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# Effects of Audio-Visual Information on Interpersonal Distance in Real and Virtual Environments

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**Abstract.** In this study, interpersonal distances were measured in a real environment (RE) and an immersive virtual environment (VE) under each audiovisual condition (bimodal (V-A), visual-only (V/o), and auditory-only (A/o)), in order to design interpersonal services in a VEs and experiments in a VEs that are usually difficult to set up in REs. The experiment revealed the interpersonal distances in the VE that can be converted to the RE and the audiovisual conditions that cause them.

## 1 Introduction

Personal space is one of the most important factors for the smooth operation of social life. Leslie Hayduk described personal space as the area around a person where the intrusion of others causes discomfort [1]. The length of interpersonal distance that forms personal space changes accordingly as the environment changes [2] and affects the quality of service [3].

The virtual reality market is currently growing, with more and more services such as stores and offices communicating through avatars in a virtual environments (VEs) [4]. Therefore, there is a need to communicate at an appropriate interpersonal distance in VEs, just as in real environments (REs). In addition, the study of interpersonal distance in a VE has great potential for research applications. Experiments in a VE make it possible to perform experiments that are difficult to perform in an RE [5], while maintaining external validity and taking many factors into account [6]. From the above, it is important to clarify the interpersonal distance in the VE, and it is also effective to compare it with that in the RE, where much knowledge is available.

Studies on interpersonal distance in VE include the study which revealed the existence of interpersonal distance in VE [7], and the study which revealed the length of interpersonal distance and its difference by gender and age [8][9]. In those studies, the information used to perceive the approaching person is only visual information, not auditory information. However, in two-way communication, it is necessary to examine interpersonal distance when both visual and auditory information is available. Additionally, the interpersonal distance when only auditory information is used to perceive the approaching person is

unknown. Therefore, it is necessary to study the interpersonal distance when the perceived information is visual and auditory, visual only, and auditory only. The purpose of this study is to measure the interpersonal distance in the VE under each audiovisual condition and to compare the results with those of the RE.

## 2 Experimental Design

### 2.1 Setup

To investigate the effects of RE and VE, as well as visual and auditory information, on interpersonal distance, the same space and the same confronting mannequin/avatar were prepared in an RE and a VE. Additionally, the visual and auditory conditions were restricted. Three within-subject factors were manipulated: the environment, approach direction, and perceived audiovisual condition.

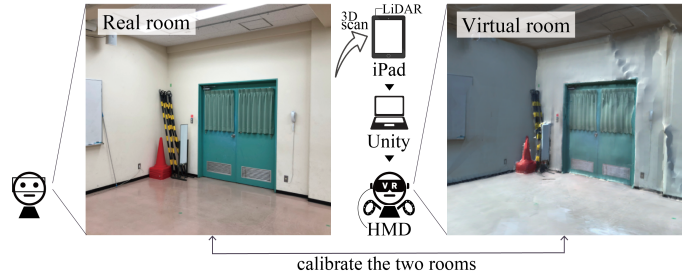
Two environments were prepared: an RE and a VE. For the RE, a 7.2 m  $\times$  7.5 m  $\times$  3.1 m room was used. A 3D scan of the room used in the RE was taken by a 12.9-inch iPad Pro with Light Detection and Ranging (LiDAR) and imported into Unity. This allowed us to recreate the real room in a VE as shown in the Fig.1. LiDAR is an optical sensor technology that identifies the distance to an object and its properties. For sound output in VE, the audio environment "Steam audio" is used, and the sound is heard in three dimensions. In the VE experiment, video and audio were presented using a head-mounted display (HMD; Dell Visor VR118, Dell Inc., resolution: 1440  $\times$  1440 on each side, 590 g) and headphones (SONY, MDR-CD900 ST). To match the viewing angle, the viewing angle was standardized to 110°, the same as the HMD, by wearing goggles that limited the viewing angle during the experiment in the RE.

Three audiovisual conditions were prepared: a bimodal condition in which the subject could see the approaching person and hear his voice (V-A condition), a visual-only condition in which the subject could see the approaching person but not hear his voice (V/o condition), and an auditory-only condition in which the subject was blindfolded and could not see the approaching person but could hear his voice (A/o condition). As an approaching person, an avatar was used in VE, and a mannequin with an iPad Pro showing an image of the avatar's face fixed on its face was used in RE. The voice of the approaching person was a recording of a voice saying "Hello".

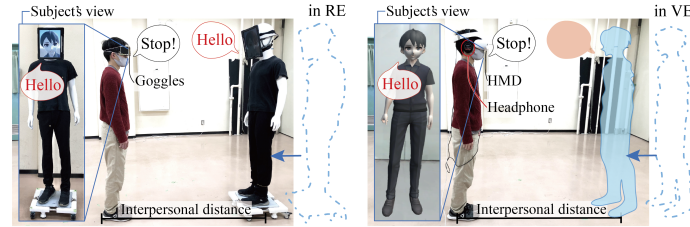
Approach directions were 8 directions of 45° each, with the front direction being 0°. Each subject was tested in a random order concerning the experimental conditions. The experiment was conducted under the scenario that the approaching person was a shopkeeper who had never met the subject before.

### 2.2 Procedure

In the experiment, the RE and VE were calibrated to match in size, the interpersonal distance was determined by the stop-distance method, and the egocentric distance was measured by the blind walking task. Initially, calibration was performed to align the perceived size of the RE and VE. This is because it has



**Fig. 1.** The real room and the virtual room used in the experiment.



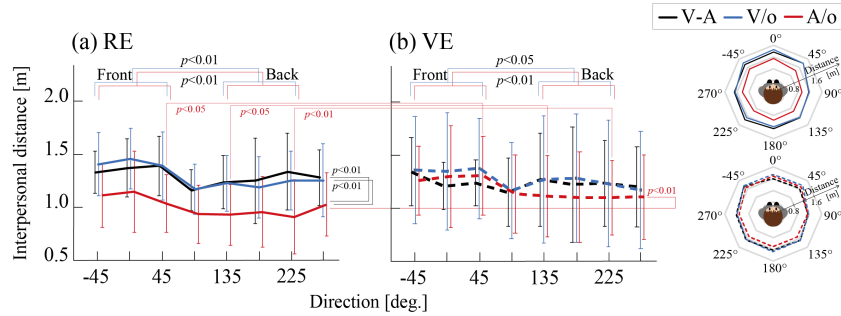
**Fig. 2.** Scene of the experiment in the case of approach from the front direction under V-A conditions.

been shown that distances are perceived as reduced in VEs compared to REs [10][11], and the degree of reduction depends on the viewing angle and image quality of the device used [12]. The subject stood facing forward with his heels aligned with the markings in the center of the room in the RE and wore the HMD. Subjects alternately looked at or listened to the RE and the VE for room size, eye level, and the appearance and loudness of the approaching person. And if they differed, the VE's were matched by adjusting their sizes. The next step was to determine the interpersonal distance using the stop-distance method as shown in the Fig.2 [13][14]. The approaching person gradually approached from a distance of 2.5 m from the subject, and when the subject felt uncomfortable if the person approached any closer, the subject signaled the approaching person to stop. Next, interpersonal distance was measured in a blind walking task [15][16]. The subject grasped the position of the approaching person based on the audiovisual information. They then closed their eyes and walked to the position where they thought the approaching person was. The distance walked was measured. This made it possible to measure the egocentric distance, which is the distance that is perceived.

The subjects were 8 males between the ages of 22 and 25 with no problems in walking, vision, or hearing. Since the length and characteristics of the interpersonal distance vary depending on gender [8][9], the subjects in this study were standardized as males.

### 3 Result and Discussion

In this section, the results and a discussion of the experiment are presented. A comparison of the interpersonal distance between each audiovisual condition in



**Fig. 3.** Graphs comparing the interpersonal distance for each audiovisual condition in the RE and the VE.

the RE and VE is shown in Fig.3. A t-test was conducted at a significance level of 5%. The experiment revealed the interpersonal distances in the VE that can be converted to the RE and the audiovisual conditions that cause them.

In the VE, there was no significant difference between the front ( $-45^\circ$ ,  $0^\circ$ ,  $45^\circ$ ) and rear ( $135^\circ$ ,  $180^\circ$ ,  $225^\circ$ ) interpersonal distances in the V-A condition, and the front interpersonal distance was significantly greater than the rear interpersonal distance in the V/o and A/o conditions, respectively. The same tendency was observed in each audiovisual condition in the RE. The fact that the front distance is greater than the rear distance is consistent with previous studies [7][17]. This suggests that the appearance of the shopkeeper with a greeting in front (V-A condition) is natural, but the silent appearance of the shopkeeper (V/o condition) or with only a voice (A/o condition) is unnatural, which may have caused greater discomfort and a desire for greater interpersonal distances.

Besides, in the RE, the A/o condition, the interpersonal distance was significantly smaller than that in the V-A condition, but it was not significantly different compared to the V/o condition. These results suggest that the interpersonal distance in the V-A condition in the RE is caused by the interpersonal distance in the V/o condition rather than the interpersonal distance in the A/o condition. In the VE, there was no significant difference between the V-A, V/o, and A/o conditions. Most of the subjects were accustomed to having a sound image nearby in the RE but were not accustomed to the presence of a sound image in the VE. Therefore, the range of alertness in the A/o condition is wider in the VE, and the interpersonal distance may be greater than in the RE.

Furthermore, in the V-A and V/o conditions, there was no significant difference in the interpersonal distance between the VE and RE. In the A/o condition, the interpersonal distance was significantly greater in the VE than in the RE, especially in the  $45^\circ$ ,  $135^\circ$ , and  $225^\circ$  directions. This indicates that the interpersonal distance in the VE is significantly greater than that in the RE, especially when approaching from a diagonal direction.

In this study, the experiments were conducted with the same appearance and voice of the approaching person with the same resolution and viewing angle of the HMD, but the effects of these factors on the interpersonal distance should be studied in the future.

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