The Effects of Egocentric Distance and Screen Size on Virtual Presence: Implications for the Design of Virtual Reality Environments in Large- Screen Displays[*]

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This study examined the effects of egocentric distance and screen size on learners' perceived virtual presence in a virtual reality environment with a large-screen display. Sixty-four undergraduate students participated in the study, which used a 3×2 randomized-block factorial design with repeated measures. Two independent variables were included: 1) egocentric distance, or the physical distance between the viewer's position and a screen display, and 2) screen size, or different screen heights with fixed width. Learners' perceived virtual presence, comprising involvement, spatial presence, and realness, was the dependent variable. Results showed that egocentric distance had significant effects on virtual presence, while screen size had none. A detailed discussion and implications are provided.

Keywords: Egocentric distance, Screen size, Virtual presence, Virtual reality environment, Large-screen display

Introduction

Immersive virtual environments have been recognized as a promising area for education and simulation-based training (Johnson et al., 2016). Virtual reality environments provide learners with realistic experiences that enable them to explore real-world situations. Researchers in the field of immersive-virtual environments have claimed that enhanced learning experiences can create more varied scenarios than learners face in the real life. This wide range of scenarios can result in better outcomes for learners (Howard, 2018). Many studies have focused on examining the effects of virtual environments that foster more engaged and authentic learning opportunities, with their great potential to overcome the current shortcomings of education, including the lack of concrete experiences (Huang, Rauch, & Liaw, 2010; Merchant et al., 2014). In this line of research, virtual presence has been examined as an important construct, since it provides the subjective experience of being in a real place while in a virtually created situation (Schubert, Friedmann, & Regenbrecht, 2001). Virtual presence also has been considered as an indicator of learners' immersion and engagement, which potentially positively affects learning. Current theoretical development of embodied cognition also suggests that a higher level of perceived presence is important from a cognitive perspective, because learners' immersive experiences with compelling multimodal-learning resources can help them understand learning contents (Han & Black, 2011; Lindgren, Moshell, & Hughes, 2014).

Current development of technologies has made virtual devices such as head-mounted displays (HMD)s, affordable, enabling us to offer immersive user experiences with this new technology. While HMDs increasingly have been used for virtual reality, previous studies have reported that the Cave Automatic Virtual Environment (CAVE) also provides significant virtual experiences. We argue that the CAVE system has a significant impact on creating realistic situations for users. Along with the importance of the CAVE system to immerse users, a large projection

screen also can facilitate learners' immersive experiences, because it embeds users in the virtual reality (VR) environment (Dulina & Bartanusova, 2015). It can be an effective alternative to virtual environments as well (Howard & Gutworth, 2020). However, compared with the growing number of studies that examine the use of HMDs in education, there have been relatively few studies on the use of large-screen displays to induce comparable learning experiences without causing severe motion sickness.

It is crucial to consider learners' experiences in VR environments. In terms of virtual presence, immersion refers to a user's psychological state of mental involvement. For optimal immersion, learners' mental involvement in the virtual reality environment necessitates their disregarding their physical bodies. The degree of immersion depends on the size of the visual input. If the size is not large enough to embed learners to in the scene, it is difficult to get them completely involved in the virtual space. The size of the visual field is defined as the field of view (FOV) that can be viewed instantaneously. FOV influences learners' perceptions, including immersion, presence, enjoyment, and physical side effects, in the virtual reality environment (Lin, Duh, Abi-Rached, Parker, & Iii, 2002).

The FOV depends on the physical distance of the learner from the screen, and the distance from the visual reflection can determine the FOV. For example, in the CAVE system, a learner is supposed to look around to view a visual scene from the ceiling- to the floor-screens. Previous studies have suggested that higher FOVs can provide better learning outcomes, such as increased levels of recall, memory function, and immersion. Because FOV is the angular cone perceived at a particular instant of time, the size of the visual angle can be changed.

Therefore, this study included the multiple variables of egocentric distance, screen size, and perceived virtual presence, to determine how to design virtual reality environments in a physical space.

The research questions were as follows:

Research Question 1: What are the effects of different levels of egocentric distance on learners' perceived virtual presence in a large-screen display?

Research Question 2: What are the effects of different screen sizes on learners' perceived virtual presence in a large-screen display?

Research Question 3: What are the interactive effects of egocentric distance and screen size on learners' perceived virtual presence in a large-screen display?

Theoretical Background

Egocentric distance and FOV in large-screen displays

Egocentric distance refers to the physical distance between the viewer's position and a screen display (Piryankova, De La Rosa, Kloos, Bülthoff, & Mohler, 2013). In a large-screen setting, the user's field of view (FOV) is affected by changing his standing position. The smaller the distance between the person and the screen, the greater the FOV. This means that one's FOV is inversely proportional to his egocentric distance physically.

In several VR environment studies, FOV and field of regard (FOR) have been included as critical factors that affect the perceived level of immersion. FOV refers to the size of the visual field in degrees of visual angle that can be viewed instantaneously, while FOR refers to the total size of the visual field in degrees of visual angle surrounding the user (Laha, Sensharma, Schiffbauer, and Bowman, 2012). FOV and FOR are important components of visual immersion. In particular, a high FOR (e.g., four-walled CAVE) is more effective than a low FOR (e.g., single-walled CAVE) in visual-perception tasks (Laha et al., 2012) and spatial-perception tasks (Laha, Bowman, & Socha, 2014). High FOV and FOR provide better performance in visual- and spatial-perception tasks in VR environments. Previously mentioned studies (Laha et al., 2012; 2014) only focused on increasing FOR by the size of screen,

such as using a single-walled CAVE and a four-walled CAVE. However, when the screen size is fixed, egocentric distance plays a crucial role in determining FOV. It is known that smaller egocentric distances generally provide greater spatial perception because FOV increases. Researchers tried to explain this phenomenon by examining the accuracy of distance estimation and found that its accuracy increases with decreasing egocentric distance in large-screen displays (Alexandrova et al., 2010; Bruder, Argelaguet, Olivier, & Lécuyer, 2016; Lin & Woldegiorgis, 2017; Piryankova et al., 2013) and HMDs (Leyrer, Linkenauger, Bülthoff, Kloos, & Mohler, 2011). Spatial perception is one of the key elements determining subjective experience in an immersive VR environment. Schubert et al. (2001) indicated that spatial presence is one of the core constructs of virtual presence. Few studies have been conducted to consider virtual presence in terms of egocentric distance and FOV in an immersive VR environment.

Virtual presence in immersive virtual environments

Virtual presence refers to the subjective perception of being present in a virtual environment (Schubert et al., 2001). It is primarily important to provide users with the realistic feeling of being in the virtual environment, so that visual fidelity, laws of physics, and social interactions are core elements in a simulated real world (Selzer, Gazcon, & Larrea, 2019). The more realistic perception learners have, the more virtually transmitted experiences occur in the virtual reality environment. In this regard, many educational researchers interested in virtual presence have investigated virtual presence based on three sub-constructs involvement (INV), spatial presence (SP), and realness (REAL) (Schubert et al., 2001). According to Schubert et al. (2001), INV, also known as situation awareness, is the subjective evaluation of a given scene. SP measures how involved a participant feels in the scene and REAL estimates how realistically the scene was perceived. Witmer and Singer (1998) also argued that virtual presence is strongly associated with feelings of immersion and involvement.

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In virtual presence studies, HMDs have been used widely to enhance virtual presence. However, they still present challenges for learning. First, motion sickness, or nausea is one of the frequently discussed issues of using HMDs (Kennedy, Stanney, & Dunlap, 2000; Porcino, Clua, Trevisan, Vasconcelos, & Valente, 2017). Second, immersive experience does not guarantee positive learning outcomes. A recent study by Han (2020) found that the use of immersive virtual field trips using HMDs, compared with traditional virtual field trips using TVs, enhances virtual presence, but is not favorable for learning.

As an alternative to HMDs, large-screen displays such as CAVEs (Dulina & Bartanusova, 2015; Muhanna, 2015) generally have been considered for a few decades to enhance virtual presence in immersive virtual environments. Compared with normal-size display (e.g., desktop monitors), large-screen displays offer a wider FOV that enhances visual immersion (Bowman & McMahan, 2007). The larger the screen size, the wider the FOV - it provides. Hou, Nam, Peng, and Lee (2012) found that large screens enhance presence and overall virtual experiences.

Methods

Participants

Sixty-four undergraduate students at a flagship university in South Korea participated in this study. They were recruited through the university website and paid for their participation. Nineteen students were male (29.7%) and forty-five were female (70.3%). Twenty-two students' majors were in humanities and social studies (34.4%), and forty-two students' were in natural science and engineering (65.6%). They were four freshmen(6.3%), twelve sophomores(18.8%), 19 juniors(29.7%), and 29 seniors(45.3%). The average age of participants was 22.52 years.

Experimental design and variable measures

The experimental design was a 3×2 randomized-block factorial design (RBF-32) with repeated measures. Two independent variables were included: 1) egocentric distance (2m, 3.5m, and 5m) and 2) screen size (normal: 1.6m and extended: 2m). The blocks in the RBF-32 consisted of six treatment conditions per participant. Repeated measures were used, so the order of presentation of the six treatments was assigned randomly for each participant.

The first independent variable of this study, egocentric distance, had three levels: 2m, 3.5m, and 5m from the screen. The closest distance, 2m, was as close as possible without causing interference from the participant's shadow. The FOV for each distance was 64, 39, and 28 degrees, respectively (See figure 1.). The second independent variable, screen size, had two levels: normal (1.6m) and extended (2m), while the width was fixed at 2.3m.
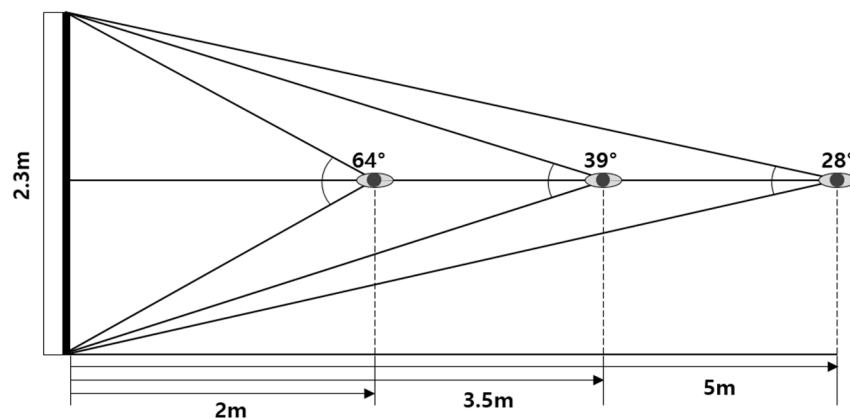

Figure 1. Three experimental distances and FOV angles

The dependent variables were three constructs of virtual presence: involvement (INV), spatial presence (SP), and realness (REAL). The questionnaire was developed using the 7-point Likert scale, based on two previous studies (Schuemie, Van Der

Straaten, Krijn, & Van Der Mast, 2001; Witmer & Singer, 1998). According to Schubert et al. (2001). INV factor, situation awareness, was the subjective evaluation of a given scene determined by asking the participant how much s/he understands the situation. In order to answer the question, participants need to figure out how the visual elements were structured. SP factor measured how immersed in the scene the participant felt and REAL factor estimated how realistically the scene was perceived. Although the scene was a realistic video clip, its focus was on the participants' subjective perceptions. The total number of questions was 10 (INV=3, SP=4, and REAL=3), and the internal consistency of the questions from each treatment condition was evaluated: INV(.85~.90), SP(.86~.92), and REAL(.90~.95), respectively (see Table 1).

Table 1. Internal Consistency for Each Treatment Condition

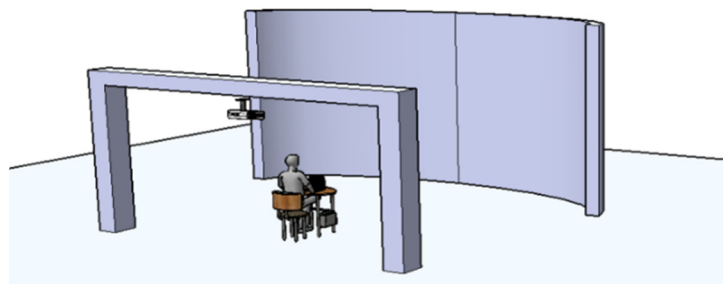| Egocentric distance	2m		3.5m		5m	
Screen size(height)	1.6m	2m	1.6m	2m	1.6m	2m
Involvement(INV)	.88	.89	.88	.89	.85	.90
Spatial Presence(SP)	.88	.88	.88	.87	.92	.86
Realness(REAL)	.91	.90	.93	.93	.92	.95

Experimental setting

Figure 2. Studio setting for the study experiment

Figure 2 depicts the studio setting for the study experiment. The size of the curved screen was approximately 3.7m in width and 2.5m in height. The beam projector was

mounted in the center 2m above the floor. The participants were asked to sit in front of the screen.

Figure 3 shows the large screen with the frame used in the experimental setting. The screen frame was installed to maximize the size from the floor. The curved shape was constructed using three veneer panels.
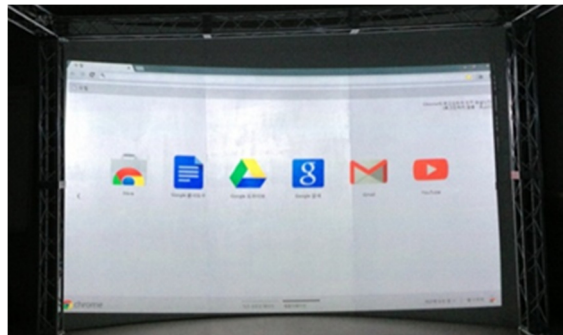

Figure 3. Screen size and demonstration

Figure 4. Experiment material - Video-clip setting

Experiment procedure and data analysis

In the experiment, the participants were asked to complete six treatment settings. Each participant was randomly assigned to a different sequence of treatments to prevent an order effect. In each treatment, when the participant was seated, a 20-second video clip(See figure 4 for example) was played. The video clips showed a

normal high-school classroom setting with eight students talking during a recess from class. The video clips were recorded in HD mode with the students' voices. The camera was set in the front and center of the class to record the scene.

After watching the video clip, the participant answered a virtual presence questionnaire in a paper-and-pencil form. Participants answered six times consecutively while they were seated in different treatment settings. The whole time spent for all six treatments was about 30 minutes.

Data were analyzed with a 3×2 randomized-block factorial design with repeated measure. A post-hoc test using Bonferroni was conducted when a significant difference was found in difference egocentric distance conditions. We used SPSS v21 for the statistical analysis.

Results

Descriptive statistics for dependent variables

Descriptive statistics, including the means and standard deviations of the dependent variables based on all six treatments, are shown in Table 2.

In order to determine whether the differences shown in the descriptive statistics were significant, a repeated-measure MANOVA with two within-subject factors of egocentric distance (2m, 3.5m, and 5m) and screen size (1.6m and 2.0m) was conducted. First of all, Mauchly's Test of Sphericity indicated that the assumption of sphericity had been violated for egocentric distance in three presence measures, $\chi^2(2) = 13.23, p = .001$ for INV, $\chi^2(2) = 18.30, p < .001$ for SP, and $\chi^2(2) = 12.11, p = .002$ for REAL. Therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.84, 0.80,$ and 0.85 respectively). Corrections for a within-subject factor with only two levels (screen size) were not needed, and sphericity was assumed for the interactive effect between egocentric distance and screen size.

Table 2. Descriptive Statistics

Virtual Presence (N=64)	Screen Size (Height)	Ego-centric Distance			
		2m	3.5m	5m	Total
Involvement (INV)	1.6m	3.49 (1.45)	3.23 (1.36)	3.16 (1.32)	3.30 (1.38)
	2m	3.85 (1.48)	3.51 (1.29)	3.26 (1.34)	3.54 (1.39)
	Total	3.67 (1.47)	3.37 (1.32)	3.21 (1.33)	3.42 (1.39)
Spatial Presence (SP)	1.6m	4.11 (1.28)	3.92 (1.21)	3.70 (1.22)	3.91 (1.24)
	2m	4.34 (1.37)	4.21 (1.16)	3.71 (1.23)	4.09 (1.28)
	Total	4.23 (1.33)	4.07 (1.19)	3.71 (1.22)	4.00 (1.26)
Realness (REAL)	1.6m	4.12 (1.50)	3.96 (1.30)	3.81 (1.35)	3.97 (1.39)
	2m	4.35 (1.41)	4.28 (1.26)	3.93 (1.39)	4.19 (1.36)
	Total	4.24 (1.45)	4.12 (1.29)	3.87 (1.37)	4.08 (1.38)

Effects of egocentric distance on virtual presence

The multivariate test revealed that the main effect of egocentric distance was significant [$F_{(6, 248)}$ = 3.612, Wilks' λ < .005, partial η^2 = .08]. To determine how students' INVs, SPs, and REALs differed depending on egocentric distances, a univariate ANOVA for each construct was performed. The results showed that students' INVs differed significantly depending egocentric distances [$F_{(1.68, 105.7)}$ = 5.612, Greenhouse-Geisser = .008, partial η^2 = .08]. Students' SPs and REALs also were significantly different : [$F_{(1.59, 100.3)}$ = 6.999, Greenhouse-Geisser = .003, partial η^2 = .10] and [$F_{(1.70, 107.0)}$ = 3.410, Greenhouse-Geisser = .044, partial η^2 = .05], respectively. Figures 5, 6, and 7 present each sub-construct of virtual presence based on the independent variables.
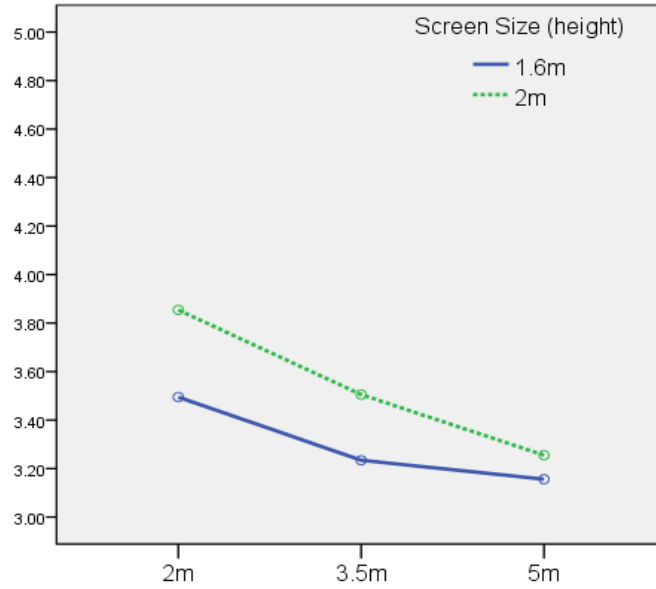
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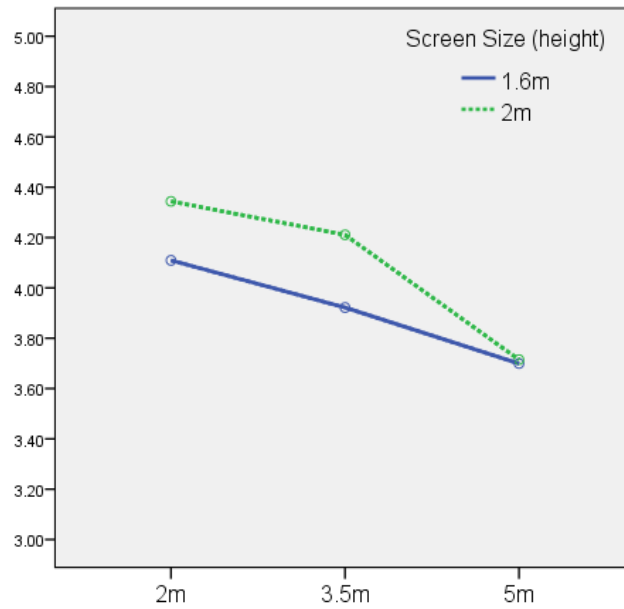Figure 5. Significant effect of egocentric distance on INV

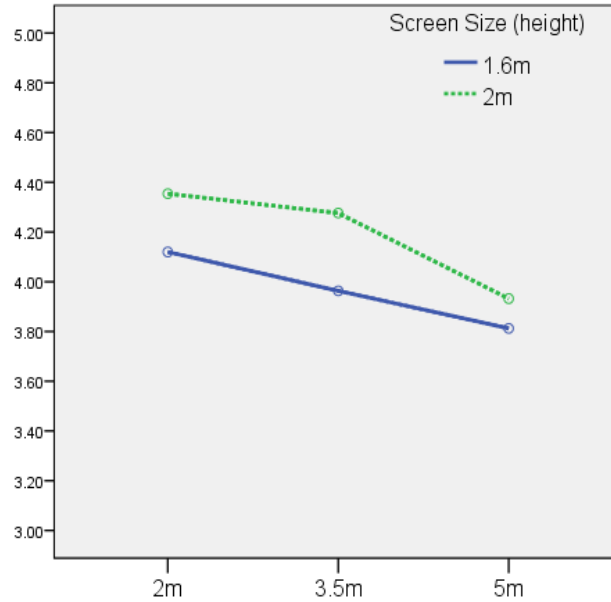Figure 6. Significant effect of egocentric distance on SP

Figure 7. Significant effect of egocentric distance on REAL

Since there were three levels (2m, 3.5m, and 5m) of egocentric distance, post-hoc analyses with Bonferroni correction were conducted to investigate pairwise comparisons for presence measures with estimated marginal means (See Table 3.).

Among the three distances, INV was the highest in 2m (M = 3.67, SE = .17), followed by 3.5m (M = 3.37, SE = .15) and 5m (M = 3.21, SE = .15), and the difference between 2m and 5m was statistically significant. SP was also highest in 2m (M = 4.23, SE = .15), followed by 3.5m (M = 4.07, SE = .17) and 5m (M = 3.67, SE = .17). Among three levels, students perceived significantly more SP at 2m and 3.5m than at 5m, but the difference between 2m and 3.5m was not significant. Finally, the mean REAL scores were 4.24 (SE = .16), 4.12 (SE = .15) and 3.87 (SE = .16) for 2m, 3.5m, and 5m, respectively. However, pairwise comparisons for REAL among the three egocentric distances were not statistically significant. There was no significant effects of the screen size on virtual presence [F (3, 61) = 2.229, Wilks' λ = .094, partial η^2 = .99]. Egocentric distance and screen size had no significant interactive effects on virtual presence [F (6, 248) = .736, Wilks' λ = .621, partial η^2 = .02].

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Table 3. Pairwise Comparisons for Virtual Presence by Ego-centric Distance

	I	J	I-J	SE	p	95% confidence internal for difference	
						Lower	Upper
Involvement (INV)	2m	3.5m	.305	.125	.054	-.004	.613
		5m	.469*	.170	.023	.050	.888
	3.5m	2m	-.305	.125	.054	-.613	.004
		5m	.164	.126	.589	-.145	.473
	5m	2m	-.469*	.170	.023	-.888	-.050
		3.5m	-.164	.126	.589	-.473	.145
Spatial Presence (SP)	2m	3.5m	.160	.128	.650	-.155	.476
		5m	.520*	.174	.012	.091	.948
	3.5m	2m	-.160	.128	.650	-.476	.155
		5m	.359*	.118	.010	.070	.649
	5m	2m	-.520*	.174	.012	-.948	-.091
		3.5m	-.359*	.118	.010	-.649	-.070
Realness (REAL)	2m	3.5m	.117	.131	1.000	-.206	.440
		5m	.365	.170	.106	-.053	.782
	3.5m	2m	-.117	.131	1.000	-.440	.206
		5m	.247	.122	.142	-.053	.548
	5m	2m	-.365	.170	.106	-.782	.053
		3.5m	-.247	.122	.142	-.548	.053

*p < .05

Discussion and Conclusion

Effects of egocentric distance and screen size

This study examined the effects of egocentric distance and screen size on learners' virtual presence in a large-screen display. In the research design, the values of these independent variables tested were: egocentric distance– 2m, 3.5m, and 5m, and screen size– 1.6m and 2m. The dependent variable, virtual presence, was used to

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explain learners' perceptions and experiences. Three constructs of virtual presence included involvement (IV), spatial perception (SP), and realness (REAL).

Egocentric distance (2m, 3.5m, and 5m) had significant effects on the sub-constructs of virtual presence INV, SP, and REAL. Post-hoc tests revealed that the egocentric distance of 5m yielded the worst virtual presence. In general, the 2m egocentric distance produced the highest level of virtual presence. We argue that the smallest egocentric distance in the experiment (2m) provided the widest FOV (64 degrees), offering the highest level of visual perception of the video clip. This high level of visual perception may enable participants' visual immersion, and so provide the best virtual presence. Regarding INV, only the difference between 2m and 5m was significant. In other words, it can be argued that 2m was the best and 5m, the worst distance. This means that INV, or situation awareness, apparently was affected by egocentric distance: the smaller the egocentric distance, the greater the awareness of the given scene.

However, the post-hoc test showed that SP was significantly different comparing 2m and 5m, and 3.5m and 5m. This shows that the 5m egocentric distance apparently was the worst condition for SP, or subjective immersion. In this case, the narrower FOV is particularly unfavorable to SP. Interestingly, the post-hoc test for REAL showed no significant differences among the 2m, 3.5m, and 5m egocentric distances. We assumed that the real classroom scene in the video clip was familiar enough to not be affected by these distances and their FOVs.

Despite the effects of egocentric distance on virtual presence, screen size made no significant difference. We assumed that the 0.4m difference between the 1.6m and 2m screens was neither large enough to be statistically significant, nor to affect FOVs. We found that wider FOVs generally provided better virtual presence. These results are supported by previous studies by Bowman & McMahan, 2007; Hou et al., 2012; and Laha et al., 2012; 2014. Particularly, Laha et al. (2012; 2014) argued the importance of FOR in visual perception and spatial judgment in an immersive VR setting. They argued that HMDs are better than single-walled CAVEs, and that four-

walled CAVEs are better than other settings because they provide a better FOR, which assures optimal FOV.

Designing VR environment using large-screen display for optimal FOV

A single-walled CAVE provides the lowest degree of FOV physically, compared to a four-walled CAVE or HMDs. It means that, for VR designers, one's FOV plays a critical role in being presented using a single-walled CAVE. In such large-screen display, one's FOV is determined by his egocentric distance, but it is normally unchangeable due to the fixed sitting/standing position. In this case, one's FOV should be controlled by the VR contents itself, not by the physical distance. VR contents are usually produced by a 3D development engine such as Unity 3D. VR developers can control the properties in the Camera Inspector to change FOV in the VR content.

It seems that FOV studies proposed an effective FOV level around 140~180 degrees. Lin et al. (2002) examined the effects of FOV on virtual presence. They compared four FOVs (60, 100, 140, and 180 degree), and found that virtual presence levels approached asymptotes for FOVs beyond 140 degrees. It indicated that VR designers should consider an optimal FOV level with over 140 degrees. However, VR sickness is also higher with increasing FOV because virtual presence is positively correlated with VR sickness(Fernandes & Feiner, 2016; Lin et al., 2002). In conclusion, in terms of VR environment design, one's FOV should be concerned by his egocentric distance as well as the VR content itself.

Limitations and future research

The results of the present study contribute to the principle frequently argued in previous studies (Bowman & McMahan, 2007; Hou et al., 2012; Laha et al., 2012; 2014), that a wider FOV provides better visual perception and virtual presence,

particularly in a large-display setting. Nevertheless, the present study included several limitations. First, the difference between the two screen sizes was too small to be statistically significant. It is necessary to conduct a further study using screens of more distinct size. Second, the video clip showed an actual scene of a normal classroom. In the immersive VR environments, virtual contents such as avatars and 3D models are widely used. Also, virtually represented contents can be differently perceived in experimental settings. Third, the participants' eyesight levels were not considered as a possible factor to hinder the results of the study. Further research needs to be conducted taking those limitations into account.

In addition, CAVE systems have a distinctive advantage for collaborative learning (Mestre, 2017).; multiple students are able to experience VR together in the same space. Further research should focus on the design of collaborative VR learning with CAVE system. In this manner, a few recent studies (Chen et al., 2019; de Back, Tinga, Nguyen, & Louwerse, 2020) have shown the application of CAVE-based VR for immersive collaborative learning.

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