Just noticeable difference of ISO 3382-3 metrics for open-plan office noise

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ABSTRACT

In this study, the sound environment characteristics of open-plan office (OPO) were investigated, and design criteria with the single number quantity ($L_{p,A,S,4m}$) specified in ISO 3382-3 was suggested. In addition, a design guideline that can improve work performance from the perspective of audio-visual privacy has been proposed. Two real office spaces were measured and modeled by computer simulation, and auditory evaluation was performed on 29 subjects for the stimulus generated based on $L_{p,A,S,4m}$. A new design grade criterion was proposed based on responses to speech privacy, annoyance, and willing to work. Next, the evaluation environment for audio-visual stimulation was implemented using virtual reality technology for four office spaces. For 25 subjects, work performance was quantified through a digit-span test, and various semantic attributes and audio-visual preferences (privacy, satisfaction, willing to work) were evaluated. As a result, it was found that audio-visual privacy complemented each other and contributed differently to work performance. It is believed that the results of this study can be used as basic data for the design of the optimal OPO sound environment.

INTRODUCTION

Most recent offices are in the form of an open-plan office (OPO) to create an efficient office space. Such a flat configuration is a structure that is disadvantageous in securing work productivity and comfort, such as obstruction of work concentration, because it is easy to transmit sound such as telephone calls and business discussions. According to existing studies, noise generated in offices can reduce work efficiency, and can have a greater impact on privacy infringement than visual factors [1-3].

Although research on audiovisual interactions in indoor spaces has been actively conducted in recent years [5-6], research on OPO is insufficient. As various single number quantities that can quantify the OPO sound environment have been proposed, a grading standard based on these indicators has been proposed [7]. However, since this is proposed based on case studies on several office spaces, a more detailed investigation is needed.

Therefore, in this study, the existing rating criteria for the OPO space were reviewed, and the optimal sound environment design guidelines were presented from the viewpoint of audio-visual privacy.

EXPERIMENT 1: OPTIMAL CONDITION FOR SPEECH PRIVACY

Methods

In Experiment 1, an audible sound source generated based on computer simulation was used as an evaluation stimulus to suggest the optimal sound environment standard for securing speech privacy within OPO. To this end, basic data necessary for the implementation of simulation modelling were collected for two real OPO sites of different sizes. The measurement was conducted according to ISO 3382-3 standard, and a single number quantity ($L_{p,A,S,4m}$, $D_{2,S}$, R_D) was analysed, and based on this, a sound environment model similar to the actual OPO environment was created using Odeon simulation. Implemented. In addition, a total of 12 OPO models were created, 6 for each model by changing the sound absorption coefficient of the floor and ceiling finishing materials to have different $L_{p,A,S,4m}$ values within the OPO model.

The reference sound source for evaluation was a sound source in which the male voice recorded in the anechoic room and the background noise of general OPO were combined. At this time, in order to secure the background noise of OPO, the background noise was recorded for 1 hour at three different points at OPO (F Office). As a result, the L_{Aeq} averaged 54.4 dB(A), which was similar to the 53.6 dB(A) evaluated for 43 different OPOs in the previous study [8]. Therefore, it was confirmed that the background noise collected in this study is representative of the general OPO background noise. However, since a separate anechoic room voice source was used when generating the evaluation stimulus in this study, it is necessary to assume that the OPO background noise does not include voice. When the L_{Aeq} of the eight OPO background noises provided with open access to the Internet was adjusted to 54.0 dB(A), the L_{Aeq} of the sound source section excluding voice was averaged 47.0 dB(A). Based on these results, the section where the voice was excluded from the background noise collected in F office was edited, and the L_{Aeq} was adjusted to 47.0 dB(A) using Audition software. As a result, in Experiment 1, a total of 12 sound sources generated by audible in OPO models were used as evaluation stimuli, and the length of each sound source was the same as 1 minute.

A total of 29 subjects (22 males and 7 females) participated in the experiment (mean age = 23.94, SD = 3.48). In order to reduce the response error, the evaluation was performed on only students enrolled in the same university. The questionnaire used in the experiment was configured to respond to annoyance, speech privacy, and willing to work on a 7 point bi-polar scale. Each subject received evaluation stimuli in random order through an open type headphone (sennheiser HD 650). As a result, a total of 348 response data (12 X 29 = 348) were collected for each evaluation item.

Results and discussions

Probit analysis was performed based on the subject's response results for speech privacy, annoyance, and willing to work, and the results are shown in Figure 1. In this case, the percentage of response means the proportion of subjects who evaluated the median value of 0 or higher on a 7-point bi-polar scale. Based on this, the rating criteria were presented by varying the 20% section for each parameter and are summarized in Table 1. A new rating criterion was proposed based on the average value of the three parameters. Compared with the previous study [7], it was confirmed that it is necessary to strictly strengthen at least 2 dB for each class.

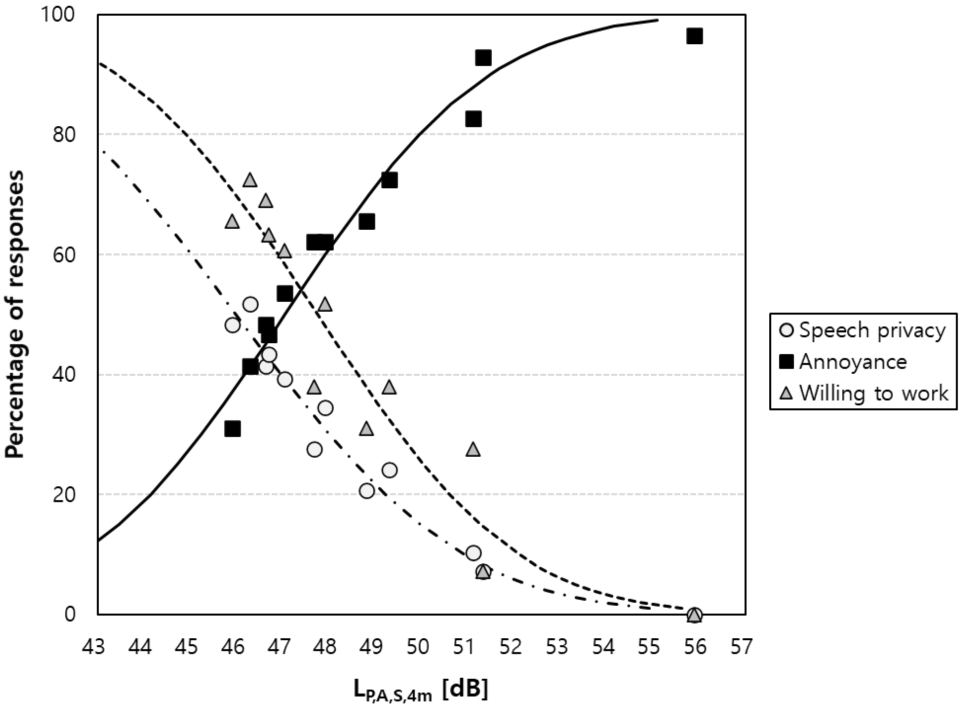

Figure 1. Visual view of office models

Table 1: Criteria of $L_{p,A,S,4m}$ for optimal sound environment in OPO.

Grade	Speech privacy	Annoyance	Willing to work	Our suggestion	Previous study [7]
A	< 45	< 46	< 47	< 46	< 48
B	45 – 47	46 – 48	47 – 49	46 – 48	48 – 51
C	47 – 49	48 – 50	49 – 51	48 – 50	51 – 54
D	> 49	> 50	> 51	> 50	> 54

EXPERIMENT 2: DESIGN GUIDELINE FOR WORK PERFORMANCE

Methods

In Experiment 2, for the purpose of improving work performance, auditory evaluation was conducted to present the optimal OPO design guidelines considering visual and speech privacy. At this time, virtual reality technology was used to implement an evaluation environment similar to the actual OPO environment in the laboratory environment. First, for sound stimulation, a sound source that satisfies the upper/middle/lower grades was selected based on $L_{p,A,S,4m}$ among the 12 sound sources used in Experiment 1. For visual stimulation, four OPO models with different window to wall ratios, volumes, and interiors provided by the Unity software asset store were used (see Figure 2). At this time, the view that can be seen outside the OPO window is composed of two. As a result, a total of 24 evaluation stimuli (3 X 4 X 2 = 24) were generated according to the audiovisual stimulus binding method.

A digit span test was performed to quantify the work performance response according to each audiovisual stimulus. In the state of exposure to each evaluation stimulus, the subject was asked to answer in reverse order to the numerical sequence provided to the subject. Starting with two number arrangements, when correct answers are successively corrected, the number is increased to a maximum of 9 in a way that the arrangement is added, and a total of 16 questions are composed. At this time, the numerical arrangement was provided through a speaker, and the subject responded verbally.

The subjects were 25 subjects out of the subjects who participated in Experiment 1. The questionnaire was composed of two parts, each for the visual environment and the auditory environment: audio-visual preference (satisfaction and work intention, privacy), and semantic attributes (physical and psychological). Each questionnaire was answered on a 7-point bi-polar scale. Sound stimulation was provided to each subject through an open-type headphone (Sennheiser HD 650), and visual stimulation was provided through a head mounted display (VIVE Pro EYE). Subjects responded to the questionnaire after conducting a digit span test for each evaluation stimulus. As a result, a total of 300 (24 X 25 = 600) response data were collected for each evaluation item.

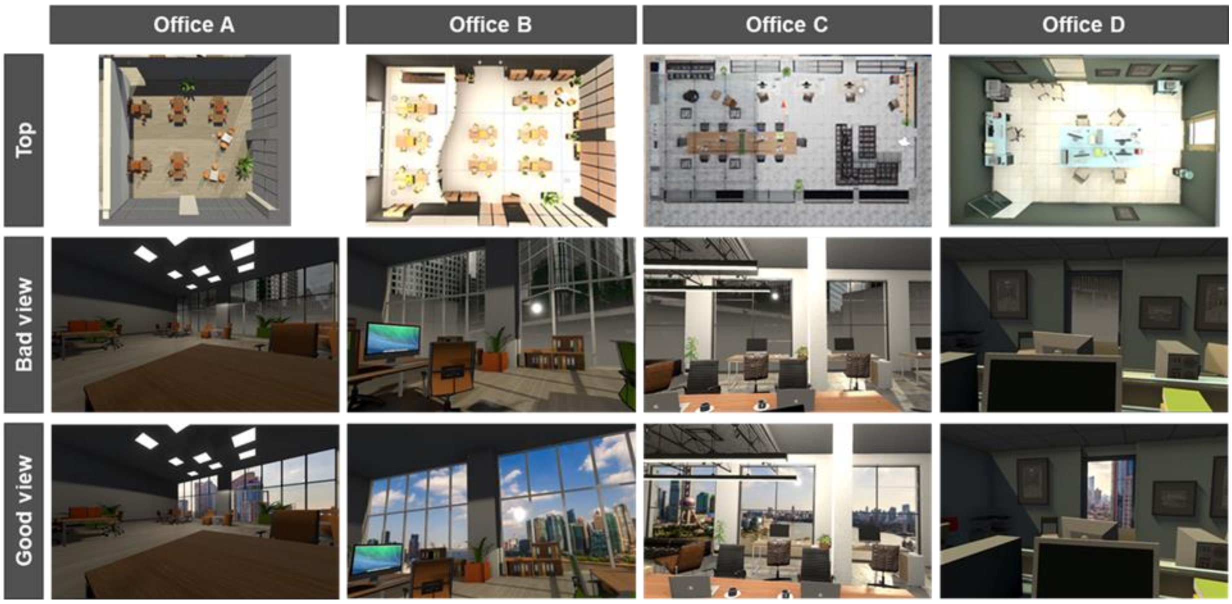

Figure 2. Visual view of office models

Results and discussions

ANOVA analysis was performed to find out whether the difference in response to preference, satisfaction, work intention, and work performance was significant according to changes in office location, window view, $L_{p,A,S,4m}$, and the results are shown in Table 2. As a result, it was found that Acoustic preference showed significant difference according to office location and $L_{p,A,S,4m}$ change. In particular, Office A and B showed higher acoustic preference (privacy, satisfaction, willing to work) than Office D. Visual preference showed significant difference according to office location and view change. Office A and C showed higher visual privacy than office D. In addition, Office A, B, and C were significantly higher than Office D in terms of visual satisfaction and willing to work.

Table 2: Summary of ANOVA analysis of audio-visual preference with different type, view, $L_{p,A,S,4m}$.

Reference	Sum of Squares	df	Mean Square	F	p	η^2
Acoustical privacy						
Office	62.513	3	20.838	8.3259	< .001	0.030
View	9.127	1	9.127	3.6466	0.057	0.004
$L_{p,A,S,4m}$	566.310	2	283.155	113.1363	< .001	0.270
Visual privacy						
Office	119.565	3	39.855	14.821	< .001	0.068
View	42.135	1	42.135	15.669	< .001	0.024
$L_{p,A,S,4m}$	5.410	2	2.705	1.006	0.366	0.003
Acoustic satisfaction						
Office	100.52	3	33.508	14.952	< 0.001	0.051
View	1.21	1	1.215	0.542	0.462	0.001
$L_{p,A,S,4m}$	569.64	2	284.822	127.089	< 0.001	0.287
Visual satisfaction						
Office	618.86	3	206.286	96.183	< 0.001	0.293
View	191.54	1	191.535	89.305	< 0.001	0.091
$L_{p,A,S,4m}$	5.77	2	2.885	1.345	0.261	0.003
Willing to work of acoustic environment						
Office	79.69	3	26.564	12.170	< 0.001	0.039
View	4.51	1	4.507	2.065	0.151	0.002
$L_{p,A,S,4m}$	651.57	2	325.787	149.253	< 0.001	0.323
Willing to work of visual environment						
Office	580.780	3	193.593	78.9014	< 0.001	0.260
View	181.500	1	181.500	73.9726	< 0.001	0.081
$L_{p,A,S,4m}$	1.853	2	0.927	0.3777	0.686	0.001
Work performance (Accuracy)						
Office	5097	3	1699.0	5.210	< 0.001	0.026
View	1134	1	1134.4	3.479	0.063	0.006
$L_{p,A,S,4m}$	1936	2	968.2	2.969	0.052	0.010

Table 3 shows the correlation results between semantic attributes and audio-visual preference. First, looking at the visual attribute, it was found that the more visually spacious and well-organized place the work space has a positive relationship with satisfaction or willing to work. Interestingly, these visual features were found to have an excessively positive relationship with acoustical privacy. However, it was found that visual privacy is secured when the complex visually increases. When examining the relationship between accuracy and visual attributes, it was found that the interior space of the OPO should be designed to induce a visual dispersion effect to some extent rather than being monotonically composed. Next, looking at the acoustical attributes, it was found that acoustical privacy or satisfaction and willing to work are secured when the space is quiet and without reverberation and internal inactivity is secured.

Table 3: Pearson correlation between semantic attributes and audio-visual preference.

Attributes		Privacy		Satisfaction		Willing to work		Accuracy
		Visual	Acoustical	Visual	Acoustical	Visual	Acoustical	
Visual attributes								
Physical	*Orderly*	-0.15	0.37**	0.60**	0.31**	0.31**	0.55**	-0.18**
	Wide	-0.13	0.25**	0.65**	0.29**	0.29**	0.61**	-0.15**
	Bright	-0.10	0.20**	0.64**	0.24**	0.24**	0.55**	-0.01
	Open	-0.12	0.23**	0.71**	0.28**	0.28**	0.64**	-0.07
Psychological	*Pleasant*	-0.11	0.27**	0.78**	0.31**	0.31**	0.69**	-0.10*
	Comfort	-0.17**	0.40**	0.74**	0.38**	0.38**	0.66**	-0.17**
	Complex	0.23**	-0.34**	-0.49**	-0.30**	-0.30**	-0.42**	0.14**
Acoustical attributes								
Physical	*Loud*	0.25**	-0.51**	-0.07	-0.59**	-0.60**	-0.33**	-0.11**
	Stable	-0.32**	0.55**	0.26**	0.68**	0.64**	0.43**	-0.05
	Reverb	0.25**	-0.53**	-0.05	-0.61**	-0.60**	-0.32**	-0.09*
Psychological	*Pleasant*	-0.29**	0.63**	0.33**	0.73**	0.75**	0.60**	-0.02
	Comfort	-0.33**	0.69**	0.34**	0.76**	0.78**	0.59**	-0.02
	Eventful	0.07	-0.24**	0.15**	-0.23**	-0.24**	-0.04	-0.13**
	Annoyed	0.35**	-0.58**	-0.20**	-0.61**	-0.61**	-0.40**	-0.03

CONCLUSIONS

In this study, in order to provide the optimal sound environment design in the office space, based on the auditory evaluation, sound environment design standards and guidelines were presented. As a result, it was confirmed that it was necessary to supplement the existing rating criteria through the rating criteria for Lp, and it was confirmed that visual privacy within OPO has a complementary relationship with acoustic privacy, and has an effect on work performance. A generalized conclusion will be drawn through further experiments in the future.

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