ORIGINAL ARTICLE

Effects on Cardiac and Peripheral Autonomic Nervous System by Posture Respiration Feedback Control Architecture

Samith S. HERATH, Kazuki HAYAKAWA, Osamu SAKAI,
Ryoma SEKIYA and Shusaku NOMURA

Nagaoka University of Technology, 1603-1, Kamitomioka, Nagaoka, Niigata 940-2188, Japan

Abstract: We tested the efficacy of our developed posture-respiration feedback architecture on cardiac and peripheral autonomic nervous system activity. In this system, the posture of a user lying on a bed was regulated adaptively with the rhythm of the user's respiration in a real-time manner. We hypothesized that such an adaptive posture intervention makes user's breathing deeper and longer. To investigate the efficacy of this architecture the effects of a respiration-synchronized posture intervention on cardiac and peripheral autonomic system was compared with the effects of asynchronous and constant respiration. Ten healthy males were enrolled in the within-subject experiment with a counter-balanced order. The results indicate that, as hypothesized, the deep breathing was successfully induced when the posture control was precisely synchronized with the user's respiration. Also, holistically positive efficacy in terms of the reduction in tension and peripheral sympathetic activity was demonstrated.

Keywords: *Breathing control, Posture feedback, Respiration*

1. INTRODUCTION

Historically, voluntary breathing control has been introduced in all part of the world as a means to relaxation, meditation, or alternative medicine. The psycho-behavioural benefits of voluntary breathing control include improved task performance [1], enhancing academic performance [2], alleviating anxiety [3-5], and reducing negative emotions [6]. The breathing control also brings a wide range of benefits to our body. It positively works on the autonomous nervous system, e.g., the heart rate and blood pressure [7-10], and even on the immune system [11-13]. The regular practice of slow breathing exercise improves autonomic functions [14], alleviates sympathetic nervous system activity and promotes parasympathetic nervous system activity [15,16].

Passive ventilation equipment has also been developed for use in clinics and has proved its significant efficacy in the treatment of obstructive sleep apnoea [17,18], which is one of the greatest risk factors in the cardiovascular disease [19].

However, there are still some limitations in the breathing control method, regardless of whether it is voluntary or passive. First, and above all, voluntary breathing control requires enormous effort and concentration. It is practically very difficult to continue voluntary breathing control over a long period. Meanwhile, passive ventilation techniques, e.g., continuous positive airway pressure [17] and adaptive servo-ventilation [18] require patients to wear a nasal cannula or respirator and lie motionless on a bed.

Therefore, it is not a suitable method for everyday use at home for non-clinical population.

Motivated by the need to remove the above-mentioned limitations of the voluntary and passive breathing control systems, we propose an alternative architecture for breathing control, which aims at involuntary breathing control via posture intervention. Our way of thinking comes from the simple fact of that the curved shape of the human backside influences human breathing. The bent forward shape of the back makes inspiration more difficult and expiration easier. On the other hand, leaned back shape works in the opposite manner; it makes expiration difficult and inspiration easier. In other words, the respiration resistance can be changed by the change in the posture of the human body. Therefore, it might be possible to regulate human breathing through posture control in an 'involuntarily' manner. Based on this hypothesis, we developed a posture-respiration-feedback control architecture and investigated its efficacy for breath regulation.

2. METHOD

2.1 Architecture

Figure 1 shows the overview of the developed posture respiration feedback architecture. The idea and basic specifications of this system are adopted from our previous studies [20,21]. User's respiration is detected via thermistor sensor placed near the nasal cavity. The respiration pattern is conveyed to a controller of our

Figure 1: Schematic diagram of the posture respiration feedback control architecture

proprietary design in the form of digital signal at 1 kHz of sampling rate via analogue-digital converter (NI USB-6008 DAQ, National Instruments Co., the USA). By analysing the acquired data, one can identify the state of user's respiration, e.g., increase in the raw signal means inspiration and vice versa. The posture feedback controller designed by LabVIEW (National Instruments Co., USA) controls the air flow to a chamber made of silicon placed beneath of the subject's back and inflated using a pair of air pumps (YP-20A, Yasunaga Air Pump Inc., Japan). Switching the air pumps on/off according to the user's breathing, the air-chamber deflates and inflates synchronously with the user's breathing cycle. We hypothesized that such a real-time and adaptive intervention to change the posture would make user's breathing deeper and longer and leave the user more relaxed in body and mind. To test this hypothesis, we conducted an experiment as described next.

2.2 Experiment

To test the efficacy of the posture feedback control architecture, we conducted a laboratory experiment with three different respiratory intervention conditions. These were, 1) the synchronous condition (SNC) in which the air chamber placed beneath of the subject's back inflates and deflates synchronously with the inhalation and exhalation, 2) the asynchronous condition (ASN) in which the air-chamber asynchronously inflates and deflates with breathing, as such it inflates and deflates

Figure 2: Three intervention patterns, in which the air chamber was regulated as synchronously (SNC), asynchronously (ASN), and constant rhythm (CST).

when the subject exhales and inhales, and 3) the constant condition (CST) in which the air-chamber inflates and deflates with a certain and constant rhythm. The constant rhythm of the air-chamber was set to the mean deep breathing cycle of each subject. The feedback control of the air chamber in these three conditions are depicted in Figure 2. It should be noted that the feedback control in SNC and ASN were done for each subject in real time. So, the air chamber starts inflating or deflating at the instant when the subject's inhalation or exhalation initiates. In CST, the air chamber inflates and deflates with a constant rhythm (mean duration of each subject's deep breathing) regardless of the rhythm of the actual respiration.

2.3 Experiment protocol

Ten male university students aged 22 to 24 years old voluntarily participated in this study. All subjects had no symptom or episode of respiratory impairment. The study was approved by the ethics committee of the Nagaoka University of Technology.

The experiment consisted of an initialization period (1 min), an intervention period (15 min), and a recovery period (10 min) as depicted in Figure 3. The subjects were instructed to lie on a bed in supine position with the air chamber beneath of their back. They were instructed to keep that position for the duration of the experiment. The posture intervention was made during the intervention period. All subjects went through the

Figure 3: Experiment protocol

three intervention modes on different days in a counter-balanced order (within-subject experiment design). Electrocardiogram (ECG) and the galvanic skin response (GSR) were recorded with a bio-signal amplifier system (MP150, BIOPAC Systems, Inc., USA) for evaluating the cardio and peripheral autonomous nervous system activities.

As for the subjective measure, a visual analogue scale (VAS) with the seven items, namely, ‘tension’, ‘effort’, ‘concentration’, ‘fatigue’, ‘frustration’, ‘monotonous’, and ‘boredom’, was introduced before and after the intervention, and after the recovery period.

The heart rate (HR) and the high frequency (HF) and low frequency (LF) component of its variation where HF is 0.15–0.40 Hz and LF: 0.03–0.15 Hz were found from the ECG data.

2.4 Data analysis and statistics

Because of the huge variation amongst individuals, the bio-signal data was standardized by the so-called z-score in which the average and standard deviations of the data set were transformed into 0.0 and 1.0, respectively. A paired and independent *t*-test was performed for comparison within and between subjects. Bonferroni correction was made in the case of comparison amongst the three conditions. The level of significance was set to 0.05.

3. RESULT

3.1 Respiration parameters

The change in the respiration interval and respiration amplitude are shown in Figure 4 and Figure 5. During the intervention period, the respiration interval was significantly greater in the SNC condition than in the other conditions ($p < 0.001$). Also, the respiration amplitude in the intervention period under ASN condition was significantly smaller than that of CST ($p < 0.05$). Meanwhile, the respiration amplitude in the SNC during the intervention period was significantly greater than in the other conditions ($p < 0.05$). No significant effect was found in the recovery period amongst conditions.

Figure 4: Change in the respiration interval in SNC, ASN, and CST conditions. The period in a grey background represents intervention period. **Figure 5:** Change in the respiration amplitude in SNC, ASN, and CST conditions. The period in a grey background represents intervention period.

3.2 Subjective measures

Changes in VAS scores from before to after intervention, and after intervention to after recovery period are shown in the Table 1. No significant effect was found by the intervention except for the significant reduction of ‘tension’ in SNC. Meanwhile, after the recovery period, ‘monotonous’ was increased in CST and ASN ($p < 0.01$) and “concentration” was decreased in CST ($p < 0.01$) whereas “effort” was decreased in SNC ($p < 0.01$).

3.3 Physiological measures

The heart rate (HR) decreased regardless of the conditions, but there was no difference in the intervention period ($p > 0.05$) as shown in Figure 6. After the intervention period, the HR increased temporally. Remarkably, the HR surge in the recovery period in ASN was significantly higher than under other conditions ($p < 0.05$) as it elevated to the higher value (overshot) than that of the initial value.

HF component of the heart rate variability in SNC was the lowest amongst the three conditions ($p < 0.05$) as shown in Figure 7. On the contrary, LF component in

Table 1: Results [mean (SD)] of subjective measures (VAS)

	Δ (before to after Intervention)	Δ (after intervention to recovery period)
CST		
tension	-8.8 (16.9)	10.6 (15.36)
effort	-4.2 (18.6)	7.5 (23.69)
concentration	-2.9 (23.1)	-4.3 (5.46)**
fatigue	-3.7 (23.2)	-1.3 (15.28)
frustration	5.3 (27.0)	-7.6 (17.69)
monotonous	-8.1 (32.7)	12.2 (9.45)**
boredom	5.0 (25.0)	-3.5 (17.61)
ASN		
tension	-8.1 (15.5)	-4.0 (8.12)
effort	-0.2 (5.7)	-11.2 (18.46)
concentration	-9.5 (15.0)	-4.9 (21.16)
fatigue	3.6 (25.3)	-6.7 (9.58)
frustration	15.7 (23.4)	-8.3 (15.98)
monotonous	5.2 (25.7)	9.3 (12.40)**
boredom	19.8 (29.8)	-6.1 (14.76)
SNC		
tension	-13.3 (16.3)**	-0.5 (16.92)
effort	15.7 (24.3)	-17.2 (18.14)**
concentration	2.7 (13.6)	-7.9 (13.48)
fatigue	-4.9 (11.8)	-0.3 (14.45)
frustration	1.0 (7.7)	-4.2 (12.63)
monotonous	2.5 (28.9)	7.1 (11.55)
boredom	2.4 (20.4)	-4.2 (17.27)

** $p < 0.01$ with comparison within condition **Figure 6:** Change in the heart rate (HR) in SNC, ASN, and CST conditions. The period in a grey background represents intervention period. **Figure 7:** Change in the high frequency component of the heart rate variability (HF: 0.15 - 0.40 Hz) in SNC, ASN, and CST conditions. The period in a grey background represents intervention period.

SNC and ASN were significantly greater than that in CST ($p < 0.01$) in the intervention period as shown in Figure 8. Figure 9 shows the change in the GSR. GSR decreased regardless of the condition. The mean GSR value in the intervention period in CST was lower than the other conditions, but it was not reached to the significant level ($p > 0.05$). Meanwhile, in the recovery period, GSR was significantly higher in ASN than CST ($p < 0.01$) and SNC ($p < 0.05$) conditions.

4. DISCUSSION

Voluntary breathing control methods, such as Yoga, breathing training and meditation have been used worldwide, because of their psychophysiological benefits. On the other hand, according to our knowledge, there has been no theoretical explanation and its implementation so far based on the concept of posture-control-inspired involuntary breathing control system that we have developed.

To measure the efficacy of the posture feedback control architecture, we conducted an experiment with three

Figure 8: Change in the low frequency component of the heart rate variability (LF: 0.03 - 0.15 Hz) in SNC, ASN, and CST conditions. The period in a grey background represents intervention period. **Figure 9:** Change in the galvanic skin response (GSR) in SNC, ASN, and CST conditions. The period in a grey background represents intervention period.

different respiratory intervention conditions. As for the results, the respiration interval and amplitude in SNC condition became longer and deeper as depicted in Figures 4 and 5. In short, our posture-respiration-feedback-control architecture made the subjects' breathing longer and deeper involuntarily. So, it demonstrated the efficacy of the respiration regulation by the posture intervention.

With regard to the subjective evaluation, synchronised intervention was positively received as 'tension' was significantly decreased in SNC but not in other conditions. It was followed by physiological impact as GSR profile. As GSR declined during the intervention and recovery periods: it indicated that the peripheral sympathetic nervous system was strongly suppressed. However, this synchronized intervention did not provide significant impact on the cardiac sympathetic nervous activity as HR profile did not differ from other conditions throughout the intervention and recovery periods.

Although the HF and LF components in SNC strongly decreased and increased as shown in Figure 7 and Figure 8. However, these effects should not be interpreted as suppressing effect of SNC feedback posture control on the parasympathetic nervous activity and enhanced the sympathetic nervous activity simultaneously because the respiratory modulation strongly influences the heart rate variability, or respiratory sinus arrhythmia [22]. In this case, it can be simply interpreted that the greater change in the respiration in terms of interval and amplitude in SNC reduced the relatively higher frequency variation of the heart rate but increased the relatively lower frequency variation. Holistically, our developed posture feedback control system provided positive efficacy in terms of the reduction in tension and peripheral sympathetic activity.

On the other hand, when the posture was regulated asynchronously with the respiration (ASN condition), there was no impact on the respiration interval and amplitude. However, HR overshoot right after the intervention period terminated (at the beginning of the recovery period). It was accompanied by the peripheral sympathetic nervous system activation as GSR kept the relatively higher level in the recovery period as compared with other conditions. Therefore, the intervention of the ASN type enhanced the cardiac and peripheral sympathetic nervous system activity during the recovery period. The overshooting of HR is frequently seen in the early recovery time after mild exercise, which meets the higher demand for oxygen to be used for fat catabolism [23]. It may seem to be a naïve assumption, but it seems that the low efficiency of

ventilation with ASN intervention caused a shortage of oxygen in the body. The body, mistaking this as relatively lower oxygen concentration in the ambient (during the intervention), reacted by enhancing the cardiac activity to compensate the lack of oxygen after intervention (in a normal ambient). For further discussion, oxygen saturation determination would be needed to prove the speculation to be the fact.

Regarding CST, the impact of the posture modulation on the respiration and cardiac autonomous nervous system seems to be marginal. Also, the subject seemed to adjust their respiration cycle to the constant rhythm, which is the same rhythm as their deep breathing. On the other hand, the reduction of GSR in the intervention period and even after recovery period was relatively greater. Therefore, the CST intervention functioned more positively than other conditions in suppressing peripheral sympathetic nervous system activation. However, the increased 'monotonous' and decreased 'concentration' in the recovery period indicate that the posture intervention with constant rhythm was not favourably received.

This study suffers from several limitations. Despite the well-controlled and within-subject experimental design, which is free from group effect, the small sample size with only male university students should be noted when generalising the interpretation. The strength of the pump for pumping the air in and out was fixed regardless of the physical attribute. Further, the study may promise the methodology of the effective involuntary breathing intervention for home use. This architecture will be developed as an involuntary deep breathing healthcare product and clinical treatment for the patients who have breathing-related impairment or disorder.

5. CONCLUSION

In this study, we developed the posture-respiration-feedback-control architecture and investigated the efficacy of the system. As for the results, as expected, the respiration was significantly longer and deeper when the adaptive posture control was synchronized with the respiration. This is the primary finding of this study. Also, a holistically positive efficacy in terms of the reduction in tension and peripheral sympathetic activity was demonstrated. On the other hand, HR overshoot in the recovery period was observed in the case of asynchronous regulation, which implies a negative effect on the body. Further physiological study is needed to find the most effective adaptive control of the posture and respiration.

REFERENCES

1. Solanky, A. S.; Respiration biofeedback assisted controlled breathing training to enhance shooting performance, *British Journal of Sports Medicine*, 44(1), pp.27-28, 2010.
2. Paul, G., Elam, B., and Verhulst, S. J.; A longitudinal study of students' perceptions of using deep breathing meditation to reduce testing stresses, *Teaching and Learning in Medicine*, 19(3), pp.287-292, 2007.
3. Sutarto, A. P., Wahab, M. N. A., and Zin, N. M.; Resonant breathing biofeedback training for stress reduction among manufacturing operators, *International Journal of Occupational Safety and Ergonomics*, 18(4), pp.549-561, 2012.
4. Wu, W., Gil, Y., and Lee, J.; Combination of wearable multi-biosensor platform and resonance frequency training for stress management of the unemployed population, *Sensors*, 12(10), pp.13225-13248, 2012.
5. Su, Y. H., Luh, J. J., Chen, H. I., Lin, C. C., Liao, M. J., Chen, H. S.; Effects of using relaxation breathing training to reduce music performance anxiety in 3rd to 6th graders, *Medical Problems of Performing Artists*, 25(2), pp.82-86, 2010.
6. Busch, V., Magerl, W., Kern, U., Haas, J., Hajak, G., and Eichhammer, P.; The effect of deep and slow breathing on pain perception, autonomic activity, and mood processing—an experimental study, *Pain Medicine*, 13(2), pp.215-228, 2012.
7. Liu, G. Z., Huang, B. Y., and Wang, L.; A wearable respiratory biofeedback system based on generalized body sensor network, *Telemedicine and e-Health*, 17(5), pp.348-357, 2011.
8. Lehrer, P. M., Vaschillo, E., and Vaschillo, B.; Resonant frequency biofeedback training to increase cardiac variability: Rationale and manual for training, *Applied Psychophysiology and Biofeedback*, 25(3), pp.177-191, 2000.
9. Morarend, Q. A., Spector, M. L., Dawson, D. V., Clark, S. H., and Holmes, D. C.; The use of a respiratory rate biofeedback device to reduce dental anxiety: an exploratory investigation, *Applied Psychophysiology and Biofeedback*, 36(2), pp.63-70, 2011.
10. Wang, S. Z., Li, S., Xu, X. Y., Lin, G. P., Shao, L., Zhao, Y., and Wang, T. H.; Effect of slow abdominal breathing combined with biofeedback on blood pressure and heart rate variability in prehypertension, *The Journal of Alternative and Complementary Medicine*, 16(10), pp.1039-1045, 2010.
11. Rider, M. S., Achterberg, J., Lawlis, G. F., Goven, A., Toledo, R., and Butler, J. R.; Effect of immune system imagery on secretory IgA, *Biofeedback and Self-regulation*, 15(4), pp.317-333, 1990.
12. Green, R. G., and Green, M. L.; Relaxation increases salivary immunoglobulin A, *Psychological Reports*, 61(2), pp.623-629, 1987.
13. Jasnoski, M. L., and Kugler, J.; Relaxation, imagery, and neuroimmunomodulation, *Annals of the New York Academy of Sciences*, 496(1), pp.722-730, 1987.
14. Pal, G. K., and Velkumary, S.; Effect of short-term practice of breathing exercises on autonomic functions in normal human volunteers, *Indian Journal of Medical Research*, 120(2), pp.115-121, 2004.
15. Telles, S., Nagarathna, R., and Nagendra, H. R.; Breathing through a particular nostril can alter metabolism and autonomic activities, *Indian Journal of Physiology and Pharmacology*, 38(2), pp.133-137, 1994.
16. Stancák, J. A., Kuna, M., Vishnudevananda, S., Dostalek, C.; Kapalabhati--yogic cleansing exercise. I. Cardiovascular and respiratory changes. Homeostasis in health and disease, *International Journal Devoted to Integrative Brain Functions and Homeostatic Systems*, 33(3), pp.126-134, 1991.
17. Marin, J. M., Carrizo, S. J., Vicente, E., and Agustí, A. G.; Long-term cardiovascular outcomes in men with obstructive sleep apnoea-hypopnoea with or without treatment with continuous positive airway pressure: an observational study, *The Lancet*, 365(9464), pp.1046-1053, 2005.
18. Hastings, P. C., Vazir, A., Meadows, G. E., Dayer, M., Poole-Wilson, P. A., McIntyre, H. F., Morrell, M. J., Cowie, M. R., and Simonds, A. K.; Adaptive servo-ventilation in heart failure patients with sleep apnea: a real world study, *International Journal of Cardiology*, 139(1), pp.17-24, 2010.
19. Yaggi, H. K., Concato, J., Kernan, W. N., Lichtman, J. H., Brass, L. M., and Mohsenin, V.; Obstructive sleep apnea as a risk factor for stroke and death, *New England Journal of Medicine*, 353(19), pp.2034-2041, 2005.
20. Nomura, S., and Kusumi, A.; Respiration-posture feedback system for breathing control, *Proc. The Third International Conference on Ambient Computing, Applications, Services and Technologies, AMBIENT2013*, pp.17-22, 2013.
21. Nomura, S., Hayakawa, K., Sakai, O., Sekiya, R., and Samith S. Herath; Involuntary "Deep Breathing" by posture-respiration feedback control system, *Proc. The Seventh International Conference on Ambient Computing, Applications, Services and Technologies*,

AMBIENT2017, pp.1-4, 2017.

22. Bernardi, L., Wdowczyk-Szulc, J., Valenti, C., Castoldi, S., Passino, C., Spadacini, G., and Sleight, P.; Effects of controlled breathing, mental activity and mental stress with or without verbalization on heart rate variability, *Journal of the American College of Cardiology*, 35(6), pp.1462-1469, 2000.
23. Joshi, D., Shiwalkar, A., Cross, M. R., Sharma, S. K., Vachhani, A., and Dutt, C.; 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*, 96(1), pp.36-41, 2010.

Samith S. HERATH (Non-member)

Samith S. Herath is a PhD candidate in the Department of Information Science and Control Engineering, Nagaoka University of Technology, Japan. His research interests include breathing control and psychophysiology, new media design, Kansei Engineering and biological information processing.

Kazuki HAYAKAWA (Non-member)

Kazuki Hayakawa received his Master of Engineering in the Department of Information and Management Systems Engineering, Nagaoka University of Technology, Japan.

Osamu SAKAI (Non-member)

Osamu Sakai received his Master of Engineering in the Department of Information and Management Systems Engineering, Nagaoka University of Technology, Japan.

Ryoma SEKIYA (Non-member)

Ryoma Sekiya is a student of Master of engineering in Department of Information and Management Systems Engineering, Nagaoka University of Technology, Japan.

Shusaku NOMURA (Member)

Shusaku Nomura received his Ph.D. degree in science from the Graduate School of Science and Technology, Kobe University, in 2001. He is currently working as an Associate Professor at Nagaoka University of Technology, Japan. His research interests include ambient biomedical engineering, biological information processing, and psychophysiology.