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Research article

Influence of partition layouts on speech privacy in open-plan offices

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A R T I C L E I N F O

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A B S T R A C T

Different partition layouts were compared to determine how to increase speech privacy while maintaining communication efficiency between workers in an open-plan office. A preliminary survey was used to determine current usage and conditions of partitions in open-plan offices. The survey results were used to select four partition layouts for testing: face-to-face, parallel, crossed-rod, and orthogonal. A computer modeling was used to test the partition layouts at three different partition heights: 1.2, 1.5, and 1.8 m. The modeling results showed that the parallel- and crossed-rod-type layouts offered the best speech privacy at the lowest partition height, but the differences among layouts disappeared as the partition height was increased. Furthermore, an acoustic field experiment was performed using partitions with a 1.5 m height following the ISO 3382-3 standard. The experimental results showed that the face-to-face layout resulted in the least speech privacy. Based on these results, an open-plan office needs to ensure that workers are spaced a sufficient distance apart and that they do not face each other to ensure speech privacy. Additionally, speech privacy should be considered in the design stage of the office space.

1. Introduction

The most significant factor when planning and utilizing business facilities is worker efficiency [1]. Ensuring speech privacy can enhance the concentration and productivity of office workers [2]. The floor plan of an office affects speech privacy, which in turn affects worker efficiency. Most office buildings have a floor plan that is appropriate for the nature of their work [3]. An open-plan office is a widely used floor plan to create an efficient work environment [4], and it offers the advantages of efficient worker communication and space usage for flexible work responses [5,6]. However, personal speech privacy is vital to knowledge-intensive work, and it should be given a higher level of priority than in labor-intensive work. Furthermore, a lack of speech privacy has been reported to have a detrimental effect on worker efficiency and productivity in offices [7]. Office noise can cause annoyance, fatigue, and stress, which can lead to decreased work efficiency and even health problems [8]. While numerous types of noises in office are distracting, conversation has been reported to have the greatest impact [9–11]. Owing to their inherent structural features, open-plan offices cannot provide the high level of speech privacy required by knowledge-intensive workers unless modified in some way.

Significant research has been conducted on evaluating speech privacy both theoretically [12,13] and empirically [14,15]. Internationally, the ISO 17624:2004 standard presents rules for office and workroom noise management, as well as the use of acoustic screens for noise reduction [16]. More recently, ISO 22955:2021 established technical guidelines for ensuring acoustic quality in

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open-plan offices [17]. In addition, ISO 23351:2020 offers a method to determine the potential for speech-level reduction of furniture ensembles and enclosures, thereby enabling increased speech privacy for an occupant speaking inside the product [18]. In Korea, the KS F ISO 3382-3 standard was established in response to ISO 3382-3, and it provides guidance on monitoring numerous acoustic parameters in workspaces [19]. Both ISO 3382-3 and KS F ISO 3382-3 defines several indices for evaluating the acoustic performance of an open-plan office: the speech transmission index (STI), background noise, spatial decay rate of speech ($D_{2,S}$), A-weighted sound pressure level of speech at a distance of 4 m ($L_{p,A,S,4\ m}$), distraction distance (r_D), and privacy distance (rP). These standards suggest that an open-plan office will have a good room acoustic condition when $D_{2,S} > 8$ dB, $L_{p,A,S,4\ m} < 48$ dB(A), and $r_D < 5$ m. Unfortunately, most open-plan offices have poor room acoustic condition with $D_{2,S} < 5$ dB, $L_{p,A,S,4\ m} > 52$ dB, and $r_D > 11$ m [14,19].

Meanwhile, research into the acoustics of open-plan offices has continued in various ways. Hongisto et al. [20] presented a table for evaluating open-plan offices in terms of $D_{2,S}$, $L_{p,A,S,4\ m}$, and r_D. Keränen and Hongisto [21] presented a model that can be used to predict the spatial decay of speech to address the complexity of room acoustic variables. Virjonen et al. [22] confirmed that speech privacy can be improved by adjusting screen height, room height, ceiling absorption, floor absorption, screen absorption, and masking sound level. Lee et al. [23] simulated an open-plan office to investigate the effectiveness of adjusting the partition height as proposed in IEC 60268. They [24] also investigated changes in internal sound field conditions. Song [25] studied the improvement of indoor spaces with an open floor plan and emphasized the need for partitioning to ensure space division and personal privacy. Roskams et al. [26] found that acoustic comfort in open-plan offices is largely determined by noise sensitivity. Park et al. [27] investigated the correlations between speech privacy, noise, job characteristics, and job satisfaction, and they found a negative correlation between job satisfaction and speech privacy. Yadav et al. [28] measured the acoustic performance in different types of open-plan offices according to ISO 3382-3. Yadav et al. [29] investigated the impact of changing the floor conditions in an open-plan office. Park et al. [30] studied the indoor noise level of open-plan offices and confirmed that the site characteristics significantly affected the indoor noise level. Lee et al. [31] investigated the correlations of workplace design and personal factors with speech privacy satisfaction. Furthermore, Jo et al. proposed a new four-level classification criteria based on $L_{p,A,S,4\ m}$ [32].

Hence, research on open-plan offices is focusing on ensuring the speech privacy of employees. Different factors considered to affect speech privacy include the use of sound-absorbing materials, masking noise, blocking noise using a partition, and the angle of the sound source [33]. However, sound-absorbing materials and masking should be considered at the design stage of the office space, and they can be very difficult to implement after completion. Thus, using them to adjust speech privacy to specific situations is difficult. Conversely, a partition is much more flexible and is a popular element used to separate workspaces between workers. The partition height, sound absorption coefficient, layout, and other factors influence speech privacy [34]. Partitions with a height above 1.5 m have been shown to be effective at securing speech privacy [35]. Keränen et al. [36] first conducted an experimental study that investigated the acoustic performance of several sound-absorbing surfaces and partition height in open-plan office simultaneously. While a proper partition height for speech privacy has been suggested, the proper partition layout has not been discussed. This is a critical significant because different partition layouts affect the distances between and orientations of workers. Sarwono et al. [37] emphasized the importance of the layout for open-plan offices. Rindel et al. [38] used computer simulations to analyze the acoustic environment of an open-plan office, and Sarwono et al. [39] used both simulations and field measurements to evaluate the importance of the layout for an open-plan office. Since the withdrawal of ISO 10053:1991, which was established in 1991, no standards have been established for office screens (partitions).

Therefore, the present study aims to determine whether the layout of partitions used in open-plan offices affects speech privacy. Based on the experimental results, this study proposes the optimal partition height and layout, considering speech privacy, which has not been previously investigated. For this purpose, a preliminary survey was conducted to evaluate the actual state of open-plan offices regarding the partition layout and partition height, as well as the positions of the sound sources and receiving points. Then, an acoustic field experiment and computer modeling were performed in accordance with ISO 3382-3 to compare the effectiveness of different partition layouts on speech privacy in an open-plan office.

2. Materials and methods

2.1. Preliminary survey

2.1.1. Methodology

A preliminary survey was conducted to determine the actual state of current open-plan offices. Signed consent was obtained from every participant before the survey. A questionnaire was sent to 113 workers in 51 different open-plan offices. The preliminary survey was conducted in small offices, with a maximum of 20 employees. One person per workstation was requested in each office to participate in the survey, resulting in 2–3 respondents per office. For this reason, there may be some differences from the results of the survey targeting the total number of people in the office. Of the respondents, 51.3 % were in their 20s, 38.9 % were in their 30s, 8.8 % were in their 40s, and 0.9 % were in their 50s. The questionnaire was provided through Google Forms and in PDF format to ensure that the respondents were not limited by time or location. The respondents were queried on three aspects: where they most often heard the voices of their colleagues, the average partition height, and the partition layout. The respondents were also asked to send pictures or sketches of the partition layout.

2.1.2. Results

Fig. 1 shows the survey results. Over 80 % of the respondents answered that they heard voices from the same department. In addition, 80 % of the respondents answered that the partitions had a height of 1.2 m. With regard to the partition layout, 53 % of the respondents were in a face-to-face layout, 34 % were in a parallel layout, 10 % were in a crossed-rod layout, and 3 % were in an orthogonal layout.

2.2. Research methods

2.2.1. Acoustic field experiment

The survey results were used to set up an acoustic field experiment and computer model to evaluate different partition layouts. The acoustic field experiment took place in a lecture room in C University that resembled an open-plan office, and measurements were performed in accordance with ISO 3382-3. Because offices have diverse sizes, the standard does not specify a representative size. The lecture room (W: 13 m, L: 8 m, H: 4 m) was selected because its dimensions resembled the average dimensions of open-plan offices identified in the survey. The background noise in the lecture room, which had fabric tiles on the side walls, gypsum tax on the ceiling, and decorative floor tiles, was 27.2 dB(A), and the reverberation time was 1 s. During the experiment, another workstation was placed in the office to make a typical setup, and all air conditioners were turned off.

$D_{2,S}$, $L_{p,A,S,4\ m}$, and r_D were utilized as single-number quantities of the speech privacy for both the acoustic field experiment and computer model. $D_{2,S}$ represents the spatial attenuation rate of the sound pressure level. $L_{p,A,S,4\ m}$ is related to the sound absorption power inside a space. r_D is based on STI. Hongisto et al. presented grades for the use of these single-number quantities to describe the acoustic quality [20]. Table 1 lists the grades proposed by Hongisto et al. The $D_{2,S}$ values were A: >11, B: 9–11, C: 7–9, D: 5–7, and E: <5. The $L_{p,A,S,4\ m}$ values were A: <48, B: 48–51, C: 51–54, and D: >54. r_D is A: <5, B: 5–8, C: 8–11, D: 11–15, and E: >15. Fig. 2 shows the locations of the sound sources and receiving points in each layout, which were positioned along a straight-line path across the workspace as described in ISO 3382-3. Specifically, four sound-receiving points were set between 2 and 16 m. The sound sources were monitored twice in opposing directions along lines 1 and 2. The experiment was performed after the sound sources and receiving points were placed in position (i.e., on seats).

The sound source produced pink noise from an omnidirectional speaker at 57.4 dB(A) [14,19]. The height of the source and sound-receiving points were set at a height of 1.2 m. STI measurements were performed using the HMS III from Head Acoustics. Measurements were sound pressure level were collected using NTi XL2(NTi Audio, Schhan, Liechtenstein) and B&K type 2270(Brüel & Kjær, Nærum, Denmark). The partitions were made of PVC, which is commonly used in open-plan offices. The partition panels comprised a PVC frame and 40-mm-thick layer of plywood that was finished with a 2.5-mm-thick sponge layer on one side and a 2.5-mm-thick fabric layer on the other side. Each panel was 45 mm thick, 1.2 m wide, and at least 1.5 m tall, which has been shown to help ensure speech privacy [35]. Fig. 3 shows the form of each partition layout.

2.2.2. Computer modeling

For the computer modeling, the experimental space and partitions were 3D modeled using the AutoCAD software, as shown in Fig. 4. Subsequently, the acoustic simulation software Odeon was used to construct a virtual sound field based on the acoustic

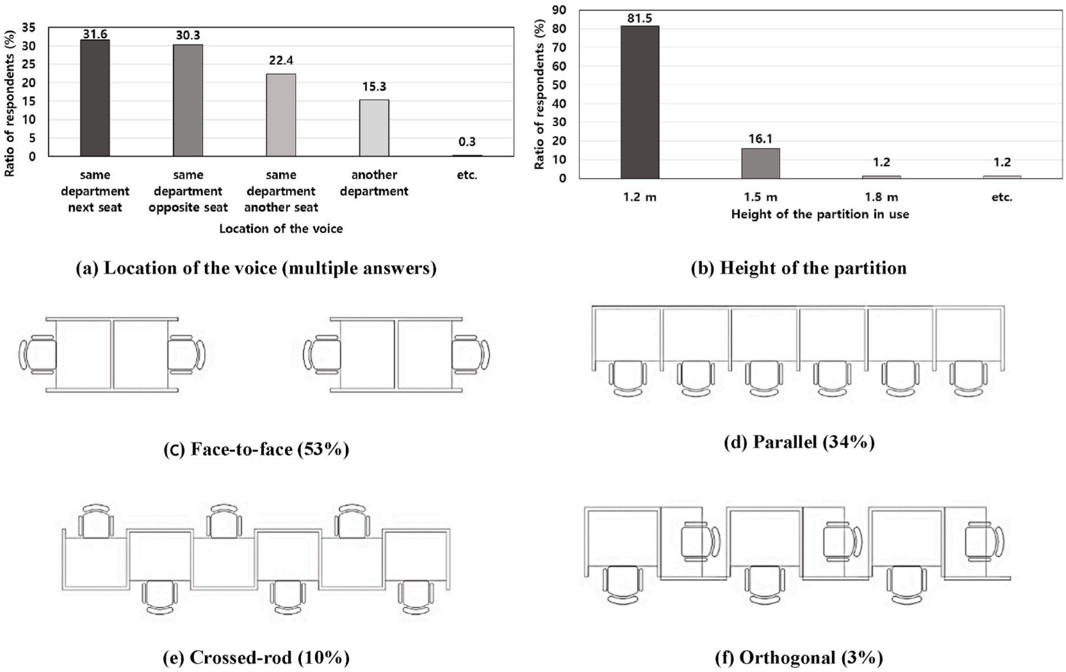
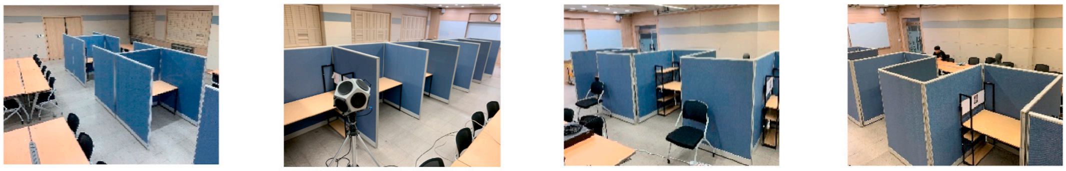


Fig. 1. Response to survey questions: (a) location of voices (multiple answers), (b) partition height, (c) face-to-face, (d) parallel, (e) crossed-rod, and (f) orthogonal.

Table 1
Classification of three single-number quantities of the ISO 3382-3 standard describing the acoustic quality of open-plan offices [20].

Grade	$D_{2,S}$ [dB(A)]	$L_{p,A,S,4\ m}$ [dB(A)]	r_D [m]
A	>11	<48	<5
B	9–11	48–51	5–8
C	7–9	51–54	8–11
D	5–7	>54	11–15
E	<5	–	>15

Fig. 2. Locations of sound sources and receiving points for different layouts: (**a**) face-to-face, (**b**) parallel, (**c**) crossed-rod, and (**d**) orthogonal.



(a) Face-to-face **(b) Parallel** **(c) Crossed-rod** **(d) Orthogonal**

Fig. 3. Office partition layouts of the field acoustic experiment: (**a**) face-to-face, (**b**) parallel, (**c**) crossed-rod, and (**d**) orthogonal.

parameters of the experimental space and the sound absorption coefficients of the materials [40]. Before portioning, the background noise in the office was set to 38 dB, ranging from 125 Hz to 8 k Hz, with a reverberation time of 1 s. The sound source, which is an omnidirectional speaker, was set to radiate at 68.4 dB(A). The sound absorption coefficient of each material was calculated by using data from the literature and information provided by manufacturers and vendors. The sound absorption coefficient was set to the noise reduction coefficient, which was computed as the average of 250 Hz, 500 Hz, 1 kHz, and 2 kHz. The materials and noise reduction coefficients for each part are shown in Table 2. Three partition heights that are commonly used in offices were also modeled: 1.2, 1.5, and 1.8 m. When a 3D virtual office created via computer modeling was examined, the reverberation time decreased and RASTI increased with increasing partition height. This confirmed the acoustic accuracy of the modeled office. The RT and RASTI of the parallel layout are shown in Fig. 5. The ISO 3382-3 Annex D provides the standard deviation of single-number quantities from a round-robin test. These values are used in the test report to describe the accuracy of the method, unless better estimates are available. The standard deviations for each single-number quantity are shown in Table 3.

3. Results

3.1. Acoustic field experiment

Table 4 presents the sound pressure levels at receiving points (R1–R4) in the acoustic field experiment for different partition layouts and a partition height of 1.5 m. The average difference in sound pressure level among the layouts was 1.5 dB. Between R1 (i.e., the receiving point closest to the sound source) and R4 (i.e., the sound source furthest from the sound source), the face-to-face layout showed the smallest decrease in sound pressure level at 2.8 dB. Meanwhile, the orthogonal layout showed the largest decrease of 3.6 dB. However, the just noticeable difference (JND) in sound pressure level is defined as 3 dB [41]. Therefore, the effect of the partition layout on the sound pressure level was concluded to be insignificant.

Table 5 presents the average grades of each layout for the three single-number quantities. All layouts had very similar values of $L_{p,A,S,4\ m}$ and $D_{2,S}$ for lines 1 and 2. Additionally, r_D was 15 m or less for all layouts except the face-to-face layout. All layouts, except for the face-to-face layout, had a grade of C or D. However, the face-to-face layout had a grade of E regardless of the line. In the face-to-face layout, r_D was 15.6 m for Line 1 and 21.3 m for Line 2. $D_{2,S}$ and $L_{p,A,S,4\ m}$ represent the attenuation of sound pressure levels within a space. Therefore, the acoustic field experiment showed hardly any changes in the grades of these indices with different layout. However, according to r_D, the face-to-face layout was the most detrimental to speech privacy for all lines. Similarly, the differences in single-number quantities between lines were very small for all layouts, but there was a slight difference in r_D between lines. $D_{2,S}$ and $L_{p,A,S,4\ m}$ depends on the obstacles present on the measurement path. However, the obstacles between the lines and the sound absorption of the space were the same, so there was no difference. Conversely, r_D is based on STI, and the difference is likely because the sound absorption and reflection of the space differ for each line depending on the position of the sound source. In summary, the face-to-face layout was concluded to be least conducive for speech privacy in an open-plan office.

In addition, the standard deviations shown in Table 3 are used to compare single-number quantities using the layout method shown in Fig. 6. Except for $L_{p,A,S,4\ m}$, $D_{2,S}$, and r_D are within the standard deviations for the parallel, crossed-rod, and orthogonal methods. Thus, no significant difference is found between the measurements for these layouts. However, the face-to-face layout tested in the same space and under the same conditions shows that $D_{2,S}$ and r_D are outside the standard deviation, indicating a potential difference in measurements compared with other layouts. The paired *t*-test was used to evaluate the statistical significance of differences among the

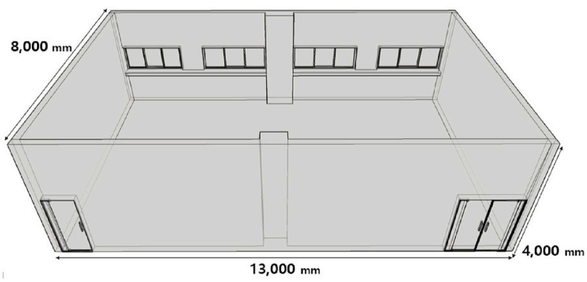


Fig. 4. 3D model of the measurement location (i.e., lecture room at C university).

Table 2
Sound absorption coefficient by material in Odeon.

Part	Material	NRC[a]
Ceiling	KCC Miton	0.520
Wall	Painted on concrete, polyester	0.015, 0.480
Floor	Linoleum tile	0.015
Partition	Partition screen	0.550
Window	Glass, PVC frame	0.038, 0.075
Desk	Wood, metal	0.083, 0.075
Chair	Wood, metal	0.083, 0.075

[a] NRC: average of the sound absorption coefficient with 250 Hz, 500 Hz, 1 kHz, and 2 kHz.

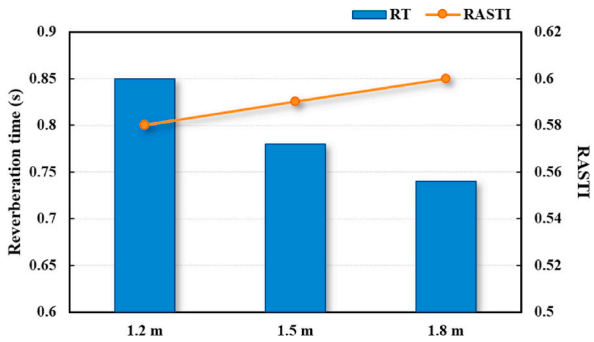


Fig. 5. Comparison of reverberation time and RASTI in parallel layouts for office modeling accuracy review.

Table 3
Standard deviations for each single-number quantity.

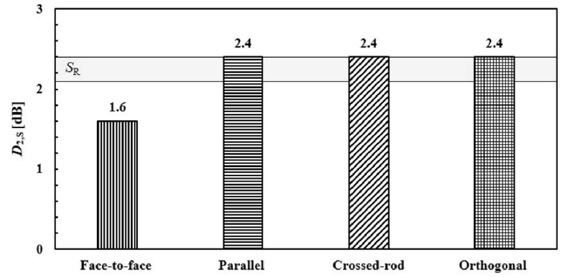
	$D_{2,S}$ [dB]	$L_{p,A,S,4m}$ [dB]	r_D [%]
S_R	±0.3	±1.1	±16

Table 4
Measured sound pressure level at each sound-receiving point in the field acoustic experiments.

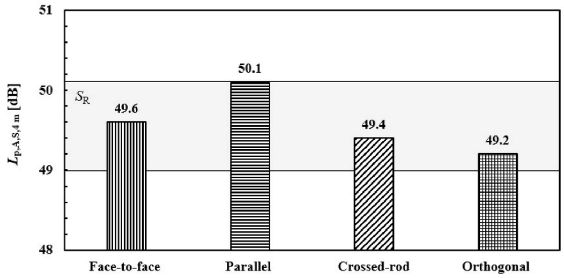
Sound-receiving points	Face-to-face		Parallel		Crossed-rod		Orthogonal	
	Line 1	Line 2	Line 1	Line 2	Line 1	Line 2	Line 1	Line 2
R1	50.1	50.1	51.7	51.7	51.1	51.1	51.1	51.1
R2	48.1	48.1	50.3	50.3	49.2	49.2	49.2	49.2
R3	49.1	49.1	49.2	49.2	49.1	49.1	48.5	48.5
R4	47.3	47.3	48.6	48.6	47.7	47.6	47.6	47.5

Table 5
Field acoustic experiment results expressed in grades.

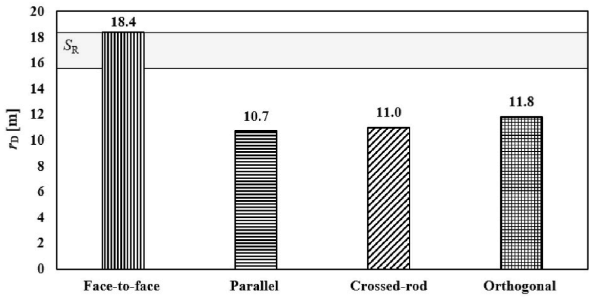
Office partition layout		$D_{2,S}$ [dB(A)]	$L_{p,A,S,4\ m}$ [dB(A)]	r_D [m]
Face-to-face	Line 1	1.6	49.6	15.6
	Line 2	1.7	49.6	21.3
	avg	1.6 (E)	49.6 (B)	18.4 (E)
Parallel	Line 1	2.4	50.1	11.3
	Line 2	2.4	50.1	10.1
	avg	2.4 (E)	50.1 (B)	10.7 (C)
Crossed-rod	Line 1	2.4	49.4	10.2
	Line 2	2.4	49.4	11.8
	avg	2.4 (E)	49.4 (B)	11.0 (D)
Orthogonal	Line 1	2.3	49.2	13.6
	Line 2	2.6	49.3	10.0
	avg	2.4 (E)	49.2 (B)	11.8 (D)



(a) $D_{2,S}$



(b) $L_{p,A,S,4\ m}$



(c) r_D

Fig. 6. Comparison standard deviation by layout for single-number quantities in field acoustic measurements.

layouts. Based on the *t*-test, the null hypothesis was accepted as all p-values were greater than 0.05. This implies that there is no statistically significant difference between the layouts. The statistical results are shown in Fig. 7.

3.2. Computer modeling

The computer model was used to compare four partition layouts: face-to-face, parallel, crossed-rod, and orthogonal. Additionally, three partition heights were compared: 1.2, 1.5, and 1.8 m. Table 6 presents the sound pressure levels at each receiving point with the different partition layouts and heights. At a partition height of 1.2 m, the average difference in sound pressure level among the layouts was 1.6 dB. At 1.5 m, the average difference was 2.2 dB, and at 1.8 m, the average difference was 2.8 dB. At the partition heights of 1.2 and 1.5 m, the crossed-rod layout showed a greater reduction in sound pressure levels between R1 and R4 compared with the other layouts. The face-to-face layout showed twice the reduction in sound pressure level between R1 and R4 at a partition height of 1.8 m compared to at 1.5 m. However, considering the JND in sound pressure level is 3 dB [36], the sound pressure level did not vary significantly among the layouts.

Table 7 compares the single-number quantities of each layout. Because $D_{2,S}$ is related to the inside of the space, the values did not change depending on the layout or partition height. Similarly, $L_{p,A,S,4\ m}$ is related to the sound absorption power inside the space, so the values did not change much depending on the partition layout or height. However, r_D showed significant variations depending on the partition layout and height. At a partition height of 1.2 m, the face-to-face layout received the lowest grade (D) for speech privacy. When the partition height was increased to 1.5 m, all layouts achieved the same grade. Finally, at a height of 1.8 m, the parallel layout

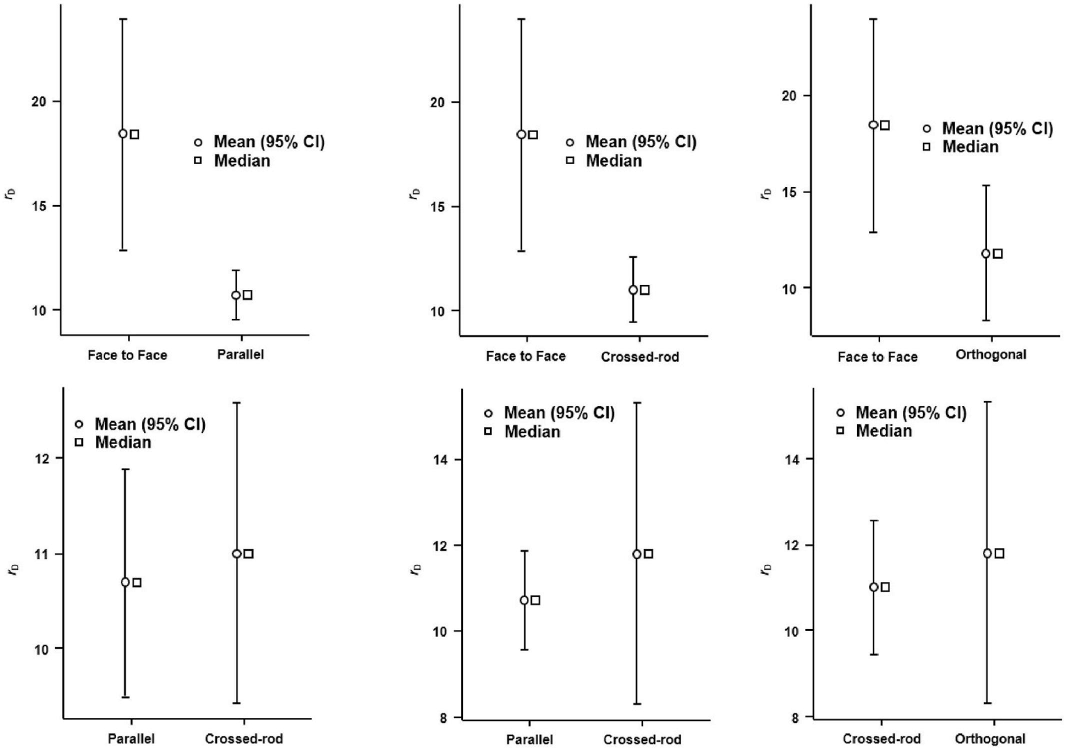


Fig. 7. Statistical differences between the experimental results of different partition layouts according to the paired *t*-test in field acoustic measurements.

Table 6
Measured sound pressure level at each sound-receiving point in the computer modeling.

Sound-receiving points		Face-to-face		Parallel		Crossed-rod		Orthogonal	
		Line 1	Line 2	Line 1	Line 2	Line 1	Line 2	Line 1	Line 2
1.2 m	R1	51.0	51.3	51.9	51.3	52.1	52.5	51.9	51.5
	R2	50.1	49.9	51.4	51.2	50.8	51.0	50.7	51.5
	R3	50.0	49.7	50.4	50.6	50.6	51.4	50.5	51.1
	R4	49.0	49.4	50.3	50.3	50.2	50.3	50.4	50.3
1.5 m	R1	49.4	49.8	50.3	50.4	50.7	51.7	50.0	50.1
	R2	47.6	47.7	49.6	49.7	49.4	49.0	48.6	49.8
	R3	48.1	48.3	48.7	49.1	48.9	50.0	48.6	47.8
	R4	46.7	46.9	48.7	48.5	48.2	48.3	48.6	48.5
1.8 m	R1	49.1	49.2	49.7	49.6	50.3	51.0	49.3	49.3
	R2	46.2	45.6	48.9	49.1	48.2	48.3	47.7	49.0
	R3	47.6	47.3	47.8	48.1	48.6	49.6	47.7	46.9
	R4	44.7	44.6	47.3	47.7	47.0	46.6	46.8	47.5

had the lowest grade. The face-to-face layout showed the worst speech privacy at a partition height of 1.2 m. When the partition height was 1.2 m, the sound source and receiving points were at the same height as the partition, so noise was not absorbed or blocked. Increasing the partition height helped absorb and block noise. However, changing the partition height did not significantly improve the speech privacy with the parallel layout.

In addition, the standard deviation values shown in Table 3 are used to compare the single-number quantities using the layout method in Fig. 8. In terms of $D_{2,S}$, for the face-to-face and crossed-rod layouts exhibited higher values, but all layouts have a grade of E. However, $L_{p,\ A,\ S,\ 4\ m}$ was within the standard deviation value for all layouts. For r_D, at a partition height of 1.2 m, the parallel, crossed-rod, and orthogonal layouts do not fall within the standard deviation of the face-to-face layout. However, as the partition height increases, the r_D of the parallel layout increases, resulting in the lower rating. Furthermore, the other layouts do not fall within the standard deviation of the parallel layout, indicating a difference in measurements. To evaluate the statistical significance of differences between layouts at each partition height, a paired *t*-test was conducted. As a result of the *t*-test, the null hypothesis was adopted because all p-values exceeded 0.05. Adoption of the null hypothesis means that there are no statistical differences between layouts. The statistical results are shown in Fig. 9.

Table 7
Single-number quantities based on computer modeling expressed as a grade.

Height		1.2 m			1.5 m			1.8 m		
Single-number quantities		$D_{2,S}$ [dB]	$L_{p,A,S,4\ m}$ [dB]	r_D [m]	$D_{2,S}$ [dB]	$L_{p,A,S,4\ m}$ [dB]	r_D [m]	$D_{2,S}$ [dB]	$L_{p,A,S,4\ m}$ [dB]	r_D [m]
Face-to-face	Line 1	1.4	50.8	11.3	1.8	49.0	6.6	2.8	48.5	4.1
	Line 2	1.4	50.8	17.0	1.8	49.0	4.9	2.8	48.5	4.3
	avg	1.4 (E)	50.8 (B)	14.2 (D)	1.8 (E)	49.0 (B)	5.8 (B)	2.8 (E)	48.5 (B)	4.2 (A)
Parallel	Line 1	1.3	51.1	6.8	1.3	49.4	6.6	1.9	48.5	5.6
	Line 2	0.9	50.9	9.4	1.5	49.5	7.0	1.6	48.7	6.8
	avg	1.1 (E)	51.0 (C)	8.1 (C)	1.4 (E)	49.5 (B)	6.8 (B)	1.8 (E)	48.6 (B)	6.2 (B)
Crossed-rod	Line 1	1.4	51.0	7.2	1.9	49.4	5.2	2.2	48.6	4.3
	Line 2	1.4	51.4	8.0	2.1	49.8	6.3	2.7	49.0	5.5
	avg	1.4 (E)	51.2 (C)	7.6 (C)	2.0 (E)	49.6 (B)	5.8 (B)	2.5 (E)	48.8 (B)	4.9 (A)
Orthogonal	Line 1	1.1	51.0	7.4	1.1	49.1	5.8	1.7	48.1	3.4
	Line 2	0.9	50.9	11.5	1.4	49.2	4.6	1.5	48.3	3.7
	avg	1.0 (E)	51.0 (C)	9.5 (C)	1.3 (E)	49.2 (B)	5.2 (B)	1.6 (E)	48.2 (B)	3.6 (A)

3.3. Comparison between field acoustic measurements and computer modeling

When comparing the 1.5-m-high partition layout commonly used in field measurements and computer modeling, some variations are observed in r_D, the distance at which an STI of 0.5 is obtained. This is attributed to differences between field measurements and computer modeling. According to ISO 3382-3, background noise in an open-plan office includes HVAC units and other noise sources operating as in a typical working day. Even if the office is equipped with a sound masking system, this should be applied to the background noise. Therefore, in the computer model, we used the background noise for an open-plan office suggested in the Odeon application note. However, actual measurements were not taken in the office, so the background noise measurements may differ. Background noise affects the distraction distance (r_D), which is used in the STI calculation. This is believed to be the reason for the difference between the two methods. Furthermore, this can be attributed to limitations inherent in simulations, including those related to diffraction, low-frequency calculation accuracy problems, and limitations of the setup, such as not including workstations in the simulation [42]. In contrast, the sound pressure level (SPL) comparison shows that the two experimental results are very similar, falling within 3 dB, which is the JND of the SPL. Differences in SPL between the field measurements and computer modeling are presented in Table 8. This results reveal that $D_{2,S}$ and $L_{p,A,S,4\ m}$, evaluated in dB, do not show significant differences. The comparison of field measurements and computer modeling in terms of single-number quantities are illustrated in Fig. 10.

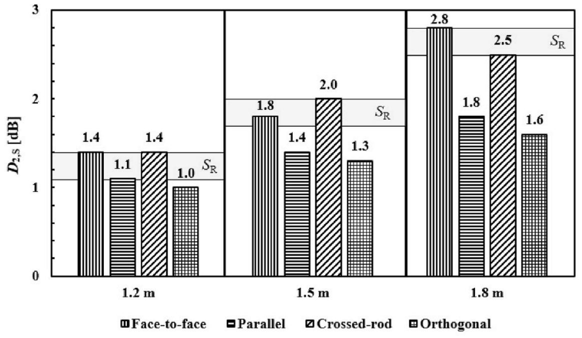
4. Discussions and conclusions

In this study, different partition layouts and heights were compared to evaluate their effects on speech privacy in open-plan offices. Partitions were focused on the effects of the partition layout on speech privacy in a circumstance to consider the situation where the office space has already been constructed and cannot be changed. A preliminary survey was conducted to identify representative parameters, and a field experiment and computer modeling were performed to evaluate the effects of the partition height and layout on speech privacy. The main findings can be summarized as follows.

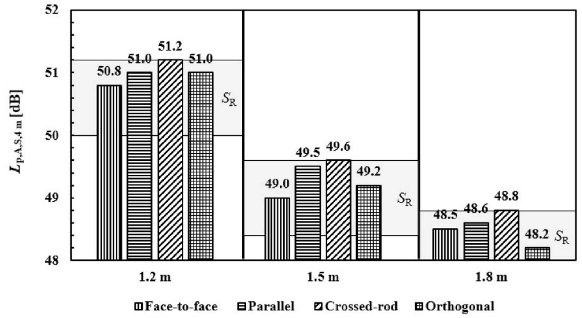
1. Field measurements showed that $L_{p,A,S,4\ m}$ and $D_{2,S}$ of the four partition layouts did not differ from the grades proposed by Hongisto. However, r_D of the face-to-face layout demonstrated a significantly lower E grade than the other layouts. Furthermore, the standard deviation of ISO 3382-3 showed that the face-to-face layout had different measured values from the other layouts. However, as a result of using *t*-test, statistical differences could not be identified. It is considered difficult to secure meaningful speech privacy only by changing the layout of partitions in an open plan office.
2. Consistent with field measurements, computer modeling found that the face-to-face layout is disadvantageous for speech privacy at a partition height of 1.2 m. However, as the height increased, the effectiveness of the parallel layout decreased, as indicated by its declining grade. This trend was further confirmed by the standard deviation analysis and significant difference identified by the *t*-test between layout methods. However, there was no statistical significance between layouts, similar to the results of field measurements. These results imply that height is more important than layout for speech privacy in open-plan offices.
3. Increasing speech privacy involves reducing rD. Moreover, the most effective measures are to ensure proper separation between workers, avoid face-to-face layout, and increase the height of partitions.
4. Utilizing only partitions to ensure sufficient speech privacy is difficult. Other methods such as installing sound-absorbing materials or masking sound sources should be utilized, but these methods are more efficient if considered during the design stage.

The present study focused on the high variability of partition layouts in open-plan offices and their effect on speech privacy. Various studies have been conducted to secure speech privacy within an open-plan office; however, no studies have been conducted to ensure speech privacy by changing the layout of partitions. Therefore, the results of this study sought to present a new research direction for securing speech privacy in open offices and to show that the layout of open offices is important, similar to Sarwono's research [37].

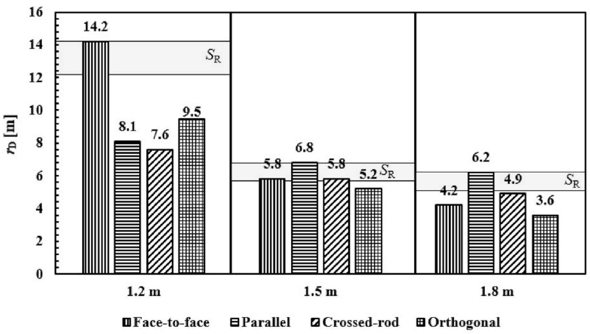
The disparity in layout is evident in Hongisto's proposed grade and ISO 3382-3 Annex D standard deviation. Nevertheless,



(a) $D_{2,S}$



(b) $L_{p,A,S,4\,m}$

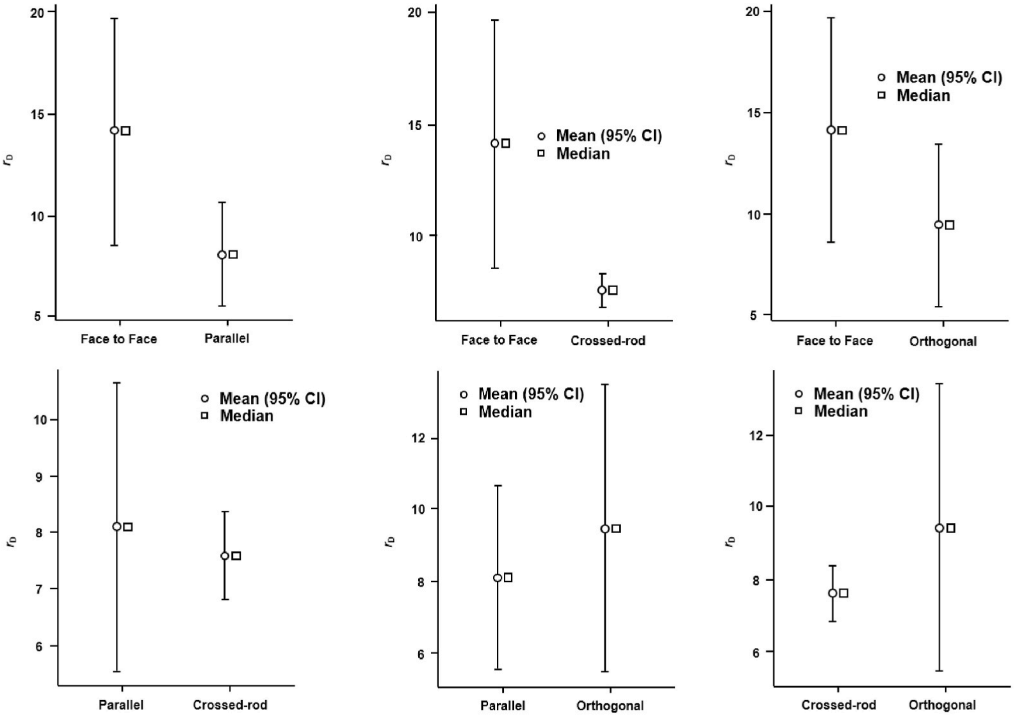


(c) r_D

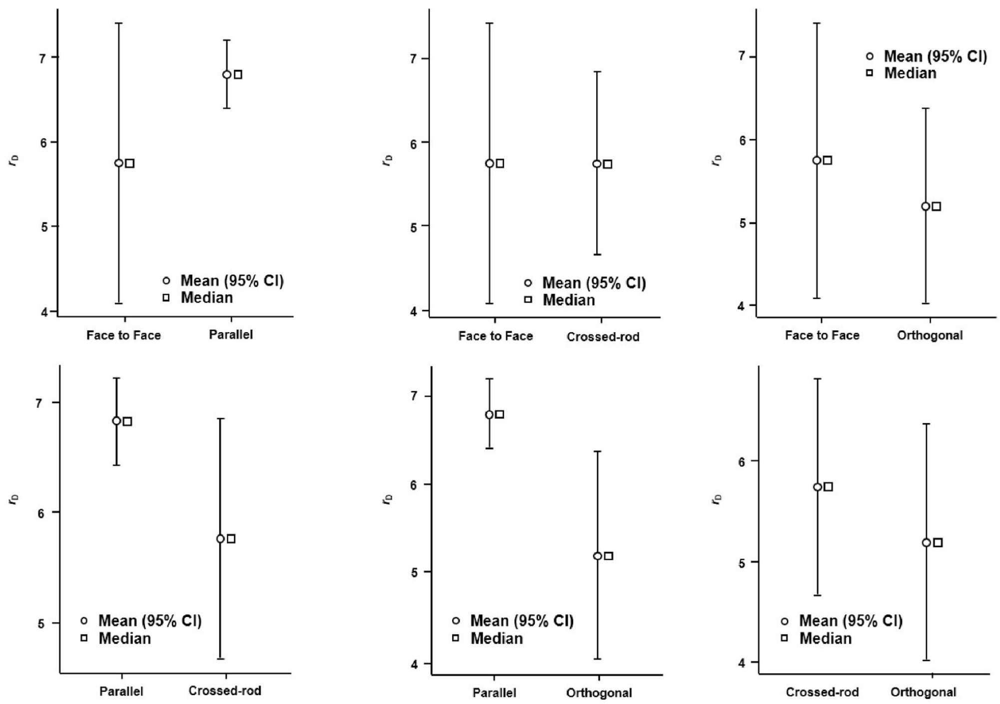
Fig. 8. Comparison standard deviation by layout for single-number quantities in computer modeling.

statistical tests do not reveal a significant difference between the layouts. This suggests that while numerical variations exist, they are not of sufficient magnitude to be statistically meaningful. Although partitions can be rearranged to adjust the distance between and directions of workers, they have limited capability to regulate noise and ensure speech privacy. As shown in the study by Virjonen et al. [22], insufficient attenuation of the horizontal sound field in an open office can severely undermine the attenuation gained from ceiling absorbers and screens. It may be difficult to ensure speech privacy even if partitions are intelligently employed to provide sufficient space between workers. According to ISO 3382-3, the concentration and privacy of workers begin to significantly increase at $r_D < 5$ m, which is the distance at which the STI is 0.5 or lower [14,19]. Reducing r_D is critical for ensuring speech privacy in open-plan offices. Therefore, speech privacy may be enhanced by installing a partition between the sound source and receiving point as well as sound-absorbing materials or baffles on the ceiling and wall surfaces to block noise from crossing the partition and absorb noise transmitted above the partition. If speech privacy is considered in the design state of business facilities, a diverse and effective range of methods can be employed to achieve a more serene working environment and higher worker efficiency. Therefore, it will be more effective to secure speech privacy in open plan offices if the above methods are applied together rather than simple layout changes.

This study has some limitations. In the field experiment, the background noise did not exceed 30 dB(A). Because the background noise was relatively low, measurements in that space may not be representative of an actual open-plan office. Measurements were

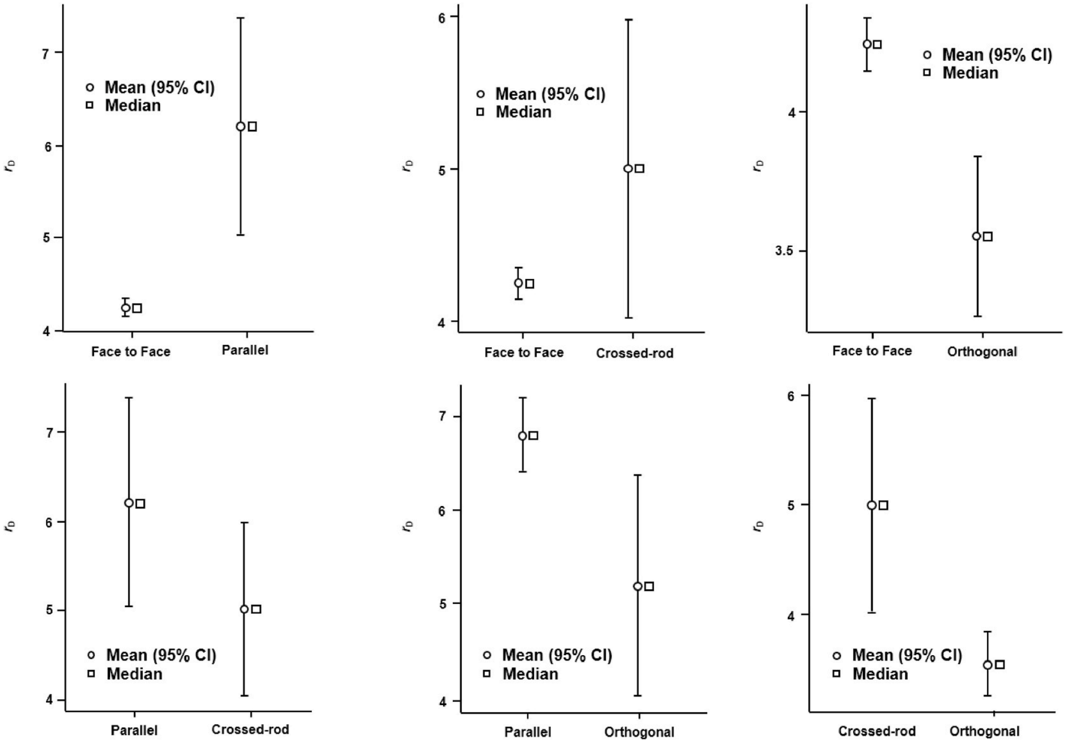


(a) 1.2 m



(b) 1.5 m

Fig. 9. Statistical differences between the experimental results of different partition layouts according to the paired *t*-test in computer modeling.



(c) 1.8 m

Fig. 9. (*continued*).

Table 8
Absolute values representing differences between the field measurement and computer-modeled sound pressure level.

	Face-to-face		Parallel		Crossed-rod		Orthogonal	
	Line 1	Line 2	Line 1	Line 2	Line 1	Line 2	Line 1	Line 2
R1	0.7	0.3	1.4	1.3	0.4	0.6	1.1	1.0
R2	0.5	0.4	0.7	0.6	0.2	0.2	0.6	0.6
R3	1.0	0.8	0.5	0.1	0.2	0.9	0.1	0.7
R4	0.6	0.4	0.1	0.1	0.5	0.7	1.0	1.0

taken under controlled conditions rather in an actual office to minimize the variables caused by external noise and isolate the effects of the partition layout. In the future, however, taking measurements in an actual office may be preferable to obtain background noise that is representative of an open-plan office. In addition, this should lead to new ways of calculating speech privacy as Hongisto suggested the grade [20]. Through this process, we expect to be able to secure sufficient speech privacy in the open plan office.

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Ethical approval

All authors approve that the research was performed under the ethical norms.

Data and code availability

Data will be made available on request.

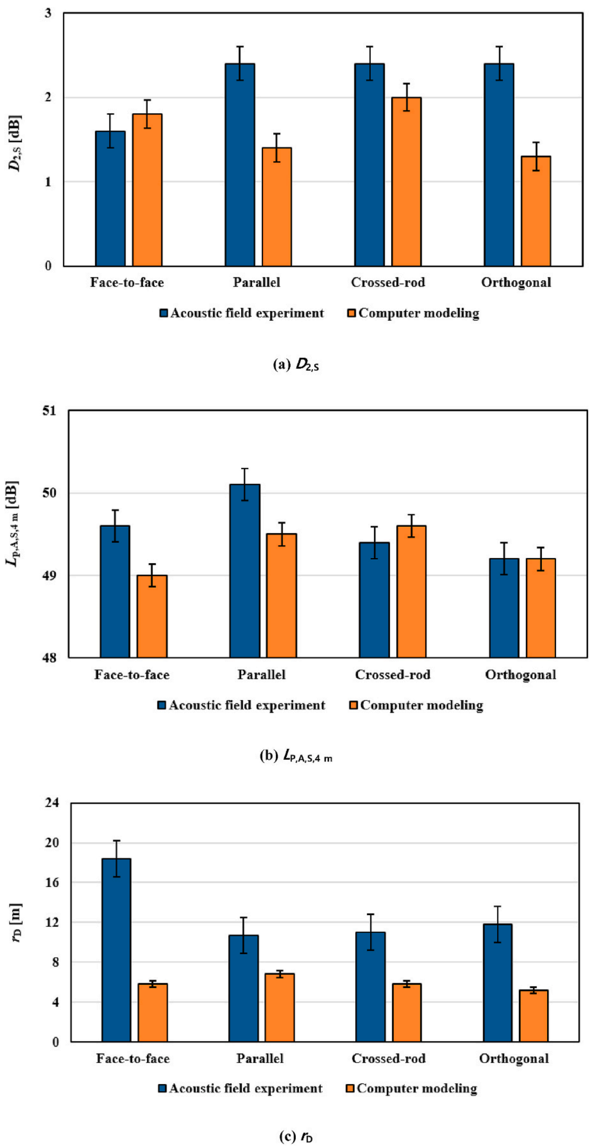

Fig. 10. Comparison between single-number quantities from field measurements and computer modeling.

CRediT authorship contribution statement

Seung-Min Lee: Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation. **Chan-Hoon Haan:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Chan-Hoon Haan reports financial support was provided by National Research Foundation of Korea.

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