# Induction of a Relaxed State Using a Vibration Stimulus Based on the Respiratory Cycle

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**Abstract.** The purpose of this study was to induce different states using a vibration stimulus based on an individual's breathing cycle. Based on the results of Lorenz plot area S (LP-area-S), breathing control with the long-period breathing pattern was able to induce a state of increased parasympathetic activity. Parasympathetic activity was greatly reduced during the task with the short-period breathing pattern. The results of LP-area-S and the AAC (alpha attenuation coefficient) showed that LP-area-S was increased with the short- and long-period breathing patterns when AAC was decreasing. Given the results of this experiment, it appears that breathing control using a vibration stimulus based on individual breathing cycles can lead to a relaxed state in terms of the physiological and psychological changes.

**Keywords:** Breathing control · Autonomic nervous system · Central nervous system · Lorenz plot · Vibration stimulus

## 1 Introduction

Effective rest is needed more today than ever before because stress and a shortage of sleep caused by various societal factors adversely affect health and work efficiency.

In addition, wearable terminals have emerged as the next generation of portable devices that can be easily worn that measure biological information such as the breathing cycle and heart rate. We think that wearable terminals will be easily used to provide biofeedback of personal biometric information in the near future.

The respiratory cycle is one of the important factors for biomedical signals. It has been reported that the respiratory cycle can affect the autonomic nervous system and brain activity in research that has involved respiratory control using vibratory stimulation derived from the respiratory cycle in test subjects that induced rest states [1]. However, respiratory control was performed using vibration changes based on the respiratory cycle of the same cycle. Thus, this does not provide accurate biofeedback of personal biometric information.

The purpose of this study was to induce a relaxed state using a vibration stimulus based on an individual's breathing cycle. The physiological changes were evaluated by

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EEG (electroencephalography), ECG (electrocardiogram), and respiratory cycle measurements. Changes in vigilance and autonomic nervous system activity were then monitored.

## 2 Experimental Methods

### 2.1 Subjects and Experimental Instruments

Thirteen healthy, non-medicated men (21–22 years old) participated in the experiment. All subjects provided written informed consent prior to participation. An EEG1100 (Nihonkoden, Tokyo, Japan) and a 45360 (GE Health Care Japan, Tokyo, Japan) were used for EEG, ECG, and respiratory cycle measurements.

### 2.2 Experimental Methods

The experimental protocol was performed using alpha attenuation test (AAT) specific activity (eyes closed (30 s), eyes opened (30 s) × 3) for 3 min, followed by a 5-minute task (breathing control), and a final AAT of 3 min. One cycle was a total of 11 min. The roken arousal scale (RAS) was evaluated before and after measurement. Subjects were given 10-minute breaks between each cycle. EEG and ECG findings and respiration were evaluated. Details of the experimental protocol are shown in Fig. 1. The task (breathing control) was randomized for every experiment to exclude an order effect.

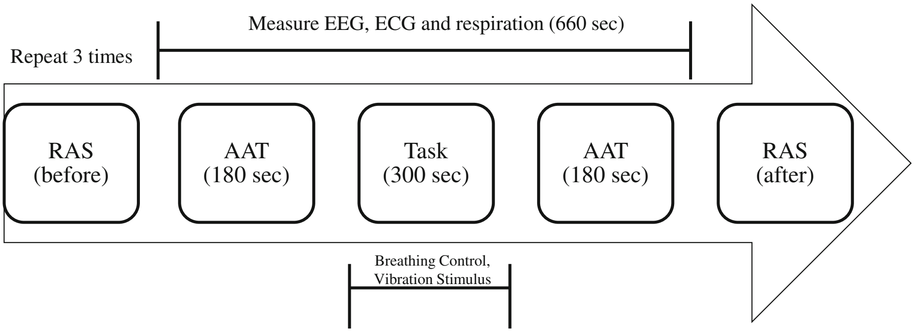


**Fig. 1.** Experimental protocol

### 2.3 Breathing Control

A vibration generator (Nihon Suribi Scientific, Tokyo, Japan) was used for breathing control. Breathing control was performed according to the strength of the vibration. A hand (finger-tip) vibration stimulus was given. When vibration was strengthened, the subjects breathed in and then breathed out when the vibration was weakened. The vibration frequency of the vibration generator in this experiment was 60 Hz.

Prior to this experiment, the subjects were seated with closed eyes for 5 min, followed by bicycle exercise (load: 40 W, speed: 45–50 rpm) for 5 min as a preliminary experiment to measure the breathing cycle. Then, three breathing patterns were created from the average period during activity breathing and resting breathing: short-period (activity breathing cycle), middle-period (resting breathing cycle), and long-period (middle-period × 1.5). The respiratory cycles of the subjects are shown in Table 1.

**Table 1.** Respiratory cycles of the subjects

| Subject number | Short-period (s) | Middle-period (s) | Long-period (s) | Subject number | Short-period (s) | Middle-period (s) | Long-period (s) |
|---|---|---|---|---|---|---|---|
| No. 1 | 2.656 | 4.082 | 6.124 | No. 8 | 2.464 | 5.448 | 8.172 |
| No. 2 | 2.248 | 5.541 | 8.312 | No. 9 | 2.68 | 3.452 | 5.18 |
| No. 3 | 2.258 | 3.47 | 5.206 | No. 10 | 1.678 | 4.104 | 6.156 |
| No. 4 | 2.204 | 3.618 | 5.428 | No. 11 | 2.476 | 3.418 | 5.128 |
| No. 5 | 1.632 | 2.908 | 4.364 | No. 12 | 2.522 | 3.46 | 5.19 |
| No. 6 | 2.632 | 5.97 | 8.954 | No. 13 | 2.666 | 3.924 | 5.888 |
| No. 7 | 2.428 | 3.878 | 5.816 | Average | 2.349 | 4.097 | 6.147 |

### 2.4 Electrode Fixation Points

EEGs were taken using the international 10–20 system. Electrodes were attached to the heads of the subjects, and measurements were taken from electrodes C3, C4, O1, O2, A1, and A2. To reduce electric resistance, cutaneous sebum was removed using a polisher before electrode application. The EEG was continuously recorded during the experimental period. The EEG signals obtained from O2–A1 were analyzed since alpha waves appear mainly from the back of the head under the conditions of wakefulness, rest, and closed eyes. An ECG was taken using the 3-point lead system. The difference in the electrodes was measured between the right clavicle and the left ribs. A respiratory sensor wrapped around the thoracoabdominal region measured the respiratory rate.

## 3 Analytical Method

### 3.1 Roken Arousal Scale (RAS)

The roken arousal scale (RAS) is a psychological evaluation method to quantify the psychological rating values of fatigue and alertness. The RAS provides a quantitative index of the following six states: sleepiness; activation; relaxation; strain (tension); difficulty of attention and concentration; and lack of motivation. The six states consisted of two similar questions. The average of the two similar questions was defined as the state value.

## 3.2 Alpha Attenuation Coefficient (AAC)

The awakening degree was evaluated using the alpha attenuation coefficient (AAC). Alpha waves appear mainly from the back of the head under the conditions of wakefulness, rest, and closed eyes. The alpha waves decrease when the eyes are opened and with sleepiness. In addition, 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. 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 s × 3) and the average power with the eyes opened (30 s × 3) of the alpha wave was defined as AAC. The AAC was analyzed using EEG signals obtained from O1–A2. A high AAC value indicates a high degree of awakening. A low AAC value indicates a low degree of awakening [2, 3].

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

## 3.3 Lorenz Plot (LP)

The ECG RR interval change was evaluated by Lorenz plot (LP) analysis. LP-area-S was calculated by Lorenz plot analysis as an index of parasympathetic activity [Fig. 2].

The LP was prepared with the $n^{th}$ RRI (RRI n) on the horizontal axis and the n + $1^{th}$ RRI (RRI n + 1) on the vertical axis. The LP was divided into RRIs using the evaluation index area S. 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 $S = \pi \times \sigma (x) \times \sigma (-x)$. A high LP-area-S value indicates a high level of parasympathetic activity [4, 5].

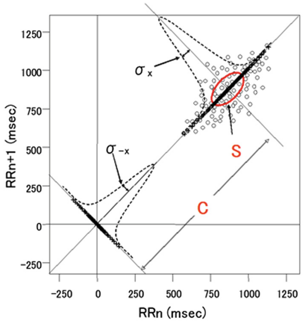


**Fig. 2.** Lorenz plot of RR intervals

### 3.4 Statistical Analysis

The values of RAS obtained before and after the task were compared using Wilcoxon's signed rank test as a non-parametric method. The values of AAC obtained before and after the task were compared using the paired *t*-test. The values of LP-area-S obtained before, after, and during the task were compared using the Tukey multiple comparison procedure. A p value of less than 0.05 was accepted as indicating a significant difference between the compared values [6]. Statistical analysis was performed using a statistical software package (IBM SPSS Statistics version 20, Tokyo, Japan).

## 4 Results

### 4.1 RAS

From the results of the RAS, the average value of the six states was calculated. Comparing the differences between before and after states, there was a tendency for psychological change in every breathing period. The result is shown in Fig. 3. The RAS results for sleepiness, relaxation, difficulty of attention and concentration, and lack of motivation increased in all periods. In addition, activation and strain decreased in the long-period breathing pattern. This showed a rest tendency. The RAS results for sleepiness and activation were significantly different ($p < 0.05$), while difficulty of attention and concentration showed a tendency to be significantly different ($p < 0.10$) in the long-period breathing pattern.

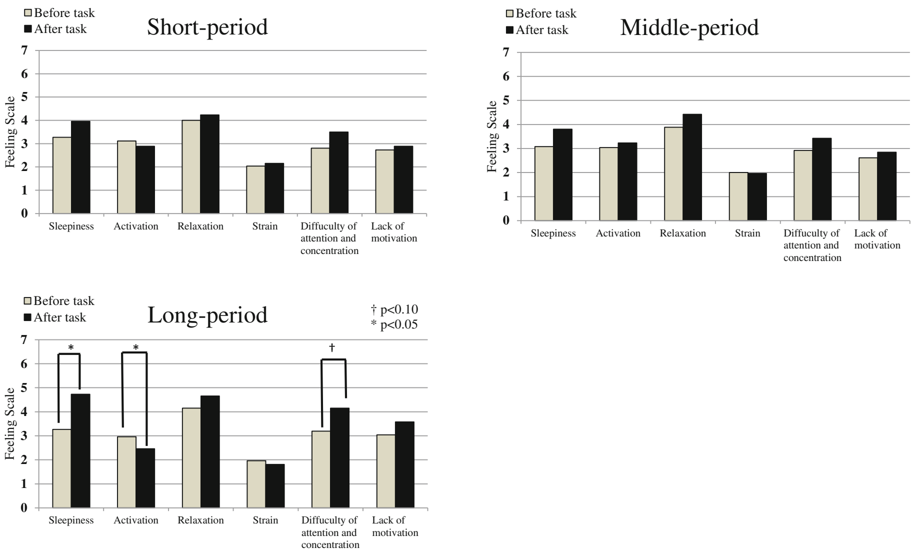


**Fig. 3.** Variation of RAS in each task

## 4.2 AAC

The AAC was normalized and compared before and after a task. The result is shown in Fig. 4. The AAC decreased with the short- and long-period breathing patterns and was slightly increased with the middle-period breathing pattern after the task. In addition, the amount of change in the AAC increased in the following order: short-period > long-period > middle-period. The AAC before and after a task was significantly different ($p < 0.05$) in the short-period breathing pattern.

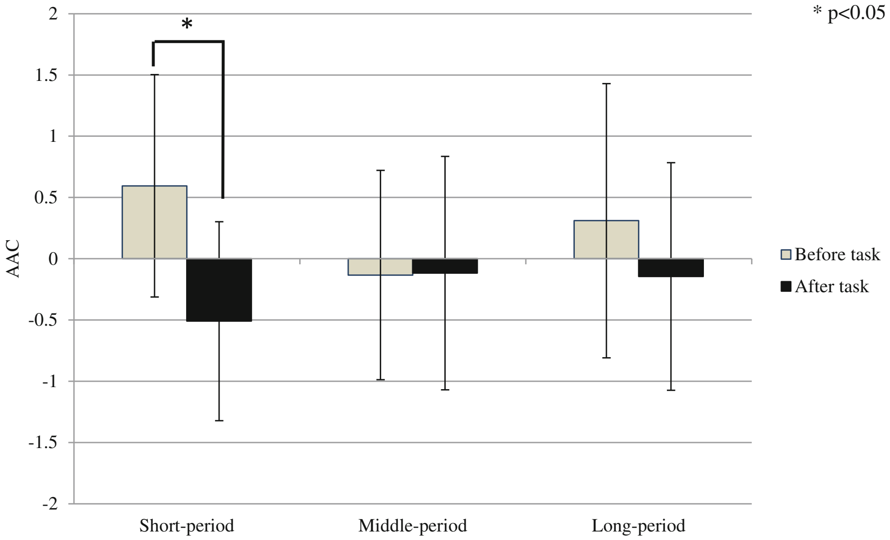


Fig. 4. Variation of AAC

## 4.3 LP-area-S

The LP-area-S was normalized and compared before, after, and during the task. The result is shown in Fig. 5.

Comparing LP-area-S before and after the task, LP-area-S increased with all breathing patterns. In addition, LP-area-S showed large changes in parasympathetic activity in the following order: long-period > middle-period > short-period. LP-area-S decreased with the short- and middle-period breathing patterns and increased with the long-period breathing pattern from before the task through during the task. LP-area-S increased with the short-, middle-, and long-period breathing patterns from during the task through after the task.

LP-area-S during the task was significantly different ($p < 0.01$) between the short-period and long-period breathing patterns. Similarly, LP-area-S during the task was significantly different ($p < 0.01$) between the middle-period and long-period breathing patterns.

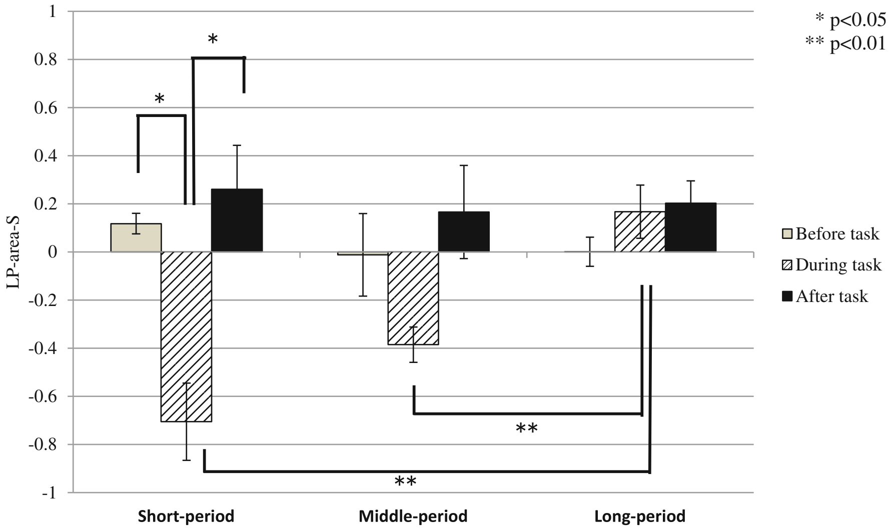


**Fig. 5.** Variation of LP-area-S

## 4.4 Relationships

Table 2 shows the correlation coefficients as a measure of the linear correlations among physiological variables (AAC, LP-area-S, respiratory cycle) for each breathing pattern. Table 3 shows the correlation coefficients as a measure of the linear correlations between the psychological (RAS) and physiological (AAC, LP-area-S, respiratory cycle) parameters for each breathing pattern. Table 3 shows (a) the short-period, (b) middle-period, and (c) long-period results. The correlation coefficients ranged between +1 and −1 inclusive, where 1 is total positive correlation, 0 is no correlation, and −1 is total negative correlation.

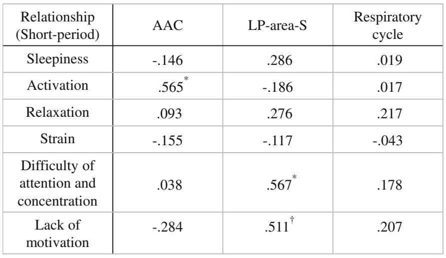
Examining the relationships between psychological evaluation (RAS) and physiological evaluation (AAC) parameters, a correlation was observed with activation in the short period breathing pattern. A strong correlation was also observed with sleepiness, activation, and relaxation, difficulty of attention and concentration, and lack of motivation in the long-period breathing pattern. In addition, examining the relationships between psychological evaluation (RAS) and physiological evaluation (LP-area-S) parameters, a strong correlation was observed with strain in the long-period breathing pattern and difficulty of attention and concentration in the short-period breathing pattern. When examining the relationships between psychological evaluation (RAS) and physiological evaluation (respiratory cycle) parameters, a strong correlation was observed with Activation in the middle-period breathing pattern. However, there were no correlations among the physiological evaluation parameters (AAC, LP-area-S, respiratory cycle).

**Table 2.** Relationships among physiological evaluation parameters

| Relationship | Short-period | | Middle-period | | Long-period | |
|---|---|---|---|---|---|---|
| | LP-area-S | Respiratory cycle | LP-area-S | Respiratory cycle | LP-area-S | Respiratory cycle |
| AAC | −.052 | −.009 | −.301 | −.053 | −.056 | −.436 |
| LP-area-S | | −.329 | | −.076 | | −.066 |

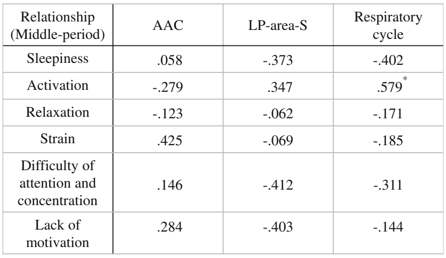
**Table 3.** Relationships between psychological and physiological evaluation parameters

(a) Short-period



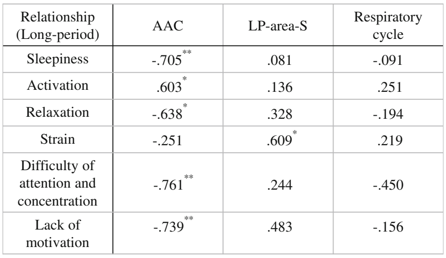
| Relationship (Short-period) | AAC | LP-area-S | Respiratory cycle |
|---|---|---|---|
| Sleepiness | -.146 | .286 | .019 |
| Activation | $.565^{*}$ | -.186 | .017 |
| Relaxation | .093 | .276 | .217 |
| Strain | -.155 | -.117 | -.043 |
| Difficulty of attention and concentration | .038 | $.567^{*}$ | .178 |
| Lack of motivation | -.284 | $.511^{\dagger}$ | .207 |

(b) Middle-period



| Relationship (Middle-period) | AAC | LP-area-S | Respiratory cycle |
|---|---|---|---|
| Sleepiness | .058 | -.373 | -.402 |
| Activation | -.279 | .347 | $.579^{*}$ |
| Relaxation | -.123 | -.062 | -.171 |
| Strain | .425 | -.069 | -.185 |
| Difficulty of attention and concentration | .146 | -.412 | -.311 |
| Lack of motivation | .284 | -.403 | -.144 |

(c) Long-period



| Relationship (Long-period) | AAC | LP-area-S | Respiratory cycle |
|---|---|---|---|
| Sleepiness | $-.705^{**}$ | .081 | -.091 |
| Activation | $.603^{*}$ | .136 | .251 |
| Relaxation | $-.638^{*}$ | .328 | -.194 |
| Strain | -.251 | $.609^{*}$ | .219 |
| Difficulty of attention and concentration | $-.761^{**}$ | .244 | -.450 |
| Lack of motivation | $-.739^{**}$ | .483 | -.156 |

## 4.5 Breathing Control Rate

The breathing control rate was calculated to reflect the degree to which the subjects were able to breathe at the target rate in response to the vibration stimulus for the different breathing patterns. The task (300 s) was divided into 60-sec intervals, and the average breathing period was calculated for every 60 s to determine the breathing control rate. The breathing control rate is shown in Table 4 for the (a) short-period, (b) middle-period, and (c) long-period breathing patterns.

From the average (5 min) of Table 4, the average breathing control rate for many subjects for the 5-minute period was greater than 98 %, and it is thought that many subjects were able to breathe at a rate that was very close to the target rate in all periods. On the other hand, a few subjects had a low breathing control rate.

**Table 4.** Breathing control rate (%)

(a) Short-period

| Subject Number | 0-60 (sec) | 60-120 (sec) | 120-180 (sec) | 180-240 (sec) | 240-300 (sec) | Average (5 min) |
|---|---|---|---|---|---|---|
| No.1 | 98.772 | 98.527 | 96.874 | 98.393 | 99.264 | 98.366 |
| No.2 | 99.808 | 99.567 | 98.980 | 99.698 | 98.884 | 99.388 |
| No.3 | 99.795 | 99.574 | 99.526 | 97.897 | 95.992 | 98.557 |
| No.4 | 95.811 | 98.021 | 95.679 | 99.723 | 92.913 | 96.430 |
| No.5 | 97.050 | 99.605 | 99.839 | 99.993 | 99.981 | 99.294 |
| No.6 | 99.733 | 99.292 | 96.059 | 99.965 | 99.174 | 98.845 |
| No.7 | 99.808 | 99.938 | 99.896 | 97.914 | 99.808 | 99.473 |
| No.8 | 99.873 | 99.198 | 98.268 | 95.713 | 96.879 | 97.986 |
| No.9 | 99.449 | 99.988 | 95.543 | 99.888 | 99.922 | 98.958 |
| No.10 | 99.437 | 99.479 | 99.101 | 99.076 | 99.816 | 99.382 |
| No.11 | 99.818 | 99.892 | 99.533 | 99.582 | 99.085 | 99.582 |
| No.12 | 99.986 | 99.297 | 99.734 | 99.925 | 99.286 | 99.646 |
| No.13 | 99.175 | 99.889 | 99.881 | 95.506 | 98.101 | 98.510 |
| Average | 99.117 | 99.405 | 98.378 | 98.713 | 98.393 | 98.801 |

(b) Middle-period

| Subject Number | 0-60 (sec) | 60-120 (sec) | 120-180 (sec) | 180-240 (sec) | 240-300 (sec) | Average (5 min) |
|---|---|---|---|---|---|---|
| No.1 | 98.926 | 97.644 | 99.073 | 99.269 | 98.594 | 98.701 |
| No.2 | 91.378 | 91.286 | 92.118 | 91.393 | 91.001 | 91.435 |
| No.3 | 99.362 | 99.597 | 97.376 | 99.123 | 98.878 | 98.867 |
| No.4 | 99.602 | 86.911 | 93.941 | 96.716 | 94.757 | 94.385 |
| No.5 | 99.808 | 99.704 | 99.508 | 99.779 | 99.897 | 99.739 |
| No.6 | 98.620 | 98.598 | 99.272 | 99.427 | 99.345 | 99.052 |
| No.7 | 99.341 | 99.595 | 99.202 | 93.715 | 99.031 | 98.177 |
| No.8 | 99.585 | 98.634 | 99.493 | 99.554 | 91.473 | 97.748 |
| No.9 | 99.891 | 99.783 | 99.406 | 99.714 | 99.532 | 99.665 |
| No.10 | 99.741 | 99.663 | 98.792 | 97.944 | 98.827 | 98.993 |
| No.11 | 99.442 | 99.824 | 99.633 | 99.574 | 99.997 | 99.694 |
| No.12 | 99.819 | 99.619 | 97.093 | 99.693 | 99.854 | 99.216 |
| No.13 | 99.862 | 99.814 | 99.825 | 94.574 | 97.554 | 98.326 |
| Average | 98.875 | 97.744 | 98.056 | 97.729 | 97.595 | 98.000 |

(c) Long-period

| Subject Number | 0-60 (sec) | 60-120 (sec) | 120-180 (sec) | 180-240 (sec) | 240-300 (sec) | Average (5 min) |
|---|---|---|---|---|---|---|
| No.1 | 99.452 | 99.013 | 99.592 | 97.003 | 98.952 | 98.802 |
| No.2 | 99.768 | 97.842 | 98.057 | 98.155 | 99.224 | 98.609 |
| No.3 | 98.798 | 98.806 | 98.696 | 99.021 | 98.457 | 98.755 |
| No.4 | 99.591 | 99.952 | 98.225 | 99.959 | 99.959 | 99.537 |
| No.5 | 98.784 | 99.736 | 99.725 | 99.905 | 99.993 | 99.629 |
| No.6 | 93.195 | 98.979 | 99.202 | 100.000 | 98.641 | 98.004 |
| No.7 | 99.818 | 99.736 | 99.499 | 97.708 | 99.438 | 99.240 |
| No.8 | 99.168 | 99.580 | 99.451 | 98.406 | 97.553 | 98.831 |
| No.9 | 99.596 | 98.863 | 98.979 | 99.792 | 99.021 | 99.250 |
| No.10 | 97.278 | 99.479 | 99.572 | 99.640 | 97.859 | 98.766 |
| No.11 | 98.011 | 94.856 | 95.152 | 99.869 | 98.511 | 97.280 |
| No.12 | 99.468 | 99.986 | 99.559 | 99.668 | 99.304 | 99.597 |
| No.13 | 99.566 | 99.415 | 98.094 | 99.180 | 97.985 | 98.848 |
| Average | 98.653 | 98.942 | 98.754 | 99.101 | 98.838 | 98.858 |

# 5 Discussion

Based on the results of LP-area-S, breathing control with the long-period breathing pattern was able to induce a state of increased parasympathetic activity. Parasympathetic activity was greatly reduced during the task with the short-period breathing pattern. This result is presumably the result of the fact that the short-period breathing pattern was created based on the activity breathing cycle. Furthermore, LP-area-S increased with the short- and long-period breathing patterns when AAC was decreasing.

From the results of the breathing control rate, it appears that the breathing control rate of some subjects decreased temporarily in the middle of the time period. For example, the breathing control rate in (a) short-period No. 4 120–180 (sec) of Table 4 decreased temporarily compared to before and after the breathing control rate. Thus, it is thought that it is necessary to judge the relationship between the diachronic physiological change and the breathing control rate changes of every subject.

Based on the correlation coefficients between the psychological (RAS) and physiological (AAC, LP-area-S) parameters, it appears that the central nervous system

(EEG) and psychological changes were strongly correlated, while heartbeat (autonomic nervous system) and psychological changes were weakly correlated.

In this experiment, the results were significantly different, and short-period breathing control decreased the degree of awakening from before to after the task, decreased parasympathetic activity from before to during the task, and increased parasympathetic activity from during the task to after. On the other hand, middle-period breathing control was not significantly different. However, the middle-period breathing pattern showed increased parasympathetic activity from during the task through after the task. Long-period breathing control increased sleepiness and difficulty of attention and concentration and reduced activation. Only long-period breathing control affected the psychological state.

Short-, middle-, and long-period breathing control showed differences in the psychological and physiological evaluation parameters. Depending on the purpose and circumstances, it is necessary to use the breathing pattern appropriately.

From the results of this experiment, it appears that breathing control using a vibration stimulus based on individual breathing cycles can lead to a relaxed state in terms of the physiological and psychological changes.

Based on the different results with different breathing patterns, a breathing pattern can be put together, e.g., we change breathing control into the middle-period pattern on the way from the long-period pattern to increase parasympathetic activity from before the task through after the task. It is thought that this may provide a way to produce physiological changes, such as inducing a more effective relaxation state.

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