display. The hypotheses are that when the HMD is worn on the flight simulator, the sense of presence is higher, but the SS is induced.

3. **Method.** Total number of 18 participants (avg. age = 22.6) participated in the experiment who do not have prior experience of flying aircraft. The independent variables in the experiment are the display type and task complexity. Two display types, flat LCD screen and HMD are used. The flat-screen consists of three Dell UltraSharp U3011 30" monitors which provides about viewing angle of 160°. The HMD used in the experiment is HTC VIVE which provides viewing angle of 110° in a fixed position and 360° when turned.

When the experiment session starts, the participants follow the route by passing through the waypoint located in the sky. The waypoint in the sky is colored green, if the airplane passes through it, the color was changed to red and the direction to the next waypoint appears. The complexity of flight task has two levels of hard and easy. The task was manipulated by the scenarios with different levels of difficulty. An easy scenario has the waypoints that need to pass are almost in a straight line whereas hard one has waypoints spread vertically and horizontally. Thus when playing the hard scenario, participants should make complex maneuver which generates sharp turns, steep climbing and descending. To do this, the roll, pitch, and yaw of the aircraft must be sharply tilted to perform the whole operation. In addition, if the participant did not pass the waypoint, they had to turn sharply and pass through the waypoint again.

Dependent variables of this study are SS and presence. Although there are several ways to measure SS, Simulator Sickness Questionnaire (SSQ) was used for measuring SS because it is a validated way of measuring SS conveniently [4]. For measuring the presence, the Presence Questionnaire (PQ) was used. The control variables are ‘flight

Table 1. Factors hypothesized to contribute to presence [13]

	Items
Control Factors	Degree of control: When users become more controllable/interact with the VE (virtual environment), the presence grows [11].
	Immediacy of control: The consequences of action should be appropriately apparent to users and provide the expected continuities [7].
	Anticipation: If users can anticipate what will happen, they will experience more sense of presence [2].
	Mode of control: When users need to learn new reactions, they can reduce their sense of presence until they are well learned [2].
	Physical environment modifiability: The greater the ability for user to modify physical objects in the environment, the more the sense of presence [11].
Sensory Factors	Sensory modality: Since most information comes in through visual channels, visual information can have a strong impact on presence [13].
	Environmental richness: The greater the range of sensory information delivered to the appropriate sensors, the stronger the sense of presence. An environment that contains much information to stimulate the sensors causes a strong presence [11].
	Multimodal presentation: The more complete/consistent the stimulation of all sensors, the greater sense of presence [2].
	Consistency of multimodal information: The information that the user perceives through all modalities should describe the same object [2].
	Degree of movement perception: When the user perceives itself moving in VE and seeing the object move relatively the presence increases.
	Active search: When the observer can control the relationship between its sensors and the environment, the environment could enhance the presence [11].
Distraction Factors	Isolation: Devices that isolate users from physical environment can increase presence [13].
	Selective attention: User's willingness or ability to focus on stimulus and ignore distractions outside the VE could increase the presence experienced in VE [13].
	Interface awareness: An unnatural, awkward, or artificial interface device intrudes on the direct explanation of the VE. Also, the awkward device decreases the presence [2].
Realism Factors	Scene realism: Presence is increased as a function of the VE scene realism (scene content, texture, resolution, light sources, field of view, dimensionality, etc.) [13].
	Information consistent with objective world: The more the information transmitted by the VE is consistent with the information learned through actual experience, the stronger the sense of presence [2].
	Meaningfulness of experience: When the situation is more meaningful, the presence increases [13].
	Separation anxiety/disorientation: Users may perceive disorientation or anxiety when returning to the real world from the VE. The amount of loss of this sense of direction may increase as the presence experienced in VE increases [13].

Figure 1. Experimental setup for 2D and 3D displays

scenario execution rule' and 'caffeine drink'. The flight scenario execution rule is to set the execution time for each task to more than 2 minutes. If the scenario ends before 2 minutes due to an airplane crash or stall, the scenario was reopened. In addition, if the scenario was not completed due to inexperienced participants, it is decided that the task will be finished in maximum 4 minutes. Excess intake of caffeine promotes the secretion of gastric acid [10]. Excessive gastric acid secretion can cause nausea. Nausea is one of the significant symptoms of simulator motion sickness [4]. In the experiment, the effects of SS symptoms and the effects of caffeine drink through the simulator were controlled so as not to be confounded.

Procedures. Before experiment, participants were informed that SS may occur. Experiment can be stopped at any time when they asked for it. After that, they watched a manual video about the basic operation of flight maneuver. After watching the clip, participants rehearsed the flight control technique using the pre-set scenario. An LCD screen was set to learn how to operate a flight. When they operate basic motion such as left/right turn, rise/fall became familiar or practice time reached 10 minutes, practice was finished. 4 tasks were performed according to the randomized conditions. After each task was completed, they were asked to fill out the SSQ and PQ immediately. If symptom of the SS occurred and a rest was requested, enough rest was provided. After completing all tasks, they were briefly interviewed about in which task the SS occurred and whether they felt the presence.

4. **Results.** The tendency of the quantitative indices were higher in HMD than flat-screen in SSQ. Nausea ($F(1, 67) = 7.38$, $p = 0.008$), oculomotor ($F(1, 67) = 11.89$, $p = 0.001$), disorientation ($F(1, 67) = 12.95$, $p = 0.001$), and simulator sickness (Total Score; TS) ($F(1, 67) = 13.26$, $p = 0.001$) were statistically significant as result of display type.

In presence analysis, the sensory and realism factor tend to be higher in HMD than flat-screen condition. As a result of the display types, only Sensory Factor ($F(1, 68) = 5.79$, $p = 0.019$) and Realism Factor ($F(1, 68) = 4.49$, $p = 0.038$) are statistically significant. There was no consistent trend and statistical significance due to the complexity of flight task.

5. **Discussion.** In the aspect of SS, it was confirmed that nausea, oculomotor, disorientation, and SS occurred significantly in HMD. In addition, experimental results show that HMD can better perceive the presence due to sensory and realism factor.

5.1. **Factors causing SS in HMD.** The causes of SS in immersive displays were analyzed in terms of 'viewing angle' and 'viewing range'. In 2D LCD screen environment, three DELL 30" monitors were connected to set the viewing angle to 160°. In contrast, the VR device of HTC VIVE was set the viewing angle to 110°. On the other hand, when

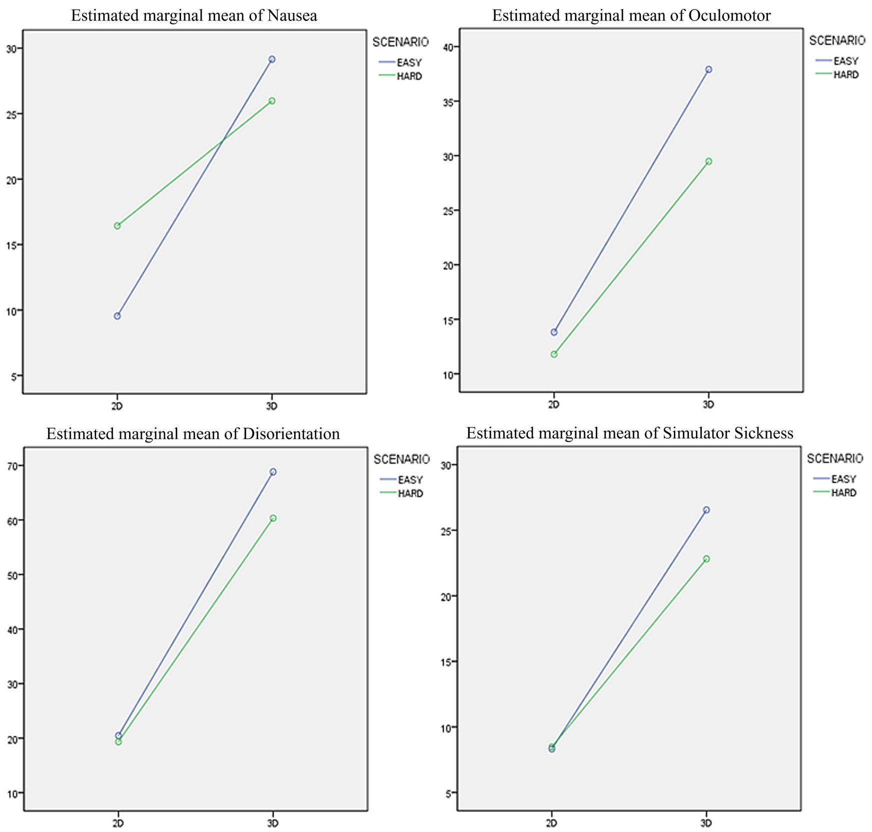

FIGURE 2. Simulator sickness and symptoms due to display type

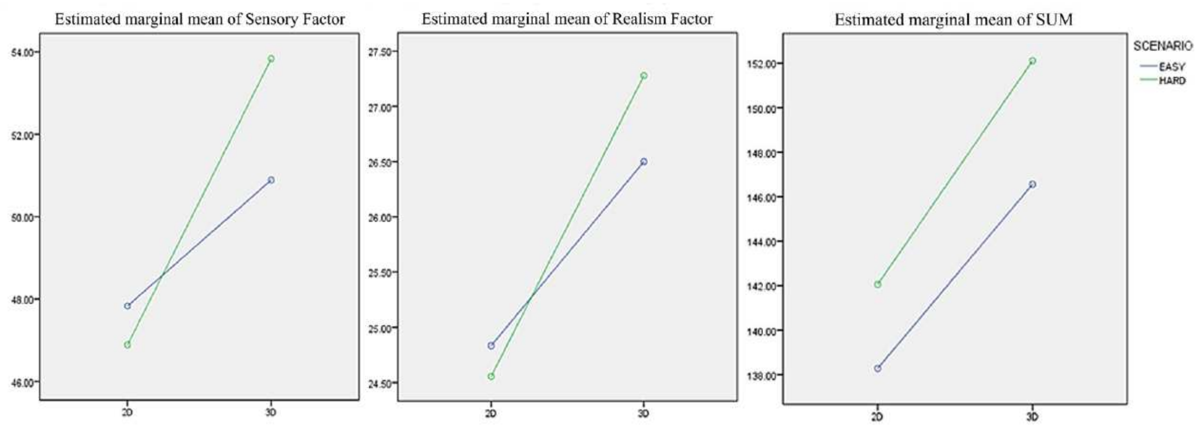

FIGURE 3. PQ factors due to display type

analyzed in terms of viewing range, the viewing range of the 2D LCD screen environment is 160° which is the same as the general viewing angle. However, in the HMD environment, since the head can be turned vertically and horizontally, the viewing range is extended to 360°. That is, there is no limit of the viewing range in the HMD. Emoto et al. (2008) showed that as the horizontal viewing range increased, the motion sickness evaluated by the SSQ increased [1]. Therefore, it is suggested that the cause of the increase of the SS in the HMD compared to the 2D LCD screen in this study may be the influence of the increase of the horizontal viewing range.

5.2. **Sensory factor.** There were concepts of environmental richness, degree of movement perception, and active search in the sub-concept of sensory factor investigated in the literature study. According to Sheridan (1992), the greater the range of sensory information transmitted to the appropriate sensory organ, the more the observer feels a higher level of the presence [11]. In experiment, the viewing range of immersive HMD was 360°, which was larger than 160° of flat-screen. The range of visual information acceptable to the participants in the HMD was wider. Therefore, the environmental richness affecting the presence was increased.

The degree of movement perception is a concept that recognizes that an observer moves by himself in a VE and increases the sense of presence if person observes that another object moves relatively. In addition, active search is a concept that when an observer can control the relationship between the sensory organ and the environment, the VE increases the sense of presence of the person experiencing it. Witmer and Singer (1998) presented an example of active search, in which the observer changes the viewpoint, turns the face to hear the sound with both ears, or tactually searches the environment [13]. In experiment, if participants fail to pass through the green waypoints, they must turn and re-enter. Most participants felt difficult to pass through the 2nd and 3rd waypoints in difficult scenario at once. In the case of the flat-screen display, participants had to search the waypoints depending on the navigation or the control tower. In contrast, in an HMD with 360° of viewing range, they turned their head directly to search for a waypoint to pass through, and was able to better perceive the relative movement of the waypoint from themselves. It was concluded that these are the factors affecting the improvement of the presence in HMD.

5.3. **Realism factor.** There were concepts of meaningful experience and separation anxiety in the sub-concept of realism factor. A meaningful experience means that the situation presented in a VE increases the presence when the situation is more meaningful. Since all the participants were novices the learning process could be a meaningful experience of flying and flight maneuver. It may be a factor affecting the sense of presence improvement.

In addition, the concept of separation anxiety is the state that feels a disorientation or anxiety when returning to the real world after finishing a simulation in a VE. The degree of this disorientation is higher as the sense of presence experienced in VE is higher. Compared with the flat-screen, when the flight simulation is performed with the HMD, the visual disconnection with the surrounding environment and the isolation of the participant occur. This isolation leads to disorientation, and it can be considered as a factor to increase presence.

Scene realism is a sub-concept of realism factor. The concept indicates that presence increases as the function of VE scene realism (ex. resolution) improves. In the experiment, the resolution of the flat-screen was higher than that of the VR device. If participants felt more presence according to resolution, the result would be a higher sense of presence on the flat-screen display. However, the results show that HMD provides a higher presence under the influence of sensory and realism factors. In terms of consistency, it can be considered that the natural way of perceiving the environment (Consistency of information with the objective world) such as turning head, has a greater impact on improving presence rather than recognizing presence in terms of resolution (scene realism). In other words, the sub-concept of realism factor, scene realism (resolution) and consistency, can conflict in the HMD environment. The result is implying that the latter effect is greater in presence.

5.4. **Control & distraction factor.** Control and distraction factor were not statistically significant for the hypothesis that the sense of presence was better in the immersive display (HMD) than the LCD screen. First, control factor has a sub-concept called Mode of Control. According to Held and Durlach (1992), when a person has to learn a new reaction in a given environment, the sense of presence may degrade until the response is well learned [2]. The experiment was conducted on the general public who had no flight maneuver experience. Therefore, it was discussed that the performance of the task progressed simultaneously with the learning of the flight manual, and the sense of presence decreased until the participants learned the response to the new environment. The effect of LCD screen and HMD due to distraction factor on presence was not statistically significant. Therefore, it is considered that the degree of the sense of presence decrease due to distraction factor in the general LCD screen and the HMD is similar.

6. **Conclusion.** In this study, the SS and the sense of presence according to 'type of display' and 'complexity of flight task' were studied. Participants highly evaluated the sense of presence according to the sensory and realism factor in HMD. Also nausea, oculomotor, disorientation, SS were more likely to occur in HMD. When the fidelity of the simulation environment is increased as the display type in the flight simulator, the SS is more induced in the immersive HMD than the flat-screen. It has been confirmed that sensory and realism factors could affect the presence. It is expected that it will be a good precedent study because there are not enough previous studies on the improvement of the fidelity of the simulator due to the difference of display types. The results of this study can be used as a basic research data to develop and improve factors to consider when developing a flight simulator in order to improve the presence or to reduce SS.

Limitations and Future Directions. Some participants mentioned that complexity of flight task influenced the simulator sickness, but the task execution time was too short. In a study by Regan (1993), participants stated that the most severe SS occurred 20 minutes after the start of the experiment [9]. To fully observe simulator sickness, it is recommended to provide a simulator experience about 20 minutes.

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