33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

EEG Recovery Enhanced by Acute Aerobic Exercise after Performing Mental Task with Listening to Unpleasant Sound

Seiji Nishifuji

Abstract—**The present paper investigated response of electroencephalogram (EEG) to aerobic exercise with low intensity after performing mental task with listening to acoustic stimuli in order to measure a recovery effect of the acute exercise on the EEG. The mean amplitude of the alpha wave (8-13 Hz) was significantly reduced during performing mental arithmetic and/or listening to 5 KHz unpleasant tone. In particular, the mean reduction rate of the amplitude was more than 20 % in the low-frequency range of the alpha wave (8-10Hz) under both stressors. On the other hand, the alpha wave was fixed after an acute exercise of 20 min; the mean amplitude of the alpha wave exceeded 30 % of spontaneous level prior to stressed conditions in the low-frequency range but unchanged in the high-frequency range. Response of the theta wave was similar to the low-alpha wave, while beta and gamma waves showed no significant change in response to the stressors and exercise. The observation indicates that the acute exercise with low intensity may be responsible for the rapid recovery and enhancement of the alpha wave in the low-frequency range and theta wave.**

I. Introduction

MENTAL stress has become serious social problems in Japan. Since 1998, the number of suicides in Japan has exceeded 30,000, many of whom have been affected by mental disorders such as depression and schizophrenia [1]. Although many measurement techniques for measuring mental states have been proposed in terms of physiological, chemical and neuronal quantities [2][3], framework of the stress measurement has not been established yet.

Electroencephalogram (EEG) reflects electrical activities of human brain neuronal populations which can be affected by emotional states directly. For example, effects of unpleasant acoustic stimuli on the alpha wave, a representative rhythm in the awake EEG with eyes closed, have been reported controversially [4][5]. Sumiya et al. claimed amplitude enhancement of the alpha wave in the low frequency range in the application of the combined stressors of music and white noise rather than music alone due to rise of consciousness by ‘unpleasant’ white noise [4]. Horii et al. showed amplitude reduction of the alpha wave during listening to the white noise and siren [5].

Recently, we have pointed out that the amplitude of the alpha wave was decreased and the amplitude fluctuation was increased significantly during listening to unpleasant acoustic stimuli such as tone and teeth gnashing [6]. Moreover, combination effect of acoustic stimuli and mental task on the alpha wave in the low- frequency range (low-alpha wave) has been also presented; the unpleasant acoustic environment reinforces the suppression of the amplitude and stability of the low-alpha wave during performing the mental arithmetic [7].

It is well known that appropriate exercise is one of effective methods to reduce mental stresses. The effect of acute exercise on the EEG (rhythms and event-related potentials; ERP) has been investigated by several researchers [8]-[16]. Krause et al. found a significant increase in the peak frequency of the alpha wave during static muscle work but no significant difference in the power densities in four EEG rhythms (delta, theta, alpha and beta waves) [8]. It has been reported that absolute EEG band power significantly increased after resistance exercise in the alpha, beta, theta and delta bands [9]. Stock et al. have also examined a suppressive influence of massage treatment during regeneration on central and frontolateral beta waves.

The effect of exercise dependency on the power density distribution within the alpha-wave bandwidth after a 45-min exercise was reported by Beh et al. [10]. They presented that the power density distribution was shifted to the lower frequency range for the low dependent subjects, while it was shifted to the higher frequency range for the high dependent subjects. Kamijo et al. indicated the dependence of the arousal level on exercise intensity in such a way that the alpha power was increased but the amplitude of contingent negative variation was decreased after high intensity exercise [11].

For response of ERP to aerobic exercise, Hillman et al. reported an increase of amplitude of P3 (P300) in a cognitive test following treadmill exercise more than rest [12],[13]. They indicated such a phenomenon was a sign of attention enhancement in the cognitive test, corresponding to improvement of cognitive control.

However, these researches focused on the influence of exercise, its quality and quantity on the EEG rhythm with reference to the pre-exercise resting state. Of interest is the assessment of a recovery effect of the acute aerobic exercise on the EEG in a stressed state which has not been well investigated conventionally. The present study thus examined the amplitude (power) of the EEG rhythms (low-alpha, high-alpha, theta, beta and gamma waves) after an acute aerobic exercise with low intensity followed after performing mental task and listening to unpleasant sound.

Manuscript received April 15, 2011. This work was supported in part by JSPS KAKENHI (Grant-in-Aid for Scientific Research (C)) 22560420.

S. Nishifuji and D. Maino are with Yamaguchi University, Ube, 755-8611 JAPAN. (corresponding author to provide phone: 81-836-85-9426; fax: 81-836-85-9401; e-mail: nisifuji@ yamaguchi-u.ac.jp).

II. METHODS

A. Subjects and Experiment

We recruited 8 healthy students (21-23 years, 2 females and 6 males) as subjects. EEG was recorded from 15 electrode sites determined with reference to the 10-20 Electrode System while the subjects closed their eyes. The linked-earlobe potential is used as the reference potential for the unipolar derivation. The EEG-5532 (Nihon Koden) was used for recording EEG. Informed consent was obtained from all the subjects in accordance with the tenets of the Declaration of Helsinki.

EEG was recorded in the following experimental conditions on the first and second days (Fig. 1). Each experimental session lasted 100 s in which an interval of 20 s with eyes opened was inserted from 40 to 60 s.

Day 1
(1) Resting state under quiet environment
(2) Listening to unpleasant sound (5 KHz tone)
(3) Resting under quiet environment
(4) Mental arithmetic under quiet environment (multiplication of 2-digit numbers, 2 problems were served at 0s and 40 s, respectively)
(5) Resting under quiet environment
(6) Mental arithmetic during listening to unpleasant sound
(7) Resting under quiet environment
(8) Resting after cycling of 20 min (50% of heart rate maximum) and resting of 10 min

Day 2
(1) – (7) same as the day 1.
(9) Resting after resting for 30 min for control

B. Analysis

EEG data discretized were divided into 8 segments of 10 s-length (2,000 samples) each session. The EEG data segments were analyzed using the discrete Fourier transform (DFT) to estimate the EEG amplitude spectra.

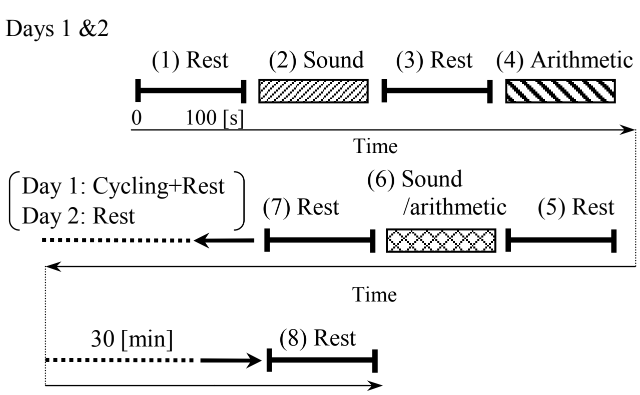


Fig. 1. Arrangement of experimental conditions

The amplitude of each EEG rhythm was obtained as an average of amplitude spectrum over corresponding frequency band for each amplitude spectrum for alpha (8-13 Hz), low-alpha (8-10 Hz), high-alpha (10-13 Hz), beta (13-30 Hz), gamma (30-45 Hz) and theta (4-8 Hz) waves. The amplitude change in each rhythm was assessed using the amplitude ratio R_a of the amplitude under each condition to that in the pre-stressed resting state (see (1) in Fig. 1) for each EEG rhythm.

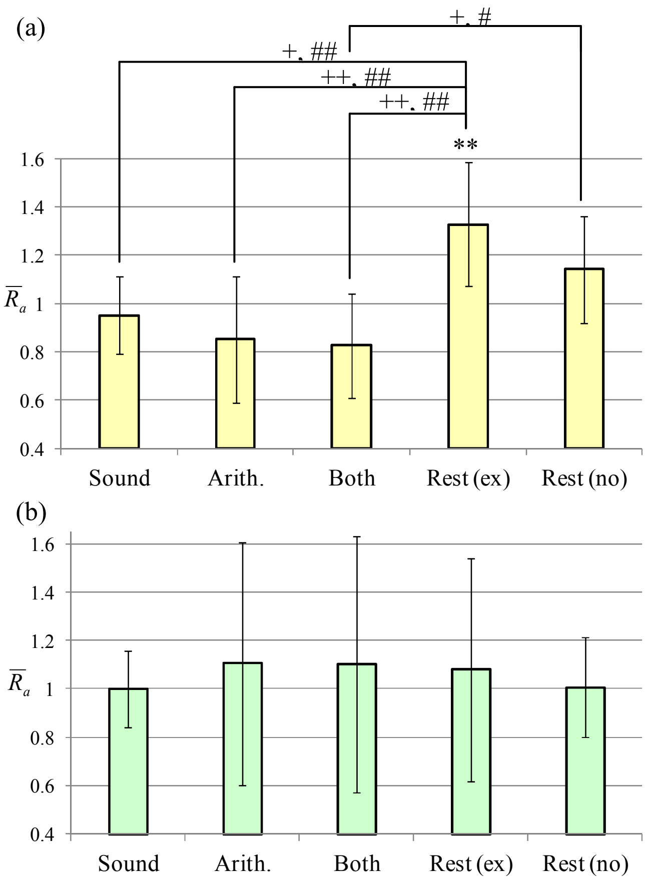
For the amplitude ratios under the experimental conditions except (9) Resting after 30 min-resting, results obtained from Day 1 were used for analysis. The main effect of condition for these ratios was statistically tested using the one-factor analysis of variance (ANOVA) with repeated measures and the nonparametric Friedman test. In the cases of existence of the main effect, the paired *t*-test corresponding to the ANOVA and the Wilcoxon signed rank test corresponding to the Friedman test were applied to investigate the significance between two groups.

III. RESULTS AND DISCUSSIONS

Figure 2 illustrates the grand means of the amplitude ratios R_a averaged across 4 segments corresponding to 80 s-length data and across all the subjects for (a) the low-alpha wave and (b) the high-alpha wave at the right occipital area O2. For simplification, the results are shown selectively for the conditions of (2) 5 KHz tone, (4) mental arithmetic, (6) mental arithmetic with 5 KHz tone, (8) resting state after the exercise and (9) resting state after the rest in Fig. 1. The mean ratios of R_a for the low-alpha wave in Fig. 2(a) are seen to be less than 1 under all the stress conditions. In particular, the mean of R_a was reduced by approximately 20 % under the condition of the mental arithmetic during listening to 5 KHz tone with reference to the pre-stressed resting state.

In contrast, the mean of R_a after the exercise was remarkably increased beyond the pre-stressed state, $R_a = 1.3$. The one-way repeated measures ANOVA was used to examine significance among all the stress conditions, rest after exercise and 30-min rest. The main effect of condition was significant, $F(4,7) = 7.5$, $p < 0.001$. Significant difference between the rest after the exercise and all the stressed conditions was found in all the pairs ($p < 0.01$ for the pairs with the arithmetic and arithmetic with listening to 5 KHz tone and $p = 0.013$ for the 5 KHz tone) using a two-tailed paired *t*-test.

The non-parametric Friedman test was also used to evaluate the overall differences for the mean of R_a among the five conditions, indicating statistical significance, $\chi_4^2 = 18.6$, $p<0.001$. The Wilcoxon signed rank test also showed significant difference between the rest after the exercise and each of the three stressed conditions, $p < 0.01$. Thus with or without normality of the amplitude distribution, the mean amplitude ratio R_a of the low-alpha wave under the rest after the exercise was seen to be significantly different from the amplitude ratios under the stressed conditions.



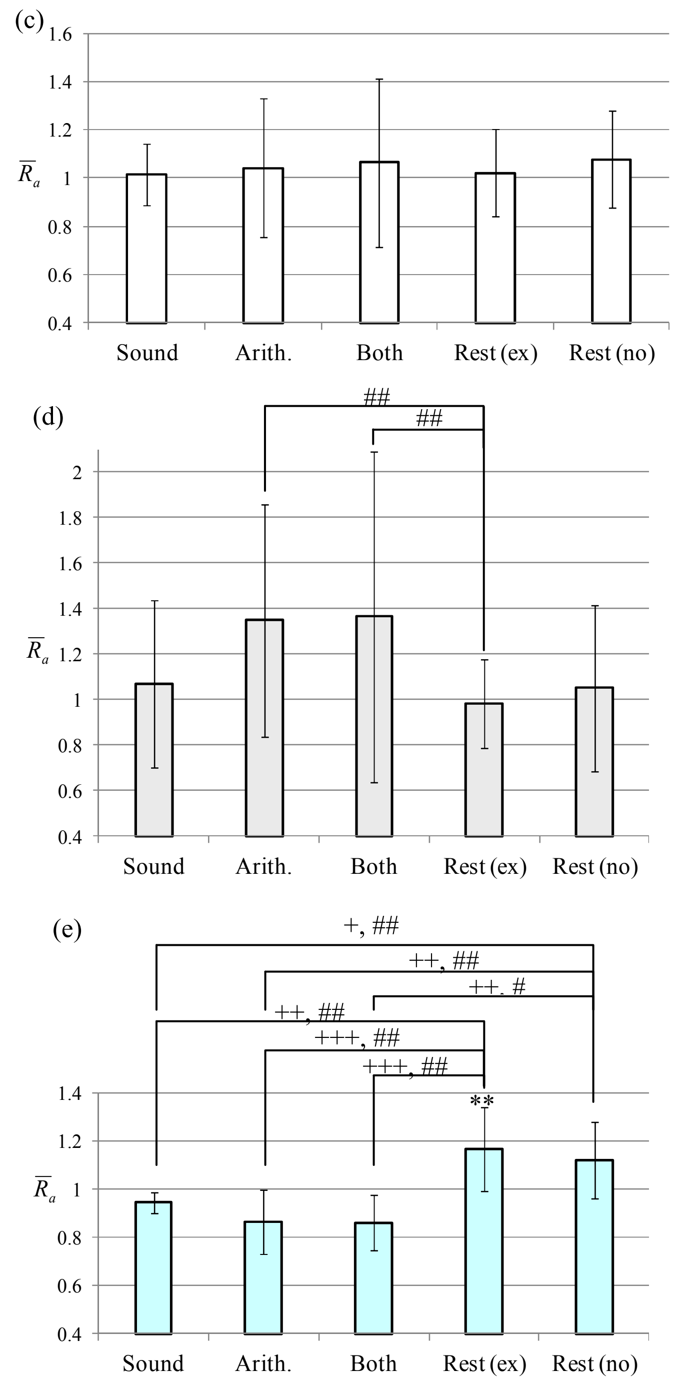


Fig.2. Grand mean of amplitude ratio for (a) low-alpha, (b) high-alpha, (c) beta, (d) gamma and (e) theta waves. Sound: 5 KHz tone, Arith: mental arithmetic, Both: mental arithmetic during listening to 5 KHz tone, Rest (ex); resting state after exercise and Rest (no): resting without exercise. All the ratios except Rest (ex) are from Day1. Error bars represent standard deviations. * and ** designate $p < 0.05$ and $p < 0.01$ for independent one-sample t-test for a population mean of R_a, +, ++ and +++ indicate $p < 0.05$, $p < 0.01$ and $p < 0.001$ for paired t-test for (a) and (e) in which there exits significant difference for one-way repeated measures ANOVA, and # and ## denote $p < 0.05$ and $p < 0.01$ for Wilcoxon signed-rank test for (a) and (e) in which there finds significant difference for Friedman test, respectively.

Such a significant increase was also observed after the rest for 30 min, $p < 0.05$ for a pair with the mental arithmetic during listening to 5 KHz tone by both the paired t-test and the Wilcoxon signed rank test. The mean R_a was at most 1.1, smaller than that for the rest after exercise by 20 %.

Additionally, a two-tailed t-test for a population mean showed a significant difference between the pre-stressed rest and the rest after the exercise with $p < 0.01$ but no significant difference for the rest after 30-min resting. Although a significant difference in the mean R_a was not found between the rest after the exercise and the rest after the 30 min rest, the aerobic exercise with low intensity seemed to increase the low-alpha wave more intensively than the 30-min resting.

In Fig. 2 (b), the means of R_a were limited to the range from 1.0 to 1.1 for the high-alpha wave. Neither the ANOVA nor the Friedman test designated no significant effect of the stress/exercise conditions, $F(4,7) = 0.32$, $p = 0.86$ and $\chi_4^2 = 0.5$, $p = 0.97$, respectively.

No significant effect of condition was also found in the mean of R_a for the beta wave in Fig. 2(c) with $F(4,7) = 0.21$, $p = 0.93$ by the ANOVA and $\chi_4^2 = 2.70$, $p = 0.61$ by the Friedman test, respectively. Although the Friedman test showed a main effect for the gamma wave, $\chi_4^2 = 11.0$, $p = 0.03$, the ANOVA indicated no significance, $F(4,7) = 1.86$, p

= 0.154. Large inter-individuality which is similar to the result for the high-alpha wave deteriorated the main effect and may lead to non-significance when the number of subjects is increased.

The results for the theta wave were seen to be similar to the low-alpha wave. A significant effect of the conditions was detected; $F(4,7) = 14.62$, $p < 0.001$ for the one-way repeated measures ANOVA and $\chi_4^2 = 22.8$, $p < 0.001$ for the Friedman test. Significant difference was found between the rest after exercise and all the stressed conditions ($p < 0.001$ for the pairs with the arithmetic and arithmetic during listening to 5 KHz tone and $p < 0.01$ for the pair with the 5 KHz tone by the paired *t*-test and $p < 0.01$ for all the pairs by the Wilcoxon signed rank test). Additionally, the *t*-test for a population mean showed a significant difference between the pre-stressed rest and the rest after the exercise with $p < 0.01$.

Similar results were obtained between the 30-min rest and the three stress conditions whereas the probabilities *p*s were slightly larger than those for the rest after exercise ($p < 0.01$ for the pairs with the arithmetic and arithmetic during listening to 5 KHz tone and $p < 0.05$ for the pair with the 5 KHz tone by the paired *t*-test and $p < 0.01$ for the pairs with the 5 KHz tone and the mental arithmetic and $p < 0.05$ for the mental arithmetic during listening to 5 KHz tone by the Wilcoxon signed rank test).

Low intensity acute exercise is generally available as one of stress reduction methods for many people including people who do not do exercise regularly. Sasaki reported that the low-alpha power from the central to occipital regions and the high-alpha, high-beta and total EEG rhythm power at midline-central area was increased and concluded that the low-intensity exercise affected the EEG rhythm, in particular, enhanced the low-alpha wave [14]. Other researchers examined the influence of exercise intensity [15] and duration [16] on affect and EEG asymmetry and observed that the positive affect corresponded to increasing EEG asymmetry.

The present study also showed significant difference between the pre-stressed rest and the rest after the light exercise. Moreover, the recovery effect of the low-intensity exercise and the sustained 30-min rest and the suppression effect of the stressors (5 KHz tone and/or mental arithmetic) on the low-alpha and theta waves was also statistically shown in terns of the amplitude ratio.

In particular, the aerobic exercise was seen to enhance the amplitude ratios of the low-alpha and theta waves significantly beyond the pre-stressed state (*t*-test with population mean of the amplitude ratio). No significance on the population mean after 30-min rest indicates that the sustained rest is limited to recover these waves.

On the other hand, the high-alpha, beta and gamma waves were not or weakly affected by the stressors and the exercise/rest. Correspondingly, the low-alpha and theta waves may be useful indices for measuring the stressed state.

Aerobic exercise, unpleasant acoustic stimuli and mental work may affect the temporal properties of the alpha and theta waves as well as the statistical property of these waves. Future studies include investigation of the amplitude/phase dynamics of the EEG rhythms during performing mental task and after aerobic exercise to establish a measure of human stressed state in terms of EEG.

IV. Conclusion

The present study examined the recovery effect of the light acute aerobic exercise on EEG after imposed the sound and mental stressors. Not only the aerobic exercise but also the mere continuous rest significantly recovered the amplitude of the low-alpha wave in such a way that exceeded a pre-stimulus level. However, the mean increasing rates of the amplitude in the low-alpha and theta waves were larger in the aerobic exercise than in the mere rest. The low-alpha and theta waves may reflect the stressed / relaxed states of human.

References

[1] National Police Agency Web Site, http://www.npa.go.jp/safetylife/seianki/" (in Japanese).

[2] N. Hjortskov, D. Rissen, A. K. Blangsted, N. Fallentin, U. Lundberg, K. Søgaard, "The effect of mental stress on heart rate variability and blood pressure during computer work," *European J. Applied Physiology*, vol. 92, pp. 84–89, 2004.

[3] M. Yamaguchi et al., "Hand-held monitor of sympathetic nervous system using salivary amylase activity and its validation by driver fatigue assessment", *Biosensors and Bioelectronics*, vol. 21, pp.1007–1014, 2006.

[4] M. Sumiya, H. Ozaki, M. Agu, "EEG topography under music and noise", *Brain Science and Mental Disorders*, vol.8, pp. 175-182, 1997 (in Japanese).

[5] A. Horii, C. Yamamura, T. Katsumata, A. Uchiyama, "Physiological response to unpleasant sounds", *J. International Society of Life Information Science*., vol. 22, pp. 536-544, 2004.

[6] S. Nishifuji, I. Miyahara, "Amplitude and phase response of brain alpha wave to unpleasant and pleasant sounds", *Transactions of SICE* (Society of Instrumentation and Control Engineering), vol. 44, pp. 776-778, 2008 (in Japanese).

[7] S. Nishifuji, M. Sato, D. Maino, S. Tanaka, "Effect of Acoustic Stimuli and Mental Task on Alpha, Beta and Gamma Rhythms in Brain Wave", in *Proc. SICE Annual Conference 2010,* pp. 1548-1555 (2010).

[8] G. Krause, P. Ullsperger, L. Beyer, H. –G. Gille, "Changes in EEG power density spectrum during static muscle work", *European J. Applied Physiology*, vol. 51, pp. 61-66, 1983.

[9] C. Stock et al., "Electroencephalogram activity, catecholamines, and lymphocyte subpopulations after resistance exercise and during regeneration", *European J. Applied Physiology*, vol. 72, pp. 235–241, 1996.

[10] H. C. Beh, S. Mathers, J. Holden, "EEG correlates of exercise dependency", *International J. of Psychophysiology*, vol. 23, pp. 121-128, 1996.

[11] K. Kamijo et al., "Changes in arousal level by differential exercise intensity", *Clinical Neurophysiology*, vol. 115, pp. 2693-2698, 2004.

[12] H. Sasaki, "The effects of low intensity exercise for EEG", *Human Welfare Studies*, no. 6, pp. 161-169, 2003 (in Japanese).

[13] C. H. Hillman, E. M. Snook, G. J. Jerome, "Acute cardiovascular exercise and executive control funcsion", *International J. Psychophysiology*, vol. 48, pp. 307-314, 2003.

[14] K. C. O'Leary, M. B. Pontifex, M. R. Scudder, M. L. Brown, C. H. Hillman, "The effects of single bouts of aerobic exercise, exergaming, and videoga me play on cognitive control ", *Clinical Neurophysilogy*, *in press*, doi :10.1016/j.clinph.2011.01.049, 2011

[15] W. R. Bixby, T. W. Spalding, B. D. Hatfield, "Temporal dynamics and dimensional specificity of the affective response to exercise of varying intensity", *J. Sport & Exercise Psychology*, vol. 23, pp. 171-190, 2001.

[16] M. Woo et al., "Examining the exercise-affect dose-response relationship: Does duration influence frontal EEG asymmetry?", *International J. Psychophysiology*, vol. 72, pp.166-172, 2009.