A Study on Virtual Reality Work-Space to Improve Work Efficiency

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***Abstract*—Many people feel a lack of efficiency while working in an Open-Plan Work-Space because of ambient noise and low privacy. Although recent research has analyzed the application of virtual reality technology for the improvement of work efficiency, as far as we know, there are no studies focused on analyzing how to design a virtual reality environment that can maintain or improve work efficiency. This article proposes a Virtual Reality Work-Space solution to focus on work efficiency. The preliminary experiment of this research compared the proposed Virtual Reality Work-Space with the Open-Plan Work-Space and showed that the proposed workspace helped participants gain better work efficiency.**

Keywords - virtual reality; workspace; work efficiency.

I. INTRODUCTION

Open-Plan Work-Space (OPWS) is an office style that allows many employees to work simultaneously in a wall-less, partition-less environment. OPWS is characterized by a high sense of openness, low cost, encouraging cooperation, and improving the collective wisdom of the team. More and more companies have chosen this kind of office since its birth in the last century. Although OPWS has already proven its value, there still exist many shortcomings. For example, studies have shown that OPWS often produces adverse effects, such as noise, stress, conflict, high blood pressure, and high turnover rate, etc., among others [1][2]. The noise has the most apparent impact on work efficiency. Compared to quiet rooms, noise interference in OPWS reduces work efficiency by one third [3]. Not only is the OPWS full of auditory and visual interference, but also the low level of privacy protection causes psychological stress to employees and reduces work efficiency. Although many researchers have been working to solve these problems, they still cannot declare that these problems are entirely solved. The obvious point is that most of the proposals suggest creating an additional workspace that needs extra cost. For example, the proposal of providing employees with various additional spaces to alleviate the problem [4] will be very difficult in some countries with demanding space utilization requirements, such as Japan, and some companies are often unable to find enough space.

On the other hand, in response to the work efficiency reduction problem caused by auditory and visual interference in the environment, Microsoft has proposed a Virtual Reality Work-Space (VRWS) that supports typing. People can use this VRWS in the original OPWS without adding additional space costs [5]. Meanwhile, VRWS is a virtual personal space independent of OPWS, so it can also solve the psychological pressure caused by the lack of privacy protection of employees in the public environment. So, this research assumes that this technology has great potential to solve the problems in OPWS. However, no studies are showing how VRWS can be designed to maintain or improve work efficiency. On the other hand, there are some opinions that virtual reality technology cannot benefit the work itself [6].

Some VRWSs have already been used to support people's office work. Among them, the VRchat [7] and Oculus Virtual Desktop [8] are the leading examples of VRWS. VRchat is a virtual reality-based social platform with more than 2 million users. It allows users to interact with others as 3D character models. Oculus Virtual Desktop also has a huge user group, which is offering excellent image quality and some useful extra features to help users with their work. In this VRWS, only a virtual desktop is shown to them, as shown on the right side of Figure 1.

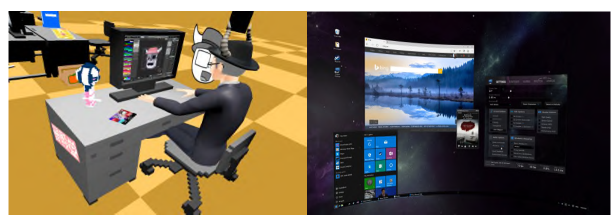

Figure 1. The scene of VRchat office and Oculus Virtual Desktop.

VRchat allows for custom VR environments, but there are no studies to show how VRWS can be designed to maintain or improve work efficiency. Thus, the design of the VR environment relies entirely on personal customization. Oculus Virtual Desktop even ignores VR environment design and shows the dim universe to the user. It is hard to believe that work efficiency would benefit from these kinds of VR environments. We believe that the VR environment can be a solution to improve or maintain work efficiency. It is different from existing ones, and the VRWS which we have suggested has a good environment that can improve work efficiency.

This research focuses on proving that VRWS can deal with work efficiency, and, at the same time, identifying the

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factors which, in virtual reality, affect work efficiency. In this article, the research consists of the following questions:

- What kind of VRWS may handle work efficiency?
- How to find the factors that affect work efficiency in VRWS?

The rest of this article is organized as follows. Section II describes the related work. Section III introduces the experimental design, result, and analysis in detail. The conclusion and future work are presented in Section IV.

II. RELATED WORK

In order to clarify the position of this research, this section introduces related work on previous OPWS and VRWS for targeted working spaces, and Semantic Differential as an evaluation method.

A. *OPWS and VRWS*

The environment of OPWS not only directly affects people's health and enthusiasm for work, but also affects work efficiency [1]-[3]. A pleasant office environment should be a cozy space that has no visual and auditory interference, good lighting, a controlled sound environment, and plenty of natural light [9]-[12].

According to our investigation, there is currently no research to confirm what VRWS design standards can maintain or improve work efficiency. Although there have been a couple of research works proposing solutions to improve the shortcomings of OPWS, it is not sure whether the solutions for OPWS can be applied to VRWS. The research tends to create a VRWS with excellent OPWS characteristics to maintain or improve work efficiency.

B. *Semantic Differential*

Semantic Differential (SD) was proposed by Osgood in 1957 as a method of psychological measurement [13]. The analytical method of the SD is to use "language" in semantics as the scale for experiments, and quantitatively describe the concept and structure of the research object through the analysis of various established scales.

The SD method for workspace can be summarized as follows: study the psychological response of participants in the space to various environmental characteristics of the target space, develop a "semantic" scale for these psychological responses, and then, evaluated and analyze all the description parameters of the scale to quantitatively describe the concept and structure of the space target.

Therefore, we adopt SD analysis to compare the quantification of different emotions obtained from the participants in both OPWS and VRWS. We obtain the difference between the two office environments on participants and we find the factors that impact work efficiency that exist only in VRWS.

III. EXPERIMENTAL DESIGN AND DISCUSSION

The purpose of this experiment is to compare the respective effects of OPWS with VRWS and explore whether VRWS can deal with users' work efficiency.

A. *Experimental Design of OPWS*

OPWS is very popular all over the world, and different types of work content will also produce OPWS with different characteristics. For example, the call center is a typical noisy OPWS because answering a call is an essential task in the call center. In this environment, working noise is unavoidable. There are also different types of OPWS. For example, librarians rarely worry about noise.

It was difficult to find a typical noisy OPWS in the area where the authors live. In order to control the experimental settings, we decided to use the Cave Automatic Virtual Environment (CAVE) system to simulate a typical noisy OPWS. The CAVE system is a projection-based virtual reality system, which consists of several projection screens surrounding the participants and it can produce a completely immersive virtual environment. At the same time, mini-speakers were arranged around the CAVE system to restore the simulated OPWS sound environment as much as possible. Therefore, the CAVE system used in this experiment can make the participants feel the real situation of a noisy OPWS very well.

The experimental arrangement of this study based on the CAVE system is shown in Figure 2. Five participants in the group performed experiments together in the CAVE system. There were five seats in the CAVE system, and a laptop and a mouse were placed in each seat to allow the participants to take the CAB test.

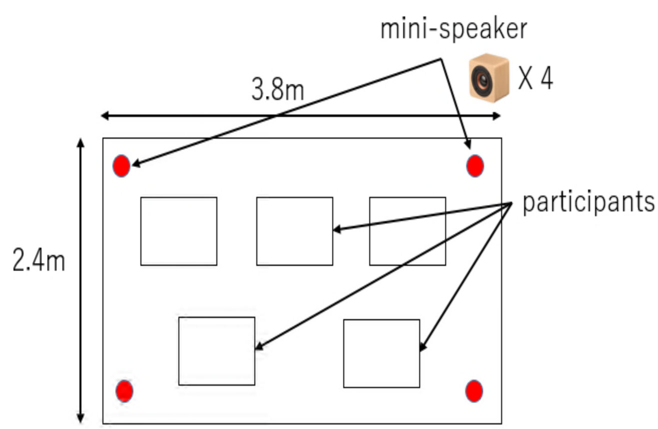

Figure 2. Experimental arrangements in the CAVE system.

For the content played in the CAVE system, the simulated OPWS chosen for this experiment was the mission center of National Aeronautics and Space Administration (NASA) [18]. One of the frequent activities in this content was to exchange information among employees. Figure 3 shows the scene in the OPWS condition.

Figure 3. The scene of the experiment in the CAVE system.

B. *Experimental Design of VRWS*

We assumed a VRWS with excellent OPWS characteristics, which was an environment without visual and auditory interference, good lighting, sufficient natural light, and privacy protection, with the expectation to maintain or improve work efficiency. In order to make VRWS met the above requirements, we did the following steps.

In order to avoid the visual and auditory interference from the environment, we decided to use a combination of Head Mounted Display (HMD) and noise-canceling earphones. The HMD could completely isolate the visual interference in the environment, and the muffler headphones could eliminate most of the auditory interference. Figure 4 shows the combination of HMD and noise-canceling earphones.

Figure 4. HMD and noise-canceling earphones.

In order to create a present lighting environment, in the initial design stage of the virtual model, we increased the brightness of the model and used natural light sources instead of ordinary light sources to make the light fill the entire virtual space.

For the requirement of enough natural light, we designed some large floor-to-ceiling windows to replace the walls on either side of the VRWS. For privacy protection, we designed VRWS as a personal workspace that could not be shared with others. In the VRWS experiment, an HMD with a computer and mouse was provided to the participants to complete the experiment. The HMD used in this experiment is Acer Windows Mixed Reality headset AH101. Each participant experimented alone in this setting. Through the above steps, we developed the VRWS, as shown in Figure 5.

Figure 5. The scene of the VRWS.

C. *Comparative Experiments*

A total of 20 people participated in the experiment, consisting of 9 females and 11 males, from 24 to 30 years old. The participants were fluent in English, but had no previous experience with VR systems and were recruited by an open call as a small part-time job for the experiment. The experiment invited the participants to share their opinions/feelings while working in specific environments rather than doing complicated problems. The complexity of the experiment might not affect the participants' motivation to join the experiment. In addition, the experiment was about 50 minutes for each participant, which was considered as a short experiment. The reward was 'thanks for their time', and that did not change their motivation much.

Before starting the experiment, we informed the participants about the experiment process, gathered data and got approval from them. Next, we assigned all participants randomly to groups A, B, C, and D. Each group consisted of five participants. Among them, groups A and C performed OPWS experiments before VRWS experiments. Groups B and D performed the experiments in the reverse order. The duration of each experiment was about 25 minutes and after the experiment, each participant was asked to fill a questionnaire. After the experiments, all the data and questionnaires were collected to compare OPWS and VRWS.

D. *Cognitive Assessment Battery Test*

In this experiment, each participant was required to complete his/her "work" in OPWS and VRWS. Therefore, we adopted the Cognitive Assessment Battery (CAB) test consisting of no language-based questions with only numbers and pictures. This test avoids deviation, such as caused by different understanding speeds and understanding difficulty in different languages.

The purpose of the CAB test was to measure people's logical thinking ability. Thus, in this "work" process, the participants were expected to concentrate on solving the test as an essential requirement. We assumed that there is a relationship between the CAB test results and work efficiency.

Every participant received an electronic test containing 45 questions for each experiment. The participants were requested to complete as many CAB tests as possible within 25 minutes. Participants could only answer the questions one by one. Each test question had four options. In order to rule out errors due to condition differences, the participants were requested not to use all tools except a mouse during the answering process in both settings. The questions were designed with reference to some related works [14][15]. Some examples of the CAB test questions are shown in Figure 6.

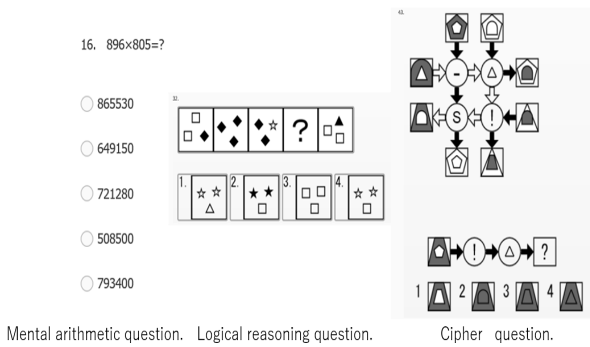

Figure 6. Examples of CAB test.

At the same time, these three kinds of test questions appeared in the same proportion in each set of test papers for each participant. The ratio of the test types is shown in Figure 7.

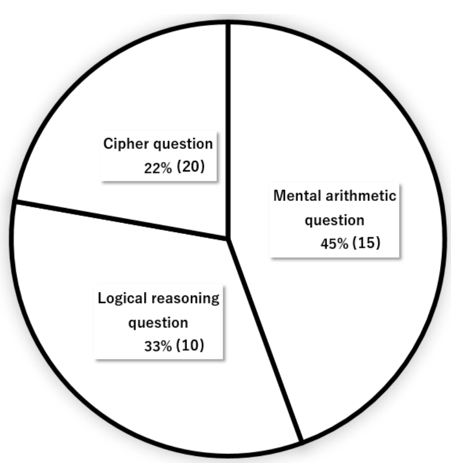

Figure 7. The ratio of the 3 types of questions in one CAB test.

E. *Questionnaire*

In order to use the SD method for evaluation, the expression phrases in the questionnaire were designed with reference to *Research on Emotional Engineering* [16] and *Versatility of Building Language Description* [17]. The set adjective pairs are shown in Table I. The reason for choosing these phrases is because they can express people's feelings where they are at the workspace.

The evaluation scale in this experiment was divided into seven levels. A small value was given for a negative evaluation, and a large value was given for a positive evaluation.

TABLE I. ADJECTIVE PAIRS FOR SD EVALUATION

1	*Broad view*	*Narrow view*
2	*Low psychological pressure*	*High psychological pressure*
3	*Free atmosphere*	*Non-free atmosphere*
4	*Comfortable*	*Uncomfortable*
5	*Well-lighted*	*Ill-lighted*
6	*Not tired*	*Getting tired*
7	*Natural feeling*	*Strange feeling*
8	*Grace*	*Graceless*
9	*Relaxing*	*Not-relaxing*
10	*Cheerful*	*Depressed*
11	*Easy to work*	*Hard to work*
12	*Not noisy in movement*	*Noisy in movement*
13	*Enjoyable*	*Not enjoyable*
14	*Not noisy in sound*	*Noisy in sound*
15	*Motivated*	*Unmotivated*
16	*Efficient*	*Inefficient*

F. *Results*

The more correct answers and the less time it took means the more efficiently the subjects worked. Similarly, the more correct answers per unit time one got, the more efficiently one worked. Thus, we calculated the difference between the number of correct results of the CAB test in each subject's OPWS and VRWS and the difference between the times taken in the two experiments.

For the questionnaire, the adjective pairs were compared with the average of the two groups' results. As shown in Figure 8, lower points are negative evaluations and higher points are positive evaluations.

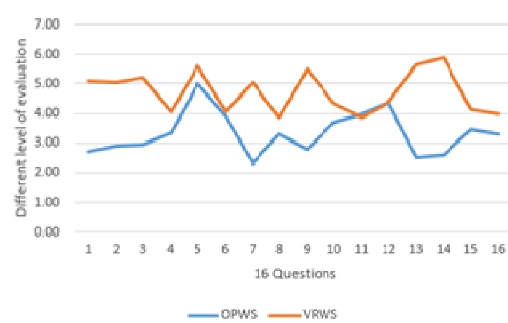

Figure 8. The average of the two groups' results.

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In order to ensure the validity of this study, a student's t-test (t-test) was used to analyze the data further. In this study, SPSSAU [19] was used for data analysis.

Before performing the t-test, we needed to confirm the normality of the sample. Because the number of sample data from the CAB test and the questionnaire were all less than 50, the Shapiro-Wilk test was chosen. Through the Shapiro-Wilk test, although some sample data were considered to have no normality traits because their P-values were under 0.05, their absolute values of Kurtosis were all less than 10, and the absolute values of Skewness were all less than 3. So, even though some sample data were not the standard normal distribution, the data could basically be accepted as a normal distribution. Therefore, all the sample data can be considered to follow the normal distribution. So, we adopted the t-test to analyze the sample data. T-test results on the CAB test are shown in Table II, and t-test results on the questionnaire are shown in Table III.

TABLE II. T-TEST RESULTS ON CAB TEST

t-test				
Items	***Environment(average ± SD)***		***t***	***p***
	OPWS(N=20)	***VRWS(N=20)***		
Correct Answer	30.70 ± 3.85	32.25 ± 4.22	-1.214	0.232
Time Difference in Two Experiments	23.10 ± 2.61	21.60 ± 2.66	1.798	0.08

TABLE III. T-TEST RESULTS ON QUESTIONNAIRE

t-test				
Question Number	***Environment(average ± SD)***		***t***	***p***
	OPWS(N=20)	***VRWS(N=20)***		
Q1	5.30 ± 0.98	2.90 ± 1.25	6.753	0.000
Q2	5.10 ± 1.21	2.95 ± 1.00	6.13	0.000
Q3	5.05 ± 1.39	2.80 ± 1.20	5.476	0.00
Q4	4.65 ± 1.39	3.95 ± 0.89	1.901	0.066
Q5	3.00 ± 1.08	2.40 ± 0.94	1.878	0.068
Q6	4.10 ± 1.17	3.95 ± 1.10	0.419	0.678
Q7	5.70 ± 0.86	2.95 ± 1.15	8.568	0.000
Q8	4.70 ± 1.22	4.15 ± 1.14	1.476	0.148
Q9	5.20 ± 0.89	2.50 ± 1.15	8.301	0.000
Q10	4.30 ± 0.86	3.65 ± 1.23	1.938	0.06
Q11	4.00 ± 1.12	4.15 ± 1.35	-0.382	0.704
Q12	3.60 ± 1.64	3.60 ± 1.10	0	1
Q13	5.50 ± 1.10	2.35 ± 1.09	9.098	0.000
Q14	5.40 ± 1.39	2.10 ± 0.72	9.424	0.000
Q15	4.55 ± 1.43	3.85 ± 0.81	1.901	0.067
Q16	4.70 ± 1.42	4.00 ± 1.03	1.789	0.082

From Table II, we can see that the Correct Answer is non-significantly different ($0.1 < p$), and Time Difference is marginally significantly different ($0.05 < p < 0.1$).

From Table III, Q1, Q2, Q3, Q7, Q9, Q13, and Q14 are significantly different ($p < 0.01$). Q4, Q5, Q10, Q15, and Q16 are marginally significantly different ($0.05 < p < 0.1$). Also, Q6, Q8, Q11, and Q12 are non-significantly different ($0.1 < p$).

G. Findings

In this research, each experiment was conducted for about 25 minutes, so we guessed that the time was not long enough to make a significant differences in the number of Correct Answers and Difference in Time between the two experiments.

A small number of participants could not bear the noisy environment in OPWS. In order to leave as soon as possible, they completed the CAB test at the fastest speed possible while giving the correct answer as much as possible. Therefore, these participants believed that although they could not bear the unbearable interference in OPWS, from the perspective of the results, the work efficiency was improved.

From OPWS to VRWS, although it was more beneficial for participants to answer CAB tests, it was impossible to make difficult questions easier just because the environment become better, so the Correct Answers had no significant difference.

The results of Q14 shows an effect of sufficient separation of auditory interference by noise-canceling earphones. At the same time, we believe that the no auditory interference environment also has a positive effect on the results of many significant and marginally significant items.

The results of Q1, Q7, Q9, and Q13 indicate the floor-to-ceiling windows greatly improve the subject's vision. The virtual nature environment surrounding the VRWS gave the subjects a more natural feeling. Because of the floor-to-ceiling windows, it was easier for natural light to enter the room through the windows.

As shown in the results of Q2, Q3, and Q9, compared with the noisy environment of OPWS, the elegant and comfortable virtual environment design and private use features can play a role in preventing psychological pressure.

HMD must be worn when using VRWS. There might be a negative effect in the physical sense, but the impact was not significant from the results of Q4, Q10, Q15, and Q16. The CAVE system used in this experiment had good lighting effects, so the participants did not strongly feel the difference in lighting effects between the two experiments from the result of Q5.

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There was no difference between Q15 and Q16 because wearing HMD could be an obstacle to face-to-face communication. When considering other network communication methods such as e-mail, HMD only caused communication failure in certain situations.

Most of the participants rejected the use of HMD for a long time. The main reasons were: the weight and volume of the HMD put an extra burden on long-term work, and virtual reality might cause vertigo. VRWS did not have sufficient input support and HMD cooling problems. These reasons have led to the results of Q6, Q8, and Q11.

The participants did not notice the visual interference problem in OPWS from the result of Q12. HMD is a display device wrapped around the eyes of the user, and the user could no longer feel the external visual interference, theoretically. Considering that the CAVE system was used to simulate OPWS in the comparative experiment, the busy scene in the noisy OPWS is displayed in 2D by several projection surfaces around the participants in the CAVE system, which might affect the psychological reality of visual interference. Thereby, they reduced the intensity of interference. Furthermore, the contrast effect between OPWS and VRWS in Q12 in the movement was not significant.

In previous VRWS work, it was not considered that VR environments could be a solution to improve work efficiency. However, this research and experiments showed that there is indeed a significant difference in some factors in the VR environment. The previous VRWS could not find these factors because of the simple VR environment. So, participants' work efficiency could not benefit from their VR environment. The research has also demonstrated those factors in the discussion section.

IV. Conclusion and Future Work

From the experiments, it is hard to confirm that VRWS could maintain or improve work efficiency. Aiming at work efficiency, the conclusions of OPWS related research maybe can be used as a design standard for VRWS. Through this research, we can know that VRWS has generally received higher evaluations and has more significant positive evaluations on Relaxing, Enjoyable, and Not noisy in sound. Using VRWS based on OPWS related research conclusions as design standard, compared to OPWS, people can get a wider virtual vision environment, can reduce the psychological pressure, feel a freer atmosphere, enjoy the office process more, and have a quieter office. Also, VRWS may be more comfortable, may have better lighting effects, help generate positive emotions, increase work enthusiasm, and increase work efficiency.

For future work, we first plan to improve the defects of the VRWS input. Because a person wearing the HMD cannot see the surrounding environment, it makes the use of the keyboard, paper, pen, and other tasks more difficult. Through the camera connected to the HMD, the keyboard, paper, and pen can be recognized and displayed in VRWS, which is convenient for users. This also means turning VRWS into Augmented Reality Work-Space (ARWS). In addition, for the virtual environment part of VRWS, we will consider the ability to customize it, which will further improve the practicality of VRWS and improve work efficiency.

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