Involuntary "Deep Breathing" by Posture-Respiration Feedback Control System

Shusaku Nomura, Kazuki Hayakawa, Osamu Sakai, Ryoma Sekiya, and Samith S. Herath
Department of Engineering
Nagaoka University of Technology
Nagaoka, Japan
e-mail: nomura@kjs.nagaokaut.ac.jp, s143394@stn.nagaokaut.ac.jp, s153406@stn.nagaokaut.ac.jp,
s141049@stn.nagaokaut.ac.jp, s145073@stn.nagaokaut.ac.jp

Abstract— **When a person bends his/her back, it makes it easier to exhale the air from lungs but difficult to inhale. In contrast, when a person lean his/her back, it makes it difficult to exhale but easier to inhale. This simple fact opens the possibility to regulate human breathing involuntary with posture control. We developed a posture-respiration feedback regulation system and tested the efficacy of the proposed architecture. The results indicate that "deep breathing" was successfully induced when the posture control was precisely synchronized with the user's own respiration.**

Keywords-breathing control; posture feedback; respiration.

I. INTRODUCTION

Breathing control has numerous benefits on our daily life. A voluntary breathing control improves the task performance [1], alleviates anxiety [2]-[4], and appropriately controls the autonomous nervous system activities such as heart rate and blood pressure [5]-[8], and even immune functioning [9]-[11]. On the other hand, breathing-related disorders appear to be a great danger to our daily life, e.g., obstacle sleep apnea is a prominent risk factor of cardiovascular disease [12].

To obtain the benefits of breathing control, a variety of methods have been developed, such as sports, yoga, religious meditation, etc. In addition to such voluntary breathing control, in a clinical setting, passive ventilation equipment has been developed and has proven its great efficacy [13][14].

However, there are still some limitations in the breathing control methods, both voluntary or passively. First of all, voluntary breathing control requires much effort and concentration so it is difficult to continue over a long period of time, especially for the elderly. On the other hand, the passive ventilation, such as continuous positive airway pressure (CPAP) [13] and adaptive servo-ventilation (ASV) [14] requires patients to be fitted with a nasal cannula or respirator, so it cannot be suitable for daily use at home.

Therefore, in this study, we propose an alternative method for semi-passive breathing control method via posture control. The idea is based on the simple fact, as follows: when a person bends (rounds) his/her back, it makes it easier to exhale the air from the lungs, but more difficult to inhale. In contrast, when a person leans his/her back, it makes it difficult to exhale, but easier to inhale. This simple fact opens the possibility to regulate human breathing involuntary with posture control. Then, we developed an architecture which forces to change the posture of the user synchronously his/her own breathing cycle.

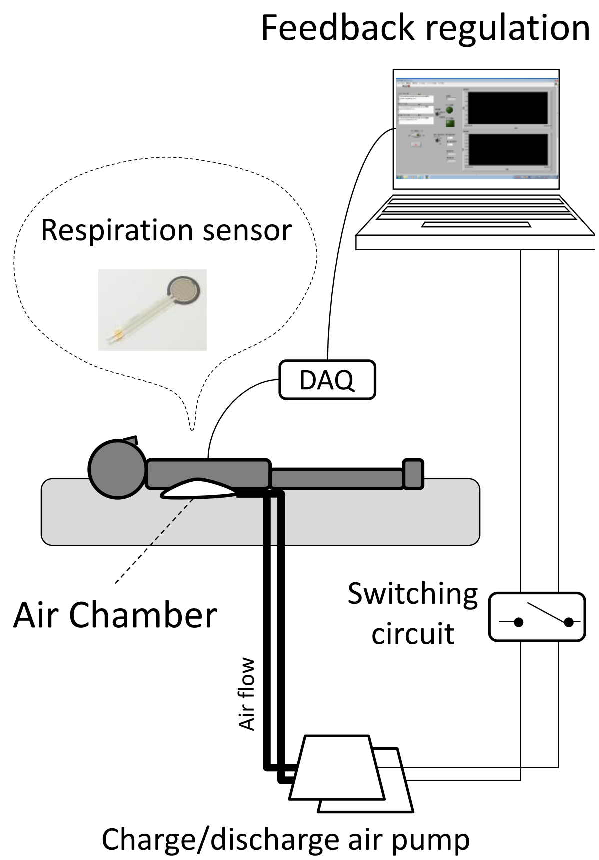

Figure 1. Schematic diagram of the posture-respiration feedback control system.

In the next section, the architecture of the developed system, the procedure of the experiment to test the efficacy of the system are described. The following sections describe the results of the experiment, discussion, and conclusion.

II. METHOD

Figure 1 shows the architecture of the posture-respiration feedback regulation system. It was basically the same architecture with our previous work as the respiration is

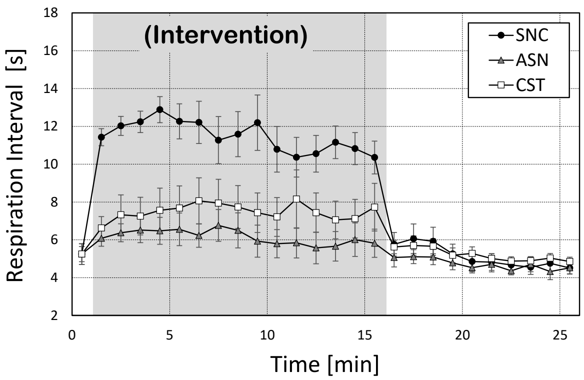

Figure 2. Change in the respiration interval (mean ± S.E.M).

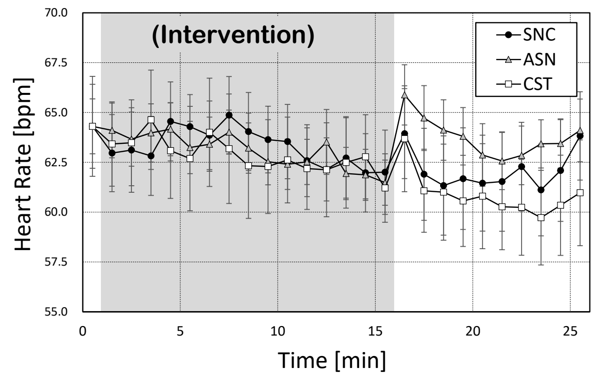

Figure 4. Change in the heart rate (mean ± S.E.M).

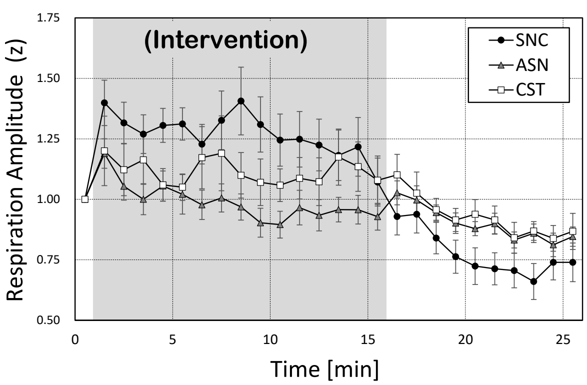

Figure 3. Change in the respiration amplitude (mean ± S.E.M).

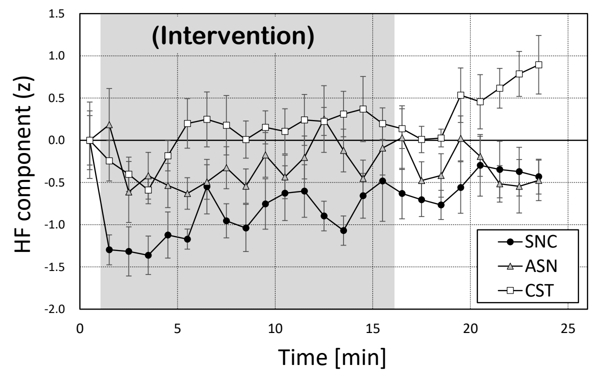

Figure 5. Change in the HF component (mean ± S.E.M).

detected by a pressure sensor, the analog signal from the sensor is converted to digital format with DAQ, the adaptive feedback (described later) is achieved with an interactive software (LabVIEW) which controls the inflation/deflation of the air-chamber via switching circuits to intervene in the posture of the user [15]. The silicon-made air-chamber placed beneath the subject's back deflates/inflates according to subjects own respiration cycle. For example, when a subject starts inhaling/exhaling, the air-chamber starts to inflate/deflates so as to assist his/her inhalation/exhalation of the air into/from the lungs. We assume such an intervention to posture would make subject's breathing deeper and longer, and leave them more relaxed in terms of body and mind.

To test this hypothesis, we conducted an experiment with three different respiratory intervention conditions: 1) the air-chamber inflates/deflates synchronously with subject's inhalation/exhalation (namely, "SNC" hereafter), 2) the air-chamber asynchronously inflates/deflates with breathing, as such it inflates/deflates when subject exhales/inhales (namely, "ASN"), and 3) the air-chamber inflates and deflates with a certain and constant rhythm (namely, "CST"). In SNC and ASN cases, the inflation and deflation cycle of the air-chamber is precisely decided with each one of the subject's respiration, whereas, in CST condition, the cycle of the air-chamber is set to the same duration with each subject's mean deep breathing cycle which was obtained in advance.

Ten healthy male university students (aged 22-24) participated in this study. The experiment consisted of 1 minute initial rest period, 15 min of intervention period, and 10 min of another rest period (recovery period).

Respiration of the subjects were measured by a thermistor sensor. Electrocardiogram (ECG) was measured with a biological amplifier to evaluate the cardio-physiological functioning by the posture-respiration intervention.

The experiment was conducted such that each participant went through all three conditions in a randomized order.

For statistics, paired-t test was performed with p-value of 0.05 as the level significance.

The study was conducted in accordance with ethical principles and informed consent was obtained for all subjects. The study was approved by the ethics committee of Nagaoka University of Technology. It should be noted that the number of participants was limited less than 10 and they were required to be among the healthy population because this is the very first pilot study to examine the physiological effect of our proprietary developed feedback architecture.

III. Result

Figures 2 and 3 show the change in the interval and the amplitude of respiration. As expected, the respiration was longer ($p < 0.01$) and deeper ($p < 0.01$) in SNC than other two conditions. In ASN, subjects' breathing was remarkably restricted. In the meantime, in CST condition, the change in respiration was depicted in between SNC and ASN.

Figures 4 and 5 show the change in the heat rate (HR) and the high frequency (HF: 0.15 - 0.40 Hz) component of the heart rate variability. As seen in these figures, HR did not differ among conditions ($p > 0.05$) in the intervention period. Meanwhile, HR in the recovery period in ASN was significantly higher than other conditions ($p < 0.01$), and it reached a higher value than the initial rest period (overshoot). HF in SNC was the lowest in the intervention period and thereafter ($p < 0.01$).

IV. Discussion

In this study, the impact of posture-respiration feedback system on respiration and cardiac autonomous system function was investigated. As expected, in SNC where the inflation/deflation of air-chamber was synchronized (i.e., no phase delay), respiration was made longer and deeper. This implies that our developed system can induce "deep breathing" unconsciously.

On the other hand, in ASN where the posture regulation was administered asynchrony with respiration (i.e., phase delay is 180 degree), there was no change in the interval and amplitude. Moreover, in the recovery period, a sort of overshoot of HR was observed in ASN. HR overshooting is frequently observed in the recovery period after mild excise [16]. It occurs to meet the requirement to balance the greater oxygen cost of fat catabolism during the early recovery period. It might be rather speculative but if the HR overshoot seen in this study share a part of the same background with that of after exercise, it might reflect the lack of oxygen in the intervention period as such, despite of the large effort of doing respiration, whether it be intentional or unconscious, ASN condition made it difficult and worsen the efficiency of ventilation, and and this phenomenon mislead the body into believing the concentration of air oxygen is "low", resulting in a higher requirement for oxygen after intervention (in "normal" circumstance).

In CST, the impact on respiration and cardiac autonomous system were marginal compared to SNC and ASN, and the breathing seemed to be gradually entrained with the constant rhythm. The cycle of air-chamber movement in CST was fixed at the same duration with each subject's "deep breathing", so subjects might modulate their breathing cycle voluntary to their deep breathing. However, the interval and amplitude of the respiration in SNC reached far beyond CST. In this sense, our developed posture-respiration intervention architecture have demonstrated the prominent impact on the respiration.

On the contrary, HF in SNC was strongly suppressed as shown in Figure 4. The HF component of the heart rate variability has been frequently taken as an index of cardiac parasympathetic nervous system activation [17]. However, one cannot interpret the result of our study as SNC condition suppress parasympathetic nervous activity. Since it is the respiration that we intervene, HF component is not just a naïve representation of parasympathetic nervous system activity. More detailed physiological study is needed to further discuss on this phenomena.

V. Conclusion

In summary, we tested the efficacy of our developed posture-respiration intervention system in a manner of real-time feedback regulation. The results indicate that "deep breathing" was successfully induced when the posture control was precisely synchronized with user's own respiration. Regarding the impact of cardiac function, HR overshoot was observed as the after effect of asynchronous regulation. Further physiological study promises to reveal the underground mechanism of the impact of our system.

Acknowledgment

This work was partially supported by the Japan Society for the Promotion of Science (JSPS) KAKENHI Grant Number 15H02767 and 16K12510.

References

[1] A. Solanky, "Respiration biofeedback assisted controlled breathing training to enhance shooting performance," Br. J. Sports. Med., vol. 44, 2010, pp. i27-i28.

[2] A. P. Sutarto, M. N. Wahab, and N. M. Zin, "Resonant breathing biofeedback training for stress reduction among manufacturing operators," Int. J. Occup. Saf. Ergon., vol.14, no.4, 2012, pp.549-561.

[3] W. Wu, Y. Gil, and J. Lee, "Combination of wearable multi-biosensor platform and resonance frequency training for stress management of the unemployed population," Sensors (Basel), vol.12, no.10, 2012, pp. 13225-13248.

[4] Y. H. Su, et al., "Effects of using relaxation breathing training to reduce music performance anxiety in 3rd to 6th graders," Med. Probl. Perform. Art, vol.25, no.2, 2010, pp.82-86.

[5] L. Guan-Zheng, H. Bang-Yu, and W. Lei, "A wearable respiratory biofeedback system based on generalized body sensor network," Telemedicine and e-Health, vol.17, no.5, 2011, pp.348-357.

[6] P. M. Lehrer, E. Vaschillo, and B. Vaschillo, "Resonant frequency biofeedback training to increase cardiac variability: rationale and manual for training," Appl. Psychophysiol Biofeedback, vol.25, no.3, 2000, pp.177-191.

[7] Q. A. Morarend, M. L. Spector, D. V. Dawson, S. H. Clark, and D. C. Holmes, "The use of a respiratory rate biofeedback device to reduce dental anxiety: an exploratory investigation," Appl. Psychophysiol Biofeedback, vol.36, no.2, 2011, pp.63-70.

[8] S. Z. Wang, et al., "Effect of slow abdominal breathing combined with biofeedback on blood pressure and heart rate variability in prehypertension," J. Altern. Complement. Med., vol.16, no.10, 2010, pp.1039-1045.

[9] M.S. Rider, et al., "Effect of immune system imagery on secretory IgA," Biofeedback Self Regul., vol.15, no.4, 1990, pp.317-333.

[10] R. G. Green and M. J. Green, "Relaxation increases salivary immunoglobulin A1," Psychol. Rep., vol.61, no.2, 1987, pp.623-629.

[11] M. L. Jasnoski and J. Kugler, "Relaxation, imagery, and neuroimmunomodulation," Ann. N. Y. Acad. Sci., vol.496, 1987, pp.722-730.

[12] H. K. Yaggi, et al., "obstructive sleep apnea as a risk factor for stroke and death," N. Engl. J. Med., vol.353, 2005, pp.2034-2041.

[13] J. M. Marin, S. J. Carrizo, E. Vicente, and A. G. N. Agusti, “Long-term cardiovascular outcomes in men with obstructive sleep apnoea-hypopnoea with or without treatment with continuous positive airway pressure: an observational study,” Lancet, vol.365, 2005, pp.1046-1053.

[14] P. C. Hastings, et al., “Adaptive servo-ventilation in heart failure patients with sleep apnea: A real world study,” International Journal of Cardiology, vol.139, 2010, pp.17-24.

[15] S. Nomura and A. Kusumi, “Respiration-Posture Feedback System for Breathing Control,” Proc. The Third International Conference on Ambient Computing, Applications, Services and Technologies, AMBIENT2013, pp.17-22, 2013.

[16] D. Joshi, et al., “Continuous, non-invasive measurement of the haemodynamic response to submaximal exercise in patients with diabetes mellitus: evidence of impaired cardiac reserve and peripheral vascular response.” Heart. vol.96, no.1, 2010, pp.36-41.

[17] B. Pomeranz B, et al., “Assessment of autonomic functions in human by heart rate spectral analysis,” Am. J. Physiol., vol.248, no.1., 1985, pp.151-153.