Effect of Heart Rate Feedback Virtual Reality on Cardiac Activity

A preliminary study with heart rate feedback "fire flame" scene

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Abstract— **In this study, the psycho-physiological effect of a heart rate (HR) feedback virtual reality (VR) scene on a human was investigated. The VR scene was a living room with a fire place, where a fire flame flickered in synchronisation with the viewer's own HR in a real-time manner. Fifteen male university students underwent this interactive installation for 60 s, repeatedly. In comparison with the control condition in which the fire flickered at a constant rhythm, the HR significantly decreased and exhibited a positive correlation with the subjective score of "comfortable." Thus, the change in the cardiac sympathetic nervous activity may be attributed to the psycho-physiological effect.**

Keywords-biofeedback; virtual reality; heat rate; ambient feedback.

I. INTRODUCTION

VR is used not only for the purpose of entertainment, but also for clinical purposes, such as treatment of phobias [1] and pain management [2]. Majority of these studies presented patients with a relaxing virtual world, and reported the alleviation of anxiety, a positive mood, and an improvement in physiological states of the patients. Therefore, immergence into the VR world has a significant influence on the viewer's psycho-physiological functioning.

Recently, attempts have been made to integrate VR with biofeedback training. "Virtual Meditative Walk" enables users to perform meditation training by walking in a virtual forest where the weather conditions change according to the user's galvanic skin response; thus, the users can train to control their sympathetic nervous activity by themselves [3].

The aforementioned studies demonstrate the possibility of expanding the use of bio-signal interactive VR, which positively induces the state of the human mind and body. However, to the best of our knowledge, no study has directly investigated the psycho-physiological effects on humans experiencing an interactive VR system using bio-signals. The present preliminary experimental study aims to investigate the effect of an interactive heart rate (HR) virtual reality (VR) scene on the human mind and body.

The remainder of this paper is organised as follows. The configuration of our developed bio-signal feedback VR system and the experiment conducted to test the system efficacy is described in Section 2. The experimental results and their discussion are presented in Sections 3 and 4, respectively.

II. METHOD

As a preliminary challenge to explore the psycho-physiological effect of the bio-signal feedback VR system, we focused on the HR signal because of its accessibility.

A. Configuration of heart rate feedback virtual reality scene

The HR feedback VR system comprises a VR head mounted display (HMD) (Oculus Rift DK 2, Facebook Technologies, LLC.), bio-signal amplifier (BIOPAC MP150, BIOPAC Systems, Inc.), game engine (Unity 5.2), and personal computer (controller). The electrocardiogram (ECG) signal was acquired by the bio-signal amplifier at a sampling rate of 200 Hz. The beat-to-beat interval (known as "RR interval") of the ECG signal was determined and conveyed to a control PC to generate the HR feedback VR "fire flame" using the game engine. Then, the VR image was exposed to a viewer via the HMD.

The VR scene was a living room with a fire place where a fire flame flickered. In the HR feedback regulation, the size and brightness of the fire flame was varied to synchronise with the viewer's own ECG signal; eventually, the size and brightness of the flame synchronised with the viewer's own heartbeat. The degree of change in the size and brightness was normalised based on the ECG signal of the viewer.

B. Experiment

The psycho-physiological effect of the HR feedback VR scene was investigated in 15 healthy university male students using a within-subject experimental design. None of the subjects had any visual disorders, such as near- or far-sightedness. To directly compare the effect of the bio-signal feedback, we prepared three different "fire flames," which were changed to synchronise with the subject's HR (SYN condition), in a manner of a sine wave at a constant rhythm (CST condition), and at random in terms of size and brightness at a constant rhythm (RND condition). The constant rhythm in CST and RND was set to the average HR of all the subjects (75 bpm), which was measured in advance. The degree of change in the size and brightness of the flame in CST and RND was set to the same range as that in SYN.

In the experiment, we used a pairwise comparison and made a subject compare two conditions sequentially, which was repeated twice. For example, a subject experienced the VR scene in SYN and RND alternatively. Each condition was experienced for 60 s with a 5 s interval (255 s in total)

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between the two conditions. Scenes presented to the subjects during this procedure were repeated for three possible combinations of input signals, i.e., SYN-RND, SYN-CST, and RND-CST; therefore, each subject experienced nine trials in total. The sequence of the presentation of the nine conditions was randomised and counter-balanced to compensate the possible order effect.

Subjective scores, namely, "spacious" (neutral item), "comfortable," and "natural," were assessed using the 11-point Likert scale of +5 (strongly agree) to –5 (strongly disagree). The HR and the high frequency component (0.15–0.40 Hz) of the HR variability (HF) were calculated from the ECG data. No information regarding the system configuration was provided to the subjects. Instead, they were instructed to just watch the presented VR scene and respond to the questionnaire.

Nakaya's variation of the Sheffé's ANOVA for paired comparisons [4] was employed for the statistical analysis of the subjective scores. The studentised range statistic (q) was further used for multiple comparisons [5]. Pair-wised student's t-test was employed to evaluate the HR and HF, and the level of statistical significance was set to 0.05.

III. RESULTS

According to a verbal interview conducted after the experiment, no subject complained about any malaise, including VR sickness, during the experiment, or abandoned the repetitive exposures in the experiment. Additionally, no subject was aware of the regulation manner of the fire flame. Moreover, no subject could differentiate between the SYN and RND VR scenes.

In the SYN condition, subjective scores of "comfortable" and "natural" were significantly higher than those in the CST condition (all for $p < 0.01$) and were marginally higher than those in the RND condition, as depicted in Figure 1.

The HR value in the SYN condition was smaller than that in the CST and RND conditions, and a significant difference was observed in the HR between the SYN and RND conditions ($p < 0.05$), as depicted in Figure 2. Furthermore, there was a moderately positive correlation between HR in the SYN condition and the score of "comfortable" ($r = 0.48$). No difference was observed in HF in any of the conditions, and no correlation was observed between HF in any condition and any of the psychological scores.

IV. DISCUSSION

The HR feedback VR fire flame that was implemented in this study demonstrated the effect on cardiac activity in terms of decline of HR. Moreover, the subjects viewed the bio-signal interactive VR as "comfortable" and "natural," and the HR was found to be associated with "comfortable," even though the subjects were not distinctly aware of the difference among the conditions.

It is well known that the sound of the heartbeat has an alleviative effect, as people say "listening your own heart beat makes you relax." The heartbeat feedback fire flame scene may induce a similar effect on the human mind. Moreover, because the HR reduced in the SYN condition,

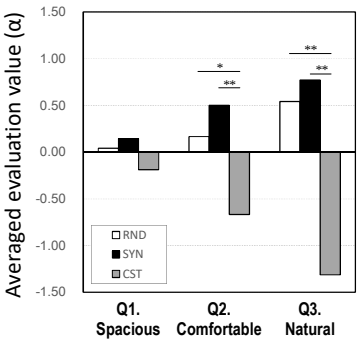

Figure 1. Subjective socres for virtual reality (VR) scene in each condition.

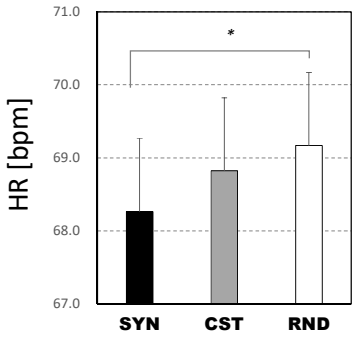

Figure 2. Mean heart rate during VR exposure.

such a psychological benefit may be mediated by the suppression of the cardiac sympathetic nervous system.

Further research with a wider population range may lead to the development of a new concept of "ambient bio-feedback system," in which the ambient stimuli (such as lightning, sound, and smell) are regulated by synchronizing with the human bio-signal, thereby fostering a positive psycho-physiological effect.

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