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Space dynamics for work performance enhancement in open plan office

Hyun In Jo, Haram Lee, Beta Bayu Santika, Jin Yong Jeon

Department of Architectural Engineering, Hanyang University, Seoul, Korea
(best2012@hanyang.ac.kr)

Abstract
In this study, the effect of indoor soundscape perception of open plan office (OPO) on work environment preference and perceived productivity was investigated. First, for auditory information, 12 sound source samples that contain various noise sources were collected through in-situ measurement in a traditional OPO. Visual information was modelled by three OPO environments with different internal layouts. The subjective evaluation environment was implemented in a laboratory condition using virtual reality technology for a total of 36 stimuli according to the combination of audio-visual stimuli. Subjective evaluation was conducted on 41 subjects, and they were asked to respond to sound source identification, perceived affective quality, and overall quality. As a result, it was found that noise perception for conversation and computer peripherals was dominant in the office environment. When indoor soundscape perception is analyzed by dividing it into comfort – content dimension, it was found that securing comfort is effective in promoting preference for work environment, and securing content has an important effect on perceived productivity increase. However, since comfort appears to reduce perceived productivity, a balanced design between comfort and content is required. The findings of this study are expected to be utilized as basic data for designing a sound environment for open plan offices.

Keywords: Indoor soundscape; comfort; content; satisfaction; perceived productivity.

1 Introduction

Open plan office is one of the most commonly used office layouts because it can promote communication and teamwork between workers and has high space utilization and low cost. Noise in an open plan office is known to have a negative effect on worker satisfaction and work productivity [1,2]. In particular, irrelevant speech or intelligible conversation between coworkers has been found to be the main cause of deterioration of the comfort and performance of open plan office workers [3]. Therefore, various attempts have been made to utilize various interior design factors (workstation, partition, and so on) to improve the sound environment of an open plan office [4].
Meanwhile, as the concept of soundscape, which interprets the sound environment in terms of human perception rather than physical interpretation of the acoustic environment, appeared, various studies were conducted to interpret human perception in the outdoor environment [5,6]. Recently, studies that apply the concept of soundscape to indoor environments have been attempted [7,8]. A draft questionnaire to evaluate indoor soundscape was proposed [7], and a method to evaluate comfort, content, and familiarity as a cognitive scale to interpret indoor soundscape was also proposed [8]. In terms of spatial functionality, studies have been conducted to evaluate soundscape in various indoor environments such as residential buildings, libraries, historical spaces, and public spaces, but there are few studies targeting open plan offices.

In this context, this study aims to examine the effect of indoor soundscape on the environmental preference and perceived productivity of workers in an open plan office, and to present a design guideline for a pleasant open plan office sound environment.

2 Methods

2.1 Audio-visual data collection

2.1.1 Sound stimuli

In order to collect sound information to be used for subjective evaluation, field measurements were conducted in a typical open plan office space located in Seoul, Korea. The open plan office is being used for business purposes and has a scale of 25.0 m (Length) × 14.5 m (depth), and the ceiling and floor are finished with Mitone (KCC) and carpet, respectively. Measurements were made during daytime working hours and were conducted for 1-hour duration using a sound level meter (SVAN 953, Svantek, Warsaw, Poland). A total of 12 sound source stimuli were obtained by editing a one-minute sound source sample for the section where various noises were generated in the office from the collected background noise sources. Table 1 shows the physical acoustic characteristics of each sound source. A-weighted sound pressure level (L_{Aeq}) was 49.9 - 59.3 dBA, and percentile level difference ($L_{A10-A90}$) was 2.7 - 12.6 dBA.

Table 1 – Acoustical characteristics of 12 sound stimuli.

Acoustical parameter	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
L_{Aeq} [dBA]	50.3	59.3	49.9	51.4	56.8	53.0	52.4	55.8	56.4	57.3	54.0	50.6
$L_{A10-A90}$ [dBA]	2.7	10.5	4.4	3.4	12.6	6.2	7.6	4.9	9.2	9.8	5.4	5.4
Noise frequency [num]	86	132	135	145	149	159	164	166	167	177	180	204

2.1.2 Visual stimuli

In this study, by applying virtual reality (VR) technology, three open plan office spaces with visually different internal conditions were implemented. In previous studies, the usefulness of VR technology for indoor noise evaluation has been confirmed [9-11]. Unity 3D software, a game engine platform, was used to implement the VR environment. Office A (L 9.5 m, W 6.0 m), office B (L 17.7 m, W 9.0 m), and office C (L 25.0 m, W 22.0 m), respectively. In addition, the window area ratio was made to have a range of 10 - 35%.

2.2 Experimental set-ups

2.2.1 Questionnaire

In this study, the questionnaire used for subjective evaluation of indoor soundscape in open plan office consisted of 3 parts. The first part is to investigate the identification of noise sources in the office environment, and 12 noise sources (conversation, laugher, computer (Keyboard and mouse), walking and footstep, chair dragging, desk noise, page turning, printers and copiers, doors Slamming, water purifier, glass cup clinking, mechanical fan and AC) were evaluated on a 7-point Liker scale (0: Not at all – 6: Extremely). In the second part, in order to investigate the perceived affective quality of office indoor soundscapes, as shown in Figure 1, the degree of agreement on 8 attributes (full of content, interesting, comfortable, private, dead, boring, annoying, dynamic) was evaluated [8]. The subjects were asked to respond on a 7-point Liker scale (0: Not at all – 6: Extremely). In the last part, the overall quality of the open plan office was divided into three aspects (satisfaction, willing to work, perceived affective quality), and the degree of agreement with each evaluation factor was evaluated on a 7-point Liker scale (0: Not at all). – 6: Extremely).

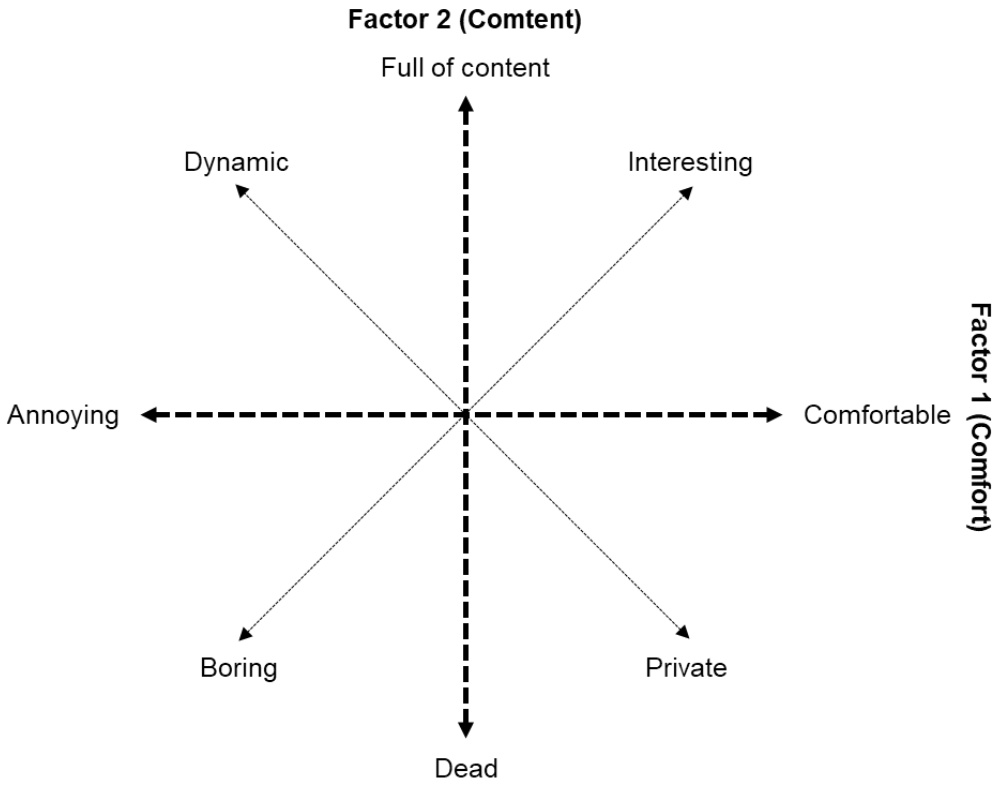

Figure 1 – Indoor soundscape perception dimensions in open plan office

2.2.2 Procedure

A total of 41 subjects (male = 23, female = 18) participated, and the age range was 20 – 29 years (mean age: 23.12, standard deviation: 2.82). In order to reduce the variation in the subject's response, students enrolled in the same university were targeted. The subjects were recruited by screening only those who had work experience in an office space. Before the experiment, as an ethical procedure, the subjects signed a consent form to participate in this experiment. The evaluation environment was implemented in a quiet laboratory, and the background noise at this time was very low, about 30 dBA.
A total of 36 stimuli (12 audio stimulus × 3 visual stimulus) were provided to the subjects in random order. Sound stimulation was provided through an open type headphone (Sennheiser HD 650), and visual stimulation was provided through a head mounted display (VIVE Pro EYE). After experiencing each evaluation stimulus for 1 minute, the subjects were asked to respond to the questionnaire while listening to the stimulus repeatedly. The questionnaire was provided as a GUI within the VR environment. As a result, a total of 1,476 responses (36 stimulus × 41 subjects = 1,476) were collected for each evaluation item.

3 Results and discussions

3.1 Sound source identification

Table 2 shows the level of awareness of various noise sources in open plan offices. Overall, speech sound generated by communication between workers was the most prominent, and noise recognition for keyboard and mouse was also dominant. However, it was found that other noise sources (walking and footstep, desk nose, and so on) were not well recognized by the subjects despite the fact that the frequency of occurrence was higher than 10 times per minute.

Table 2 – Summary of sound source identification results for 12 sound stimuli.

Acoustical parameter	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
Conversation	0.90	1.85	1.60	0.34	4.81	3.75	4.18	1.31	4.32	4.54	2.02	1.77
Laugher	0.44	0.35	1.97	0.28	1.04	1.31	0.54	0.28	3.55	1.32	2.28	4.04
Keyboard and mouse	3.65	2.11	2.15	3.02	2.15	3.37	3.05	1.85	2.33	1.99	1.70	2.46
Walking and Footstep	1.02	1.14	0.59	1.08	1.81	0.83	0.54	3.95	1.91	1.28	2.57	1.06
Chair dragging	0.33	1.47	0.72	0.72	0.83	0.68	0.38	0.63	0.92	1.01	0.63	0.46
Desk noise	0.87	2.87	1.33	1.68	1.99	1.44	0.85	1.72	1.56	2.59	1.41	1.00
Page turning	0.44	1.07	0.61	0.47	0.70	0.53	1.02	0.49	0.65	0.63	1.14	0.77
Printers and Copiers	1.41	1.37	0.57	1.23	1.06	1.11	0.76	1.51	1.46	1.15	1.40	1.25
Doors slamming	1.42	1.39	0.74	1.65	1.25	1.08	0.59	1.95	1.72	2.05	1.77	0.63
Water purifier	0.45	1.55	0.22	0.50	1.76	0.46	0.28	0.63	0.67	2.11	0.67	0.62
Glass cup clinking	0.39	3.93	0.32	0.51	2.61	0.37	0.28	0.63	0.93	0.74	0.54	0.33
Mechanical fan and AC	1.33	1.34	1.19	1.46	1.15	1.26	1.15	1.30	1.36	1.21	1.41	1.11

3.2 Perceived affective quality

Figure 2 shows the results of perceived affective quality. At this time, the indoor soundscape perception dimension was examined by dividing it into comfort and content as shown in Figure 1. As a result, it was found that the less conversations occur, the higher the comfort is evaluated, and the more conversations occur, the lower the comfort. On the other hand, as the overall noise frequency increased, the content recognition also appeared to increase. One interesting thing is that even if conversation occurs frequently, comfort does not decrease significantly when other noise source events occur variously.

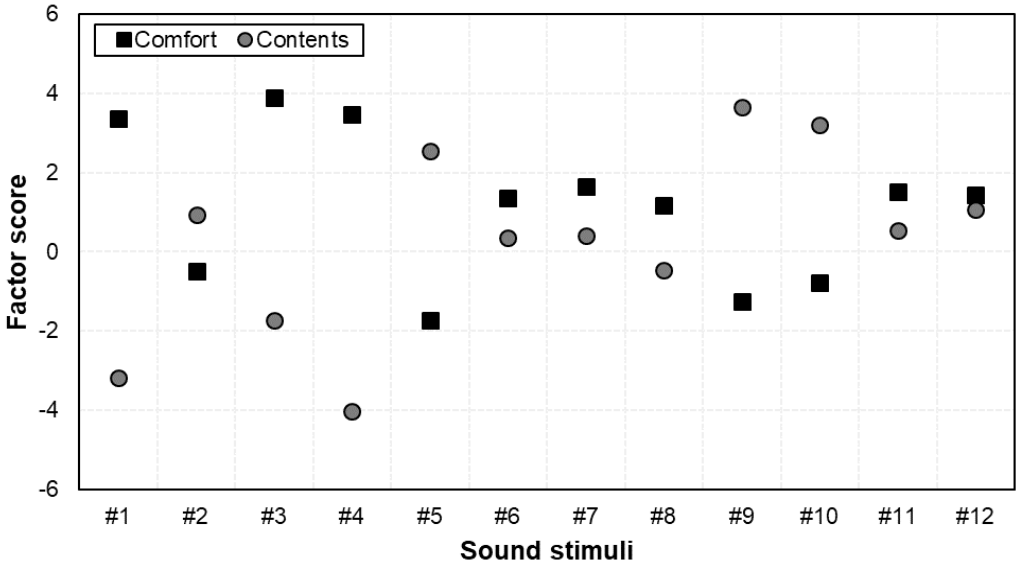

Figure 2 – Factor score of indoor soundscape in open plan office for 12 sound stimuli.

3.3 Overall quality

Linear regression analysis was performed to examine the relationship between overall quality (satisfaction, willing to work, perceived productivity) and perceived affective quality, as discussed above, and the results are shown in Figure 3. At this time, satisfaction and willing to work were grouped and interpreted as preference for work environment. First, it was found that indoor soundscape comfort in open plan office had a positive relationship with satisfaction ($b = 0.96$, $p < 0.01$, adjust $R^2 = 0.91$) and willing to work ($b = 0.97$, $p < 0.01$, adjust $R^2 = 0.93$), but had a negative relationship with perceived productivity ($b = -0.94$, $p < 0.01$, adjust $R^2 = 0.87$). On the other hand, content had a positive relationship with perceived productivity ($b = 0.88$, $p < 0.01$, adjust $R^2 = 0.77$) and a negative relationship with satisfaction ($b = -0.79$, $p < 0.01$, adjust $R^2 = 0.62$) and willing to work ($b = -0.77$, $p < 0.01$, adjust $R^2 = 0.58$). Therefore, in order to achieve a balance between environmental preference and perceived productivity, it was found that it is desirable to provide an office environment so that comfort is between 0 and 1 and content is between 1 and 2.

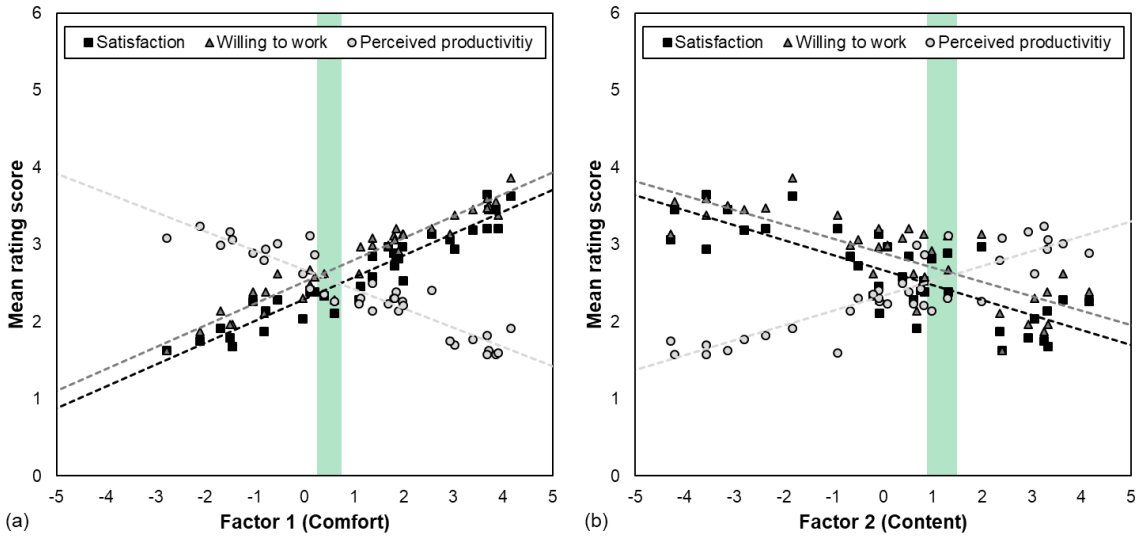

Figure 3 – Relationship between indoor soundscape perception dimension ((a) comfort and (b) content) and overall quality (satisfaction, willing to work, and perceived affective quality).

4 Conclusions

In this study, the method to secure worker's preference and perceived productivity for the office environment for open plan office was examined from the perspective of indoor soundscape. For this purpose, subjective evaluation was performed, and an appropriate level of comfort-content was suggested for a balanced design of preference and perceived productivity. The findings of this study will be used as basic data for open plan office design.

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