1. INTRODUCTION

Virtual reality (VR) is a computer generated graphical environment, which provides a real world feeling with the aid of technological hardware [1]. The idea of VR is tricking the brain into having a real environment. Virtual reality is considered to have begun in the 1950’s [2] and only came to the public’s attention in the late 1980’s [3]. VR has progressed leaps and bounds due to the fast evolution of computer technology and has been applied in many areas. The most common applications of VR include gaming [4], hazard prevention demonstrations [5, 6], air traffic simulations [7], military trainings [8], medical treatments [9] and aeronautical simulations [10].

Among the newest emerging VR applications, Oculus Rift has received considerable attention in recent years [11]. Oculus Rift is a lightweight virtual reality headset that blocks out the view of the user’s surrounding environment and immerses them into a virtual world. This head mounted display (HMD) consists of a pair of goggles with an image display unit along with gyro sensors to track the user’s head movement. The unique architecture of Oculus Rift provides users a distinctive and strong sense of immersion. However, scientific study or an attempt to develop an application besides entertainment has only just begun with this transformative VR technology (e.g., virtual reality therapy) [12].

On the other hand, many software and hardware developers are becoming increasingly interested in introducing human bio-signals into a virtual world. The video game called “Nevermind” [13] has incorporated human pulse rate into a VR game environment. In their game design, the game will become more difficult when the player becomes nervous as his/her pulse rate changes the condition to complete the quests. Nazemi and Gromala created a virtual walking meditation system called Virtual Meditative Walk, which connected to a unidirectional treadmill and the participant’s Galvanic Skin Response (GSR) [14]. The user walks through the virtual forest with changing weather conditions in the virtual world as a function of his/her GSR in real-time. Because GSR represents the peripheral sympathetic nervous system activation, this biofeedback implementation helps users train themselves to be more meditative while referencing the weather in the VR forest.

These two examples of the state-of-the-art interactive VR system using bio-signaling illustrate the potential for opening the door to a new generation of entertainment. Moreover, the benefit possibly expected from the interactive VR system using bio-signal should not be limited as in the context of entertainment but of behavioral and/or clinical psychology. Significant benefits in a clinical scene provided by “biofeedback” training include reducing anxiety, inducing relaxation, alleviating symptom of attention-deficit hyperactivity disorder, and lowering blood pressure [15]. To the best of our knowledge, there are few studies to investigate the psychological effects on humans experiencing interactive VR system using bio-signals.
Thus, this study investigates the effect of our proprietary interactive VR system using bio-signals compared with VR using sinewave and random signals on the subjective impression. In this study, three different VR scenes with three different input signals were given to the subjects and the subjective outcomes was assessed using a visual analogue scale. Specifically, the three different input signals used were bonfire (regulated with Electrocardiogram, sinewave, and random signals), firefly and butterfly (regulated with respiration signal, sinewave, and random signals).

2. METHOD

2.1 Bio-signal interactive VR system

We used respiration and heart beat signals as bio-signals that interact with the VR system observed by Oculus Rift. This system comprises a respiration sensor unit, Electrocardiogram (ECG, or heart beat signal) unit, data acquisition unit, game engine and HMD, as shown in Figure 1.

The respiration sensor unit uses a force-sensing device (FSR400, Interlink Electronics, Inc., USA [16]) and an electric signal amplifier to convert the movement of the subject’s chest that accompanies respiration into an electric signal.

We used two types of data acquisition units: BIOPAC MP150 [18] (for ECG signals) and Arduino UNO [19] (for the respiration signals). Using our algorithm, the digitalized respiration and ECG signal were integrated with the VR environment, which was presented to a subject by Oculus Rift (Oculus Rift, Oculus VR, LLC [17]). Table 1 shows the specification of Oculus DK2. With regard to the 3D game engine, we used Unity 5.2 [20] and C# programming language to combine visual simulation with the bio-signal.

2.2 Experiment

2.2.1 Subject

Subjects were randomly recruited from university students. Subjects wearing spectacles and contact lenses were also included in the study. Oculus Rift DK2 adjustable lenses were also used in preference for better vision [21]. Color blind discomfort cannot be avoided by that instrument; therefore, the color vision test was employed for screening the subject. After the screening, twenty subjects (four females and 16 males, aged from 21 to 25, 167.3 [6.7] of height in average [S.D.], eyesight from 0.2 to 1.5) participated in this study.

2.2.2 VR scenes and conditions

The experiment used three VR senses through Oculus Rift, which are bonfire, firefly, and butterfly, as shown in Figure 2(a), 2(b) and 2(c), respectively. These three scenes were chosen because they can be regulated with different controlled variables, e.g., object movement, object size variation, and change of brightness in VR environment.

In each VR scene, the appearance of the objects (e.g., movement, brightness, and size) were regulated with 1) a bio-signal (namely, “bio-signal”), 2) a random signal (“random”), and 3) a sinewave signal (“sinewave”). Table 2 summarizes the controlled variables of the objects, which affects their appearance.

As Table 2 describes, three types of VR scenes (i.e., bonfire, firefly, and butterfly) were prepared. In the bonfire scene, the flame parameters (size and brightness of the flame) have synchronized the ECG signal (Figure 3(a)). Firefly and butterfly scenes used respiration signal (Figure 3(b)) as the bio-signal. Movement speed and luminous intensity of the firefly in firefly scenes were

![Figure 1: A schema of bio-signal interactive VR system used in this study.](image)

![Table 1: Specification of Head Mounted Display used in the study [17]](table)

| Item                        | Oculus Rift DK 2                      |
|-----------------------------|---------------------------------------|
| Type                        | Binocular non-transmitting            |
| Sensors                     | Gyroscope, Accelerometer, Magnetometer|
| Refresh rate                | 60Hz – 75Hz                            |
| Resolution                  | 960 * 1080 per eye                     |
| Viewing angle               | 100°                                  |
| Software Development Kit    | Available for Windows, Mac and Linux  |
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regulated by respiration signal. Likewise, the vertical movement and flapping speed of butterfly in the butterfly scene were regulated by respiration signal.

All of the bio-signal regulated parameters (used in bio-signal condition) were changed according to the amplitude normalized from 0.0 to 1.0. The amplitude of the random and sinewave signals (used in random and sinewave condition) were also normalized from 0.0 to 1.0 for a reasonable comparison. The frequency in Sinewave was set to 0.27 Hz and 1.25 Hz in comparison with respiration and ECG signal in the bio-signal, which are similar to the average human breathing and heart beat frequency [22].

2.2.3 Measurements (Visual analogue scale)

A questionnaire was provided to record subject’s subjective impression in the system with varying scenes and conditions (input signals). The questionnaire used in this study had two parts. Subjects provided their experience in the first part. They were asked three questions:

Q1. Which VR space did you feel was more spacious?
Q2. Which VR space was more comfortable?
Q3. Which VR space was more natural?

Subjects compared each scene with two different types of inputs called A and B, which were randomly assigned in a pairwise manner (described in 2.2.4 Experimental Procedure). We provided a visual analogue scale (VAS) to obtain the intensity of attitude (Figure 4). The second part of the questionnaire collected gender, age, height, visual ability, interest in virtual videos and motion sickness of the responder.

![Figure 2: Three virtual scenes provided in the experiment.](image)

**Table 2:** VR scenes and controlled variables of the object

| Scene       | Environment                                      | Controlled variable             | Input signal                      |
|-------------|--------------------------------------------------|---------------------------------|-----------------------------------|
| Bonfire     | Indoor living room with flaring a bonfire        | Size and brightness of the flame| Bio-signal (ECG), random, or sinewave |
| Firefly     | Hundreds of fireflies flying in a dark forest    | Movement and luminous intensity of the firefly | Bio-signal (respiration), random, or sinewave |
| Butterfly  | Dozens of butterflies flittering in a green meadow | Speed of flapping and vertical movement of the butterfly | Bio-signal (respiration), random, or sinewave |

![Figure 3: Input signals in the experiment.](image)

![Figure 4: Visual analogue scale used in the experiment.](image)
2.2.4 Experimental Procedure

Subjects experienced each scene (i.e., bonfire, firefly, and butterfly) with all possible input signal combinations. In addition, our preliminary test revealed that the difference in the appearance of the scene caused by the different input signals was relatively small and difficult to see at a glance. Then, we used a pairwise comparison and made subject compare two conditions sequentially and were repeated two times. For example, a subject experienced the scene “firefly” regulated with (A) bio-signal and with (B) sinewave alternatively. Each condition was 60 sec with a 5 sec interval (255 sec in total) between the two conditions as depicted in Figure 5.

Scenes presented to the subjects during this procedure were repeated for three possible combinations of input signals, i.e., bio-signal-random, bio-signal-sinewave, and sinewave-random; therefore, each subject experienced nine trials in total.

In the experiment procedure, vision of the subject was tested first before the experiment. After the ECG sensor and the respiratory sensor were attached, the subjects were instructed to wear the HMD and check the visibility of the VR scene before the experiment. Then, a trial scene was given after delivering instructions to the subjects. Finally, the subjects were advised to pay attention on VR, where the calibration of the bio-signal was conducted.

Questionnaires were given to the subjects at the end of each trial. The experiment was conducted in a within-subject design. The order of presenting scene and the pair of regulation conditions (input signal) were counterbalanced.

Subjects were instructed to stay calm and relax during the entire experiment period. The experiment was conducted in a light- and sound-controlled room.

2.2.5 Statistics

In the statistical analysis, we employed Nakaya’s variation of the Sheffé’s ANOVA for paired comparisons [23] after re-sampling and categorizing the result of VAS into 11 point scale as $-5, \ldots, 0, \ldots, +5$. The studentized range statistic ($q$) was further used for multiple comparisons [24]. The level of statistical significance was set at 0.05.

3. RESULT

Table 3 shows the results of VAS scores (row data scaled -5 to 5) for the paired comparisons in each scene. Note that the plus and minus value shows that the condition described in the right and left column agreed significantly more.

Figure 6 (a), 6 (b), and 6 (c) shows the statistic results of Sheffé’s ANOVA (Nakaya’s variation) with the multiple comparisons for further analysis. Note that the alpha value in the figures represents the averaged VAS evaluation value, so a positive score means it agreed with the term of question (Spacious, Comfortable, and Natural).

Regarding the Bonfire condition, there were significant effects of condition on Q2 and Q3 ($p < 0.01$ for each one). Further, multiple comparisons for Q2 revealed that bio-signal is significantly higher than sinewave ($p < 0.001$) and has a trend to be higher than random ($p < 0.10$), and Random is significantly higher than sinewave ($p < 0.001$). Bio-signal referring to Q3 also indicated a significantly higher value than sinewave ($p < 0.001$). Random is significantly higher than sinewave ($p < 0.001$).

In the Firefly condition, there were significant effects of condition on Q2 and Q3 ($p < 0.01$ for each one). The multiple comparison for Q2 showed that bio-signal is significantly higher than random ($p < 0.001$) and sinewave ($p < 0.01$) and that Q3 shows that bio-signals were significantly higher than random ($p < 0.05$) and sinewave ($p < 0.05$).

Table 3: Result of VAS for pairwise comparison: average (S.D.)

| Q1. Spacious | Q2. Comfortable | Q3. Natural |
|--------------|-----------------|-------------|
| **Bonfire scene** |                 |             |
| (-)          | (+)             |             |
| Random       | -0.31 (0.31)    | -0.22 (0.55)| 0.08 (0.86) | Bio-signal |
| Sinewave     | 0.18 (0.48)     | 1.49 (0.00)| 2.08 (0.00)| Bio-signal |
| Sinewave     | 0.46 (0.28)     | 0.87 (0.12)| 1.88 (0.00)| Random    |
| **Firefly scene** |             |             |
| (-)          | (+)             |             |
| Random       | 0.77 (0.10)     | 2.39 (0.00)| 0.96 (0.06)| Bio-signal |
| Sinewave     | 0.73 (0.04)     | 1.59 (0.01)| 1.09 (0.13)| Bio-signal |
| Sinewave     | -0.52 (0.21)    | -1.71 (0.02)| -0.60 (0.42)| Random    |
| **Butterfly scene** |             |             |
| (-)          | (+)             |             |
| Random       | 0.21 (0.70)     | 3.11 (0.00)| 3.96 (0.00)| Bio-signal |
| Sinewave     | -0.65 (0.05)    | -0.98 (0.13)| -0.58 (0.30)| Bio-signal |
| Sinewave     | 0.54 (0.20)     | -3.71 (0.00)| -3.78 (0.00)| Random    |

Figure 5: An example of the timeline for a trial in the experiment.
In the Butterfly condition, there were significant effects of condition on Q2 and Q3 ($p < 0.01$ for each one). The multiple comparison for Q2 and Q3 showed that bio-signal and sinewave were significantly higher than random ($p < 0.001$). Sinewave referring to Q2 also indicated a significantly higher value than bio-signal ($p < 0.05$).

Q1 did not give any significant results in all three scenes under any condition.

4. DISCUSSION

Regarding Bonfire and Firefly, subjects responded that the scene regulated by bio-signals was the most “comfortable” and “natural.” In Butterfly, the sinewave regulated scene showed the best fit in terms of “comfortable” and “natural.” Meanwhile, the scene regulated by the bio-signal still showed the positive alpha value along with two other scenes; therefore, bio-signal can be considered the most comfortable and natural condition compared with sinewave and random.

Respiration signal was used as bio-signal in the Firefly and Butterfly scenes. Dennison et al. [25] suggested by their experiment that individuals who tend to hold their breath during HMD do not feel as ill. At present, there is no clear evidence that subjects in our experiment held their breath during the experiment.

The ECG signal was used as a bio-signal in Bonfire. There are reports that heartbeat alleviates human mental state. However, we know of no scientific report with strong evidence and robust theory that the visual image reflecting heart signal also makes one feel comfortable. Moreover, it should be noted that only two of the 20 subjects were aware that the fireflies and butterflies in the given VR scene were synchronized with their own breathing, and no one knew that the fire flame in Bonfire was synchronized with their heartbeat.

However, there was no impact on the subjective impression of “spacious” (Q1) in all three scenes under any condition. Q1 was introduced as a neutral question for this study as we focused on the difference of the signal regulating the object in VR. So the result of Q1 might be significant.

Furthermore, the demographic parameters, that are gender, age, height, and visual ability, was not associated with any item of questionnaire.

To the best of our knowledge, no study has investigated the effect of a bio-signal interactive VR system in a real-time manner. The psychological effect revealed in this study is quite interesting and new. However, this study is still in the earliest stage and there are more variations of scenes, objects and parameters to be explored. Moreover, we cannot currently common on the psychological/neurological mechanism of the observed psychological effect. More psycho-physiological experimental study is needed.

5. CONCLUSIONS

This study was conducted with the objective of investigating the effect of our bio-signal interactive VR system on the subjective impression with VAS. As a result of the experiment, bio-signals can be considered as the most comfortable and natural condition compared with sinewave and random signals. Thus, integration of bio-signal and virtual reality system would be an impor-
tant and future direction for an ambient system, of which our system could be a part. On one hand, the method demonstrated in this research offers a promise of future bio-signal integrated virtual system developments. Although bio-signal is rarely used in current practice, this study suggests that bio-signal can be adopted as a key input in developing VR systems.

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