Physiological and psychological changes during breathing control using illuminance changes with different cycles

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***Abstract*—In this study, the differences in the physiological effects of respiratory control using photic stimuli based on biological signals were examined. Comparing the alpha attenuation coefficient (AAC) before and after the task, it increased with the short-period illuminance pattern and decreased with the middle and long-period illuminance patterns. From the results of Lorenz plot (LP)-area-S, the arousal level increased and parasympathetic nervous system activity decreased with the short-period illuminance pattern. On the other hand, the arousal level decreased and parasympathetic nervous system activity increased with the middle and long-period illuminance patterns. These results suggest that the short-period illuminance pattern induced an active state, and the middle and long-period illuminance patterns induced a relaxed state.**

Keywords—breathing control; central nervous system activity; autonomic nervous system activity

I. INTRODUCTION

With the progress of informatization and globalization, modern society, which is active not only at noon but also at night, is now a 24-hour society, and this has increased the burden on employees by increasing their working hours and the quantity of information processing. According to a "Comprehensive Survey of Living Conditions", it is clear that over 60% of people feel uneasiness, discomfort, and stress [1]. The increase in stress that comes from the disruption associated with long hours of work and the disturbed life rhythm of a 24-hour society is one of the factors that decreases concentration and has a negative effect on work efficiency. In these situations, it is important to alleviate the stress effectively in a limited time and improve work efficiency by improving the quality of rest. There have been many research reports about the effects on the body of using stimuli based on highly appropriate biomedical signals [2-4]. The respiratory cycle is one of the important factors for biomedical signals, and it has been shown that respiratory control, for example, the decreasing of BP, HR, etc., has a positive effect on the body in previous research on the respiratory cycle [5]. On the other hand, it has been reported that the respiratory cycle can affect autonomic nervous system and brain activity in research that has involved respiratory control using vibratory stimulation derived from the respiratory cycle in test subjects and induced rest states [6]. However, contact with the instrument is necessary for vibratory stimulation to perform respiratory control. We then focused our attention on light-emitting diodes (LEDs), which have recently attracted attention as a form of environmental physical stimulation that enables respiratory control without contact with an instrument. It is easier to control changes in brightness with LED lighting than with conventional lighting equipment, and there is an advantage in that we can change the color of the lighting by changing the combination of LEDs with different wavelengths. Previous work regarding lighting has shown that the light environment can promote healing and rest [7,8]. It has also been found that lighting is useful for decreasing stress. In the present study, respiratory control was performed using illuminance changes based on the respiratory cycle in different physical states, for example, short-term period, middle-term period, etc. Furthermore, the physiological changes were evaluated by EEG, ECG, and respiratory cycle measurements, and changes in vigilance and autonomic nervous system activity were then monitored.

II. EXPERIMENTAL METHODS

A. Subjects and Experimental Procedures

Sixteen healthy, non-medicated subjects (14 men, 2 women; 21-23 years old) participated in the experiment. All subjects provided their written, informed consent prior to participation. An EEG1100 (Nihonkoden, Tokyo, Japan) and a 45360 (GE Health Care Japan, Tokyo, Japan) were used for measurement of EEG, ECG, and the respiratory cycle during the Alpha Attenuation Test (AAT) and the task. Details of the experimental protocol are shown in Figure 1. Regarding the task, light radiated from the downlight was reflected on a whiteboard to reduce glare. The subjects performed respiratory

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control following the illuminance changes on the whiteboard. Three types of illuminance patterns were used (short, middle, and long-period). A short-period illuminance pattern and illuminance cycle were created from the average respiratory cycle when the subject pedaled an exercise bike with a 40-W load. The middle-period illuminance pattern and illuminance cycle were created from the average respiratory cycle when the subject was in a relaxed state in the sitting position. The long-period illuminance pattern was created by extending the respiratory cycle of the middle-period illuminance pattern. The long-period illuminance pattern referred to the respiratory cycle used in yoga, and it is defined as a long-term rhythm that subjects can breathe consciously. The time of one respiratory cycle with the short-period illuminance pattern was 2.4 sec, that with the middle-period illuminance pattern was 4.0 sec, and that with the long-period illuminance pattern was 6.0 sec. The respiratory waves used to make illuminance changes are shown in Figure 2. The point of finishing expiration is defined as 0(lx). The peak point of inspiration is defined as 24(lx), since the range of recommended illumination for general lighting in a bedroom is from 10(lx) to 30(lx).

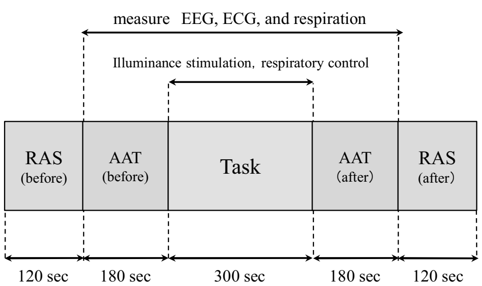

Fig.1. Experimental protocol

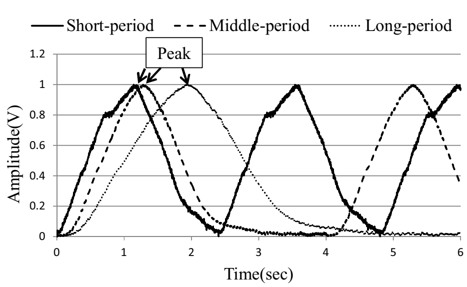

Fig.2. Respiratory wave

B. Electrode fixation points

An EEG was performed using the international 10-20 system. Furthermore, an ECG was taken using the 3-point lead system. The respiratory rate was measured by a respiratory sensor wrapped around the thoracoabdominal region.

III. Analytical Method

A. Alpha Attenuation Coefficient (AAC)

When a subject is quiet, with the eyes closed and in a state of arousal, alpha waves appear mainly from the back of the head. The alpha waves decrease when the eyes are opened and with sleepiness. Moreover, if subjects are in a state of activation and concentration, there is a large difference in the times when the eyes are opened and when they are closed. In contrast, the difference is small in the sleeping state. Thus, it is natural to examine the alpha wave. The power spectrum of the alpha-wave spectrum (8-13 Hz) was calculated by fast Fourier transform (FFT) after noise was suppressed from the measured EEG with a high-pass filter (0.1 Hz), a low-pass filter (120 Hz), and a band-stop filter (57-63 Hz). Then, the ratio of the average power with the eyes closed (30 seconds ×3) and the average power with the eyes opened (30 seconds ×3) of the alpha wave was defined as AAC. This was used as a quantitative evaluation index of the degree of arousal [9].

$$AAC = Average\ power\ eyes\ closed\ /\ Average\ power\ eyes\ opened \quad (1)$$

B. Lorenz Plot (LP)

A Lorenz Plot (LP) of the ECG RR intervals (RRIs) was prepared [10]. The LP was prepared with the nth RRI (RRI n) on the horizontal axis and the n+1th RRI (RRI n+1) on the vertical axis. The LP was divided into RRIs using the evaluation index area S [Figure 3]. From the y = x axis, the standard deviation ($\sigma(x)$) of the distance from the coordinate origin was calculated. Similarly, from the y = −x axis, the standard deviation ($\sigma(-x)$) of the distance from the coordinate origin was calculated. Area S, the area of the ellipse showing variations in the LP, is $S = \pi \times \sigma(x) \times \sigma(-x)$. The LP was used as an index of parasympathetic activity.

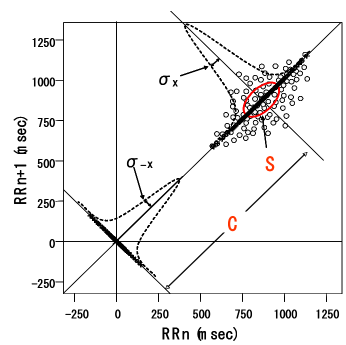

Fig.3. Lorenz plot of RR intervals

C. Roken Arousal Scale (RAS)

The RAS is a quantitative index of six states (Sleepiness, Activation, Relaxation, Strain (Tension), Difficulty of attention and concentration, Lack of motivation) with twelve questions to show mental workload. The six states consisted of two similar questions. The average of two similar questions was defined as the state value.

IV. Results

A. AAC

Figure 4 shows the mean variation of AAC before and after the task for all subjects during each procedure. AAC increased with the short-period illuminance pattern and decreased with the middle and long-period illuminance patterns. One can say that arousal degree increased with the short-period illuminance pattern and decreased with the middle and long-period illuminance patterns. A significant difference ($p<0.05$) was seen with the middle and long-period illuminance patterns between before and after the task.

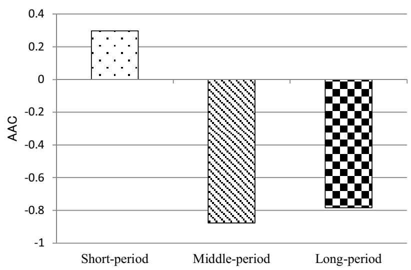

Fig.4. Variation of AAC

B. LP-area-S

Figure 5 shows the mean variation of LP-area-S before and after the task for all subjects during each procedure. LP-area-S decreased with the short and long-period illuminance patterns. On the other hand, LP-area-S increased with the middle-period illuminance pattern. One can say that subjects were in a relaxed state, since parasympathetic nervous system activity increased with the middle-period illuminance pattern.

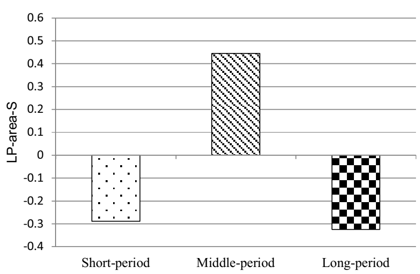

Fig.5. Variation of LP-area-S

C. Relationship between AAC and LP-area-S

Figure 6 shows the relationship between AAC and LP-area-S for each task. For the short-period illuminance pattern, when LP-area-S decreased, AAC tended to increase, and almost all of the plots were concentrated in the second quadrant. From this, one can understand that the degree of arousal increased, and parasympathetic nervous system activity decreased. The coefficient of correlation between AAC and LP-area-S was significant (5%). For the middle-period illuminance pattern, when AAC decreased, LP-area-S tended to increase, and most plots were concentrated in the third and fourth quadrants. One can understand that the degree of arousal decreased, and parasympathetic nervous system activity increased compared with the short-period illuminance pattern. For the long-period illuminance pattern, one can understand that the degree of arousal decreased, as with the middle-period illuminance pattern. LP-area-S tended to decrease in a different way than with the middle-period illuminance pattern. Parasympathetic nervous system activity was increased compared with the short-period illuminance pattern.

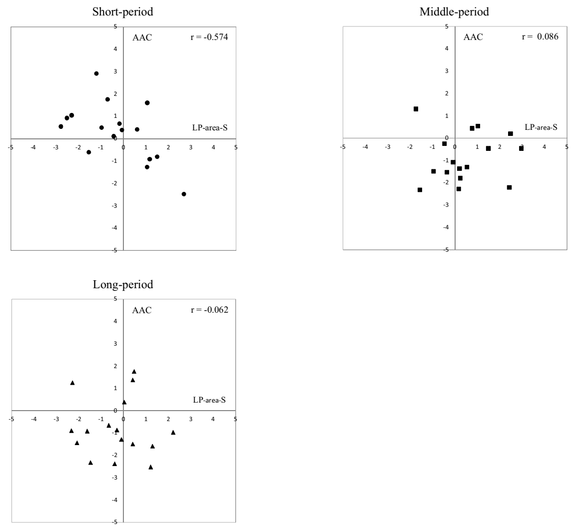

Fig.6. Relationship between AAC and LP-area-S in each task

D. RAS

Figure 7 shows the variation of RAS in each task. "Strain" and "Difficulty of attention and concentration" were significantly different between before and after the task (Wilcoxon signed-rank test $p<0.05$) with the short-period illuminance pattern. Moreover, "Relax" was unique among the three patterns in terms of decreasing. The subjects were tired after the task, since they performed respiratory control as if they were exercising. Therefore, it was considered that "Difficulty of attention and concentration" increased. "Sleepiness", "Activation", "Relax", and "Lack of motivation" were significantly increased between before and after the task with the middle-period illuminance pattern, and "Activation" decreased with the middle-period illuminance pattern from before to after the task. Based on these results, one can understand that the subjects were in a relaxed state. "Sleepiness", "Activation", "Relax", and "Difficulty of attention and concentration" were significantly different with the long-period illuminance pattern from before to after the task. The long-period illuminance pattern was the calmest state, along with the middle-period illuminance pattern. However, subjects had little tiredness because they performed long-period respiration. This does not occur on a daily basis.

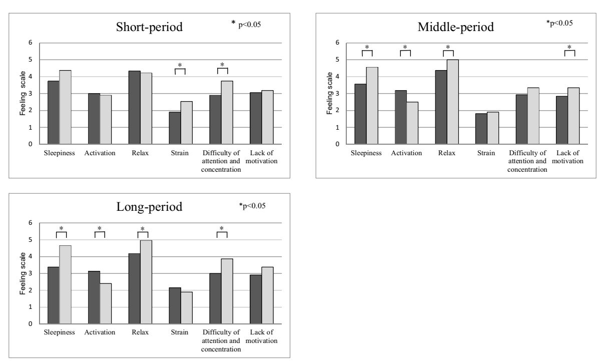

Fig.7. Variation of RAS in each task

V. DISCUSSION

From the results of the AAC and LP-area-S, it was found that the degree of arousal increased and parasympathetic nervous system activity decreased with the short-period illuminance pattern. In addition, it is conceivable that the degree of arousal decreased and parasympathetic nervous system activity increased with middle and long-period illuminance patterns. These results suggest that the short-period illuminance pattern induced an active state, and the middle and long-period illuminance patterns induced a relaxed state.

The coefficient of correlation between AAC and LP-area-S was significant (5%) with the short-period illuminance pattern. AAC decreased, even though there was no significant difference with the middle-period illuminance pattern**.** However, there was no noticeable tendency with the long-period illuminance pattern. Before the experiment, we assumed that the relaxed state would be increased more with the long-period illuminance pattern than with the middle-period illuminance pattern. In short, we hypothesized that the plot diagram would be concentrated in the fourth quadrant, with decreased AAC and increased LP-area-S. However, the results did not agree with our hypothesis. This is because the long-period illuminance pattern required forcing the respiratory cycle, while the short and middle-period illuminance patterns did not. In addition, the results of subjective assessment might have been affected by bias. For example, subjects may assume that breathing used in yoga makes people relaxed. Therefore, the physiological function is not as much affected as the subjective evaluation.

VI. CONCLUSION

The present study examined the differences in the physiological effects of respiratory control using photic stimuli based on biological signals. These results suggest that the short-period illuminance pattern induced an active state, and the middle and long-period illuminance patterns induced a relaxed state.

Previous work has shown that respiratory control using vibratory stimulation can induce the body to rest. In the present study, respiratory control using photic stimuli, which enable respiratory control without contact with an instrument, led to various states. It was possible to achieve results similar to those of previous studies in the present study, in that respiratory control using photic stimuli, as with vibratory stimulation, led to various states.

A future challenge is to create illuminance waves taking into account the individual differences of each subject. In addition, it is necessary to increase the number of women subjects in order to explore sex differences.

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