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Investigation of work performance in open-plan office with soundscape variation using virtual reality

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ABSTRACT

In this study, the relationship between soundscape elements in an open-plan office (OPO) and work performance was investigated. Experiment 1 was conducted in a real environment; subsequently, evaluation was conducted in a virtual reality environment for the diversity of the evaluation places. For the visual factors, the arrangement of the office equipment and the view through the window were different in the OPO, and the background noise was reproduced variously as an auditory factor. HRTF and head movement were applied to consider the worker's mobility within the VR environment. Consequently, it was found that the work performance improved when the natural elements were increased in the VR environment.

Keywords: Open-plan office, window view, partition height, background noise, work performance
I-INCE Classification of Participant Number: 63

1. INTRODUCTION

The emergence of the open-plan office (OPO) layout in the 1970s has replaced the stand-alone office[1]. In particular, the open-office design has been critically acclaimed for its ability to efficiently control spatial density through the number and height of partitions surrounding an employer's workspace[2]. However, previous studies[3-5] have shown that noise in an open-plan office negatively affects office satisfaction or work performance, and that concentration is lower compared to a private office room[6-8]. In other words, the negative aspects of the open-plan office are increasing. Therefore, to improve the efficiency of work (e.g., communication and productivity) among "OPO" users, continuous study must be conducted to solve the aforementioned problems by analyzing the work environment.

With the advent of virtual reality (VR) technology, it has become possible to perform the same evaluation as field assessment in a limited laboratory environment[9-10]. Recently, studies have been conducted to apply VR technology to evaluate noise in various

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environments, such as indoor and outdoor[11-13]. It is necessary to apply VR technology because factors other than experimental factors cannot be controlled in field surveys that are primarily used in the existing OPO research.

In this study, we investigate the effects of external view, partition height, and background noise level on work performance in an OPO. The experiment was divided into two stages. Experiment 1 examined the effect of window view on work performance by varying the external environment and maintaining the indoor environment. Conversely, in experiment 2, we examined the effect of partition height and background noise level on work performance by maintaining the outdoor environment and varying the internal environment.

2. EXPERIMENT 1: VARIATION IN OUTDOOR ENVIRONMENT

2.1 Test conditions

In a typical OPO, the evaluation points are selected with different viewpoints through the window, although the interior sound field is similar, as shown in Fig. 1. The space with open view is 9.45 m in width, 7.20 m in height, 9.70 m in height, and the space with close view is 9.45 m in width, 27.45 m in height, and 3.6 m in height. The $D_{2,S}$ and $L_{p,A,S,4m}$ parameters recommended in ISO 3382-3 were measured to confirm the room sound field conditions[14], and the results are shown in Fig. 2. $L_{p,A,S,4m}$ represents the A-weighted sound pressure level of speech at 4 m from the sound source, and $D_{2,S}$ represents the spatial decay rate of speech. The decay rate and $L_{p,A,S,4m}$ of the open view and close view evaluation points are almost similar to each other. The background noise in both spaces was 35 dBA.

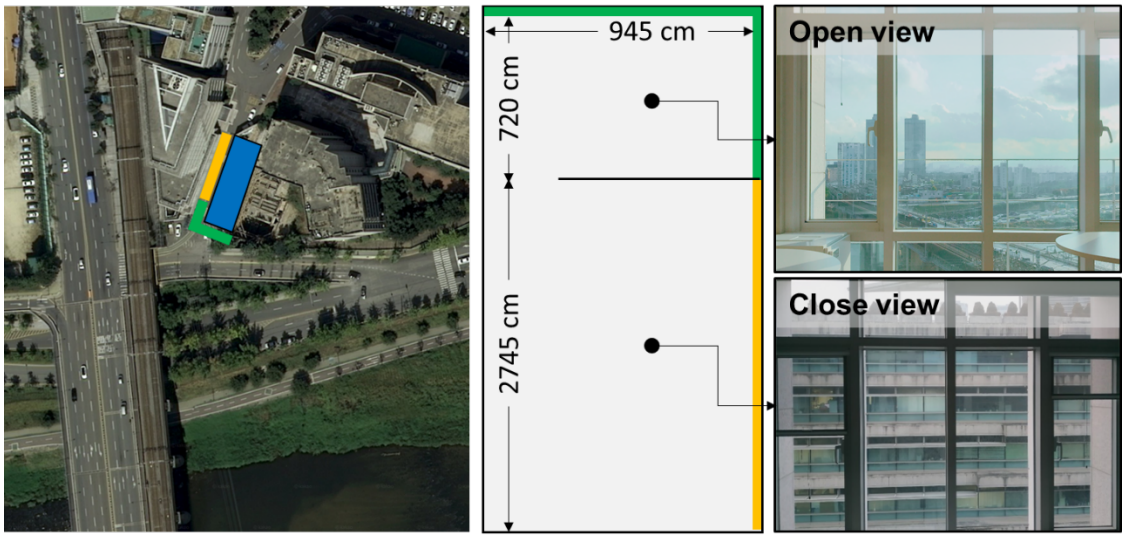

Fig. 1. Evaluation position with different window views; open and close

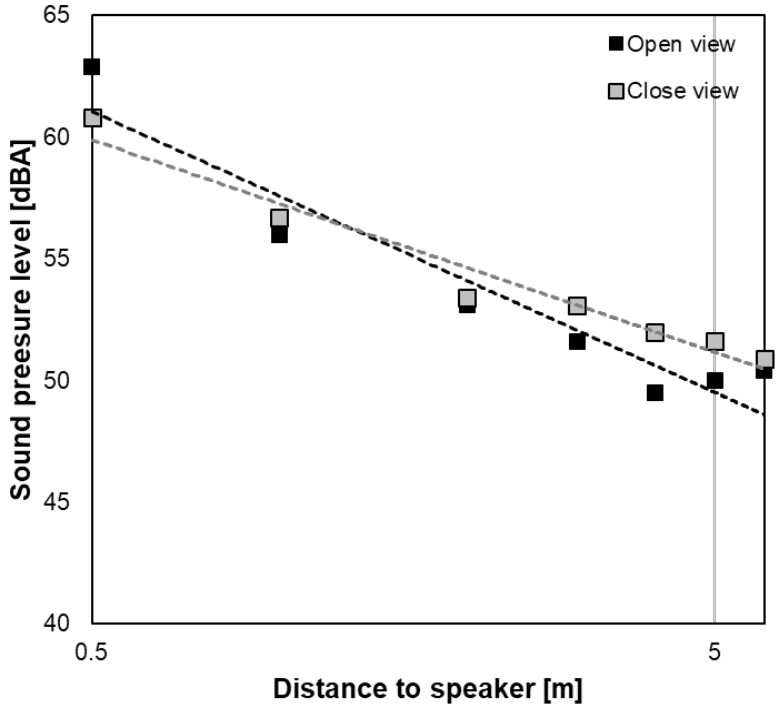

Fig. 2. Sound pressure level; $L_{p,A,S,4m}$ and $D_{2,S}$ in different positions

2.2 Procedure

For the experiment, 20 subjects (16 males, 4 females) with an average age of 27.25 years participated in the evaluation. At the other two points of the window view, the participant sat down to gaze at the window; to create an office environment, the office background noise was reproduced at 57.4 dBA at 1 m from the speaker according to the recommendations of ISO 3382-3. The background noise constituted office noise found on YouTube, and a representative sound source was used that included common speeches, such as people speech, telephone sound, and printer copy sound.

To examine the influence of socio-cultural background factors on the participant, characteristics of the preferred places and office types were surveyed. First, the participants' preferred places were evaluated as a choice question for park/architecture/river side, the preferred landscape was evaluated as artificial/natural, and the preferred office type was rated private/public. Before the evaluation, the participants were allowed to gaze out of the window for more than 10 s. The "digit span backword" of the "Wechsler Scale of Intelligence for Adult, 4th edition" was used to evaluate the work performance[15]. The problem consists of 16 problems, from simple to difficult. For example, if the evaluator outputs 3-5-4, the tester was accepted as the correct answer when he answered 4-5-3, and the length of the number became longer each time he answered the correct answer.

2.3 Results

The average of the correct answers for the 16 questions was calculated and shown in Fig. 3. The accuracy of the participants at the place with an open view was evaluated as 10% higher than that with a close view. The results of socio-cultural background factors

are shown in Fig. 4. First, as shown in Fig. 4 (a), workers who preferred a public-type office were evaluated highly in the OPO environment and were more affected by the window view. According to the results of the preferred places, as shown in Fig. 4 (b) and (c), people who preferred park was sensitive to the window view, and those who preferred natural elements in the preferred landscape responded sensitively to the window view.

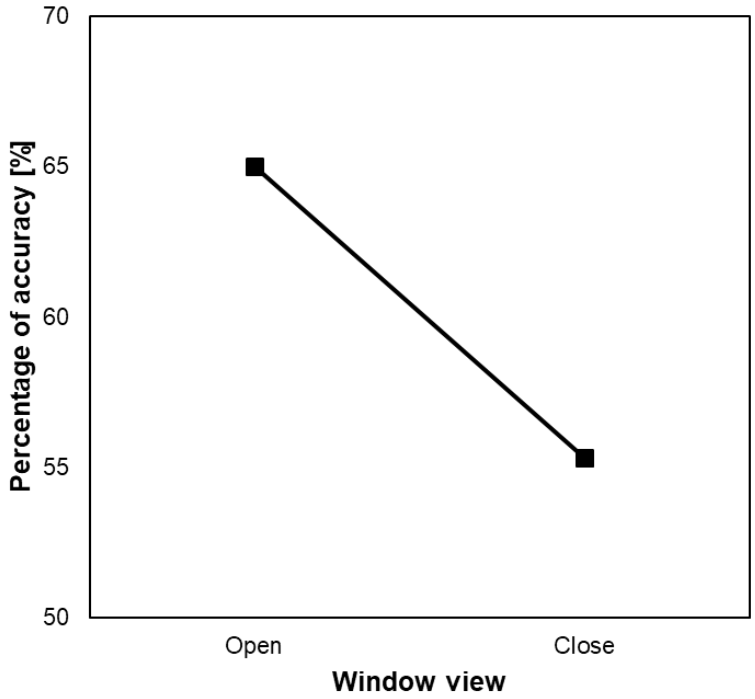

Fig. 3. Percentage of accuracy depending on different window views

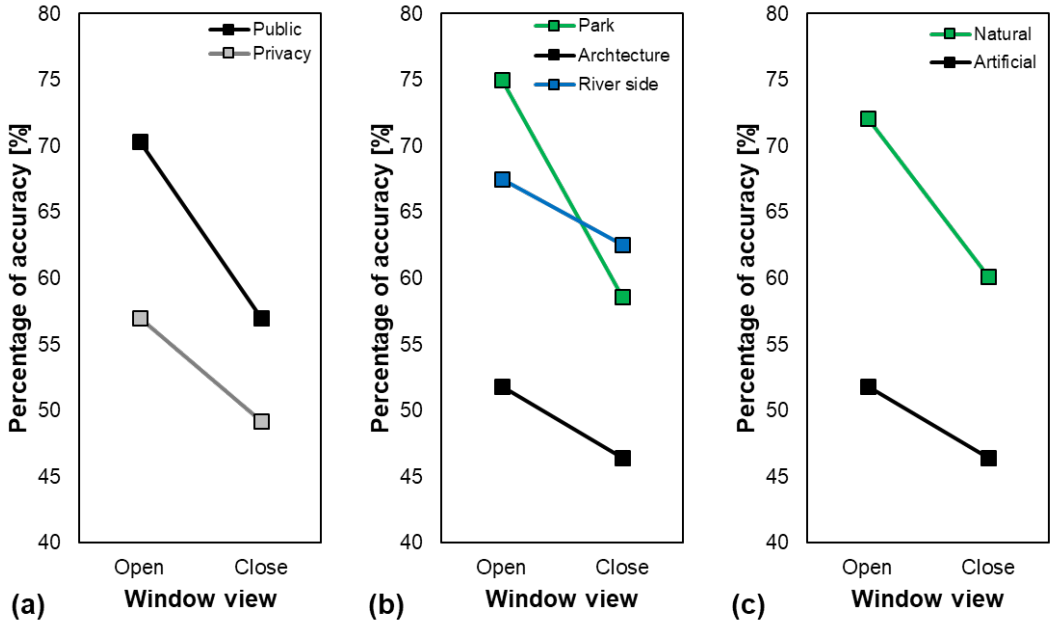

Fig. 4. Relationships between work performance and window view according to socio-cultural factors (a) preferred offices types (b) preferred places (c) preferred landscape.

3. EXPERIMENT 2: VARIATION IN INDOOR ENVIRONMENT

3.1 Test conditions

To investigate the effects of partition height and background noise level on work performance, a virtual office environment was modeled. As shown in Fig. 5, a typical OPO plane was modeled as Autodesk 3ds Max software 2018 and was implemented as an HMD device (Vive pro 2) environment using the Unity 3D software. The partition height was set to 0, 120, and 150 cm, and the background noise level was set at 5 dBA intervals in the range of 55–65 dBA. The sound source used as background noise was the same sound source as the office background noise used in experiment 1. The experiments were conducted in a semi-anechoic chamber, where the background noise was extremely low at 25 dBA.

Fig. 5. Open-plan office layout with different partition heights

3.2 Procedure

Ten subjects (7 males, 3 females) participated in the experiment. The evaluation was performed in nine different environments according to the combination of three partition heights and three background noise levels, and the evaluation was conducted randomly. To evaluate the work performance, the “digit span backword” test was used similarly as in experiment 1. The participants were asked to respond to nine questions and were provided an approximately 2-min break at the end of each assessment.

3.3 Results

The results of work performance according to each evaluation environment are shown in Fig. 6. The overall accuracy increased with the partition height. Meanwhile, with the partitions, as the background noise increases, the work performance decreases. The results of work performance according to each evaluation environment are shown in Fig. 6. The overall accuracy increased with the partition height. Meanwhile, with the partitions,

as the background noise increases, the work performance decreases. In addition, the lower the background noise, the greater is the work performance difference with partition installation, which is approximately 25%. However, the larger the background noise, the smaller is the partition effect, i.e., approximately 7%.

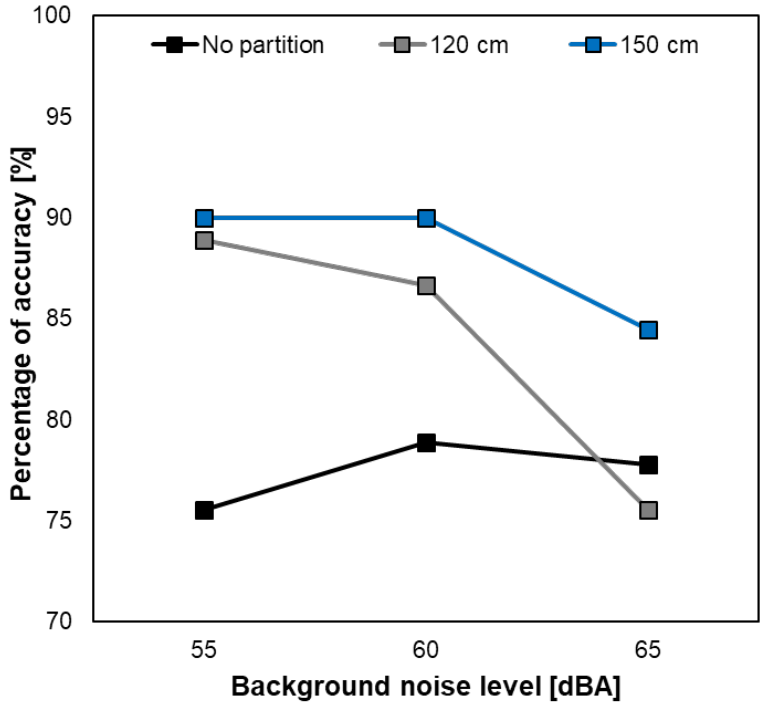

Fig. 6. Relationships between work performance and background noise level according to partition height

4. CONCLUSION

In this study, we examined the effect of window view, partition height, and background noise level on work performance in an OPO environment. In conclusion, when the indoor environment was similar, the external environment was natural and open, thereby resulting in a positive effect on the work performance. On the contrary, if the external environment was the same, the higher the partition of the office and the lower the background noise, the better was the work performance. In the future, the number of participants will be increased through additional experiments and statistical analysis will be conducted to determine whether the influence of each factor is significant.

5. ACKNOWLEDGE

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