

Extreme prolongation of expiration breathing: Effects on electroencephalogram and autonomic nervous function

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Abstract

To clarify the physiological and psychological effects of deep breathing, the effects of extreme prolongation of expiration breathing (Okinaga) were investigated using electroencephalogram (EEG) and electrocardiogram (ECG). Participants were five male Okinaga practitioners in their 50s and 60s. Participants performed Okinaga for 31 minutes while continuous EEG and ECG measurements were taken. After 16 minutes of Okinaga, and until the end of the session, the percentages of theta and alpha 2 waves were significantly higher than at baseline. After 20 minutes, and until the end of the session, the percentage of beta waves was significantly lower than at baseline. The high frequency component of heart rate variability was significantly lower after 12 minutes of Okinaga and lasted until 23 minutes. The low frequency/high frequency ratio was significantly lower after 18 minutes of Okinaga and until the end of the session. Okinaga produced relaxation, suggesting that deep breathing may relieve anxiety. However, study limitations include potential ambiguity in the interpretation of the low frequency/high frequency ratio, the small sample, and the fact that EEG was measured only on the forehead.

Introduction

Deep or slow breathing using the diaphragm is effective both psychologically and physiologically in relieving stress and anxiety.¹⁻³ I recently reported that breathing using both 6-second expiration and 4-second inspiration promotes dominance of parasympathetic nervous function.⁴

To obtain an insight into the effects of deep breathing at the neurophysiological level, electroencephalogram (EEG) measurements can be used to study theta, alpha, and beta brain oscillations. Changes in these bands reflect the current state of consciousness. A previous randomized controlled trial of the effect of deep breathing showed that when a breathing

frequency of 0.1 Hz was maintained for 5, 7, or 9 minutes, frontal theta power increased significantly after both 5 and 9 minutes, but there was no difference from control for 7 minutes.¹ There is a negative correlation between breathing frequency and the mean power of theta, alpha, and beta bands.⁵ Previous studies on the effects of deep breathing for 5 to 20 minutes have shown an increase in alpha power at 5 minutes that remains unchanged until the end of the 20 minutes, but an increase in theta power at both 15 and 20 minutes.^{6,7}

There is little research on the association between EEG changes and deep breathing. However, previous studies on mindfulness are relevant, as deep breathing is an element of many types of mindfulness meditation.³ Findings on EEG changes during mindfulness meditation are inconsistent, perhaps owing to the range of meditation techniques. An increase in frontal theta power during meditation is often reported.^{1,6-8} Several studies suggest that alpha power is associated with the frontal brain region,⁸⁻¹⁰ although alpha waves also appear in the occipital region.⁹ Although some studies have reported a decrease in beta waves associated with deep breathing,¹ others have refuted this finding.^{11,12}

The aim of this study was to clarify the physiological effects of deep breathing in individuals able to perform extreme prolongation of expiration breathing, known as Okinaga. Okinaga is a technique that was practiced by the covert special operations agents known as “ninjas,” who operated in feudal Japan. Some individuals today practice the technique of Okinaga. I measured EEG and autonomic nervous function during Okinaga practice in five participants who had mastered Okinaga. The aim was to clarify the effects of deep breathing on the mind and body, and to inform the application of the technique to anxiety disorders and depression.

Materials and Methods

Participant recruitment and ethical considerations

Recruitment focused on individuals who practiced Okinaga. Five males in their 50s and 60s volunteered to participate. This study was conducted with the approval of the ethics committee of Mie University Graduate School of Medicine, Japan. All participants provided informed consent.

Study setting

The study was conducted in a quiet room with a temperature of 22°C and illuminance

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of 300 lux. Participants were seated on a soft chair with their both arms placed on a table. All participants were tested individually.

Study design

Participants performed normal breathing for 10 minutes to provide EEG and ECG data, and then performed Okinaga for 31 minutes. The Okinaga breathing frequency was about one breath per minute. During the Okinaga, EEG and ECG measurements were taken, as described below. Participants were asked to keep their eyes closed during the study.

EEG measurement

A handheld high-powered EEG was used (BrainPro Light FM828T, Futek Electronics Co., Ltd., Yokohama,

Kanagawa); sensor bands with two electrodes were attached to the participant's forehead. The explorer electrode was Ep2 and the reference electrode was Ep1. EEG data were recorded for 3-minute periods. The percentages of the theta (4–6 Hz), alpha 1 (7–8 Hz), alpha 2 (9–11 Hz), alpha 3 (12–13 Hz), and beta (14–30 Hz) waves were calculated. Data of 20 μ V or more per second at 3.0 Hz were excluded as artifacts.

EEG was measured before starting Okinaga (baseline) and then measured at 0–3 minutes, 4–7 minutes, 8–11 minutes, 12–15 minutes, 16–19 minutes, 20–23 minutes, 24–27 minutes, and 28–31 minutes after the start of Okinaga.

ECG measurement

ECG was measured using a CheckMyHeart recorder (TRYTECH Co., Ltd., Tokyo). Measurements were taken at 5-minute periods. ECG frequency data were analyzed using a power spectrum analysis of according to the principle of maximum entropy, and the low frequency (LF; 0.04 Hz to 0.15 Hz) and high frequency (HF; 0.15 Hz to 0.4 Hz) components of heart rate variability (HRV) were calculated. The HF and LF/HF values were used as indices of parasympathetic nervous activity and sympathovagal balance, respectively. ECG was measured at baseline and then at 0–5 minutes, 6–11 minutes, 12–17 minutes, 18–23 minutes, and 24–29 minutes after the start of Okinaga.

Statistical analysis

The mean percentage of each wave for the EEG, HF, and LF/HF values at each time point was tested using the Bonferroni/Dunn test. This tests for significant differences between all pairs; $P < 0.05$ was considered to indicate significance.

Results

Changes in the percentage of the theta, alpha 2, and beta waves in this study are shown in Figure 1. There was no change in alpha 1 or alpha 3 waves. Theta and alpha 2 waves were significantly higher 16 minutes after the start of Okinaga compared with the values before the start of Okinaga (baseline); these higher values were retained until the end of the session. Theta and alpha 2 values were also significantly higher than values at 0–3 minutes and 4–7 minutes after the start of Okinaga. There was no significant difference among the values in the period 16 minutes from the start of Okinaga to the end of the session. Between 20 minutes after the start of Okinaga and the end of the session,

beta values were significantly lower than at baseline, and were significantly lower than values at 0–3 minutes and 4–7 minutes after the start of Okinaga.

Changes in LF/HF values are shown in Figure 2. These were significantly lower at 18–23 minutes and 24–29 minutes after the start of Okinaga than at baseline and at 0–5 minutes and 6–11 minutes after the start of Okinaga.

The HF values are shown in Figure 3. These were significantly lower at 12–17 minutes and 18–23 minutes after the start of Okinaga than at baseline and at 0–5 minutes after the start of Okinaga.

Discussion

Okinaga increased theta and alpha 2 waves and decreased beta waves as shown in the EEG measurements. In addition, Okinaga resulted in parasympathetic dominance. These changes were seen from about 15 minutes after starting Okinaga.

Changes in each EEG band provide information about an individual's current state of consciousness. Although there are no studies investigating the influence of the type of deep breathing used in Okinaga, the effect of deep breathing at various frequencies has been reported. The present study showed an increase in theta waves

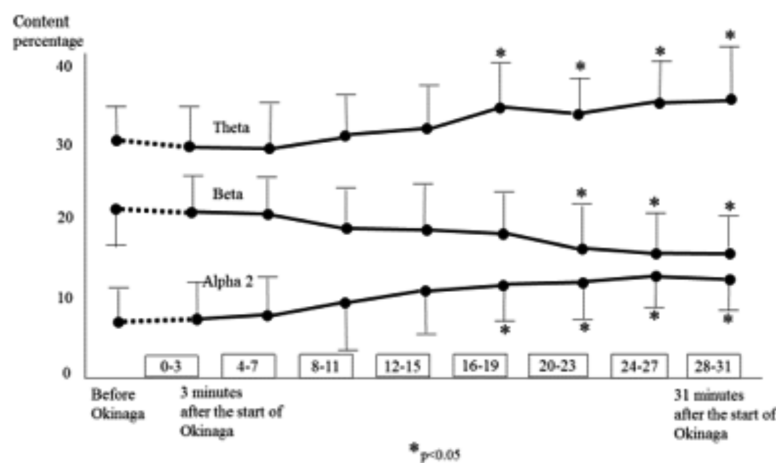


Figure 1. Changes in content percentages of theta, alpha 2, and beta waves over the time course of Okinaga.

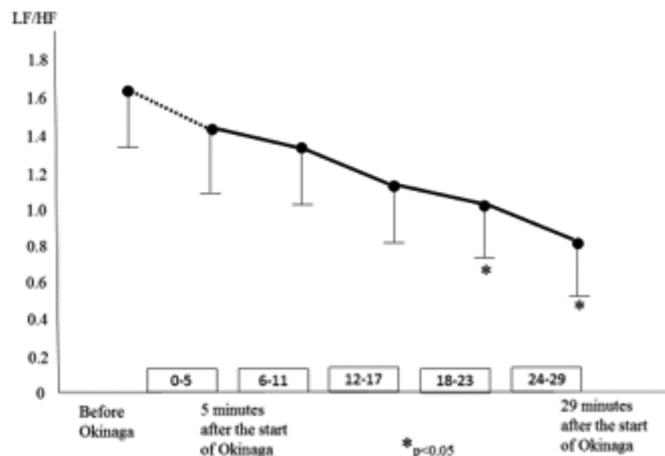


Figure 2. Changes in the LF/HF ratio over the time-course of Okinaga.

consistent with EEG findings for 3 or 4 breaths per minute,^{6,7} or 0.1 Hz breath.¹ It is also noteworthy that theta waves increased during the Okinaga session. The increase in frontal theta power could be interpreted as indicating greater focused attention.¹³⁻¹⁵ One previous study showed that frontal theta power and anxiety were negatively correlated during deep breathing.¹⁶

An increase in theta activity may be interpreted as simply fatigue or a transition into sleep. It is difficult to determine by EEG alone whether an increase in theta waves reflects a deep state of meditation or stage 1 sleep. During meditation, theta activity continues even after the eyes are opened, and it can be indicated by an alert state in participants.^{17,18} Although in this study EEG measurements were not taken after participants opened their eyes, it is unlikely that the theta activity indicated sleep because all participants confirmed that they were not sleeping and reported that their sensations remained acute. Several previous studies reported that localized frontal midline theta waves increased during meditation, indicating concentrated cognitive engagement,¹⁹⁻²¹ which is consistent with the findings of this study. Although modern applications of meditation have emphasized the hypoarousing and relaxing effects, meditation should be considered to have significance as a state of relaxed alertness that must guard against both excessive hyperarousal (restlessness) and excessive hypoarousal (drowsiness, sleep).²¹

In this study, alpha 2 waves increased with the duration of breathing. There are several reports that alpha power increases during meditation,⁸⁻¹⁰ but no studies have

examined the effect of deep breathing on different types of alpha waves (*i.e.*, alpha 1, 2, and 3). Although alpha waves initially appear in the occipital region,⁹ there are also reports that they can increase in the frontal region; this has been interpreted as indicating relaxation.^{8-10,22} The increase of alpha 2 in this study is considered to be consistent with these reports. The lower alpha band reflects vigilance and attention and the upper alpha band reflects task-specific processes, such as perceptual and cognitive processing.²³ In this study, an increase was observed in the mid-alpha band; the association of such an increase with attention and cognition requires further examination.

In this study, the beta waves were significantly lower 20 minutes after the start of Okinaga. Previous research has shown that 0.1 Hz deep breathing for 5, 7, or 9 minutes is associated with a reduction in beta power reported in the whole brain, including the frontal region.¹ This decrease in beta power has been interpreted as a decrease in anxiety²⁴ and is consistent with parasympathetic nervous system dominance.²⁵ One study found that 10 minutes of HRV biofeedback was associated with a decrease in beta power.²³ However, other reports have suggested that deep breathing does not decrease beta power.^{11,12}

HRV is a measure of beat-to-beat temporal changes in heart rate and provides indirect insight into autonomic nervous system tone. HRV analysis is a reliable non-invasive technique to quantify cardiovascular autonomic regulatory responses and mechanisms.²⁶ The Task Force of the European Society of Cardiology

and the North American Society of Pacing and Electrophysiology have recommended several time-domain measures for descriptive statistical methods.²⁶ These HRV indices are markers to assess sympathetic and parasympathetic tone. HF power is almost entirely mediated by parasympathetic nervous system activity, whereas LF power reflects the mixed modulation of parasympathetic and sympathetic activities.²⁶ The ratio of LF power to HF power (LF/HF) reflects the ratio between sympathetic nervous system activity and parasympathetic nervous system activity.²⁶ A shift of dominance from sympathetic to parasympathetic nerve activity reduces anxiety and leads to relaxation.²⁴ In this study, parasympathetic nervous activity became dominant as the Okinaga session progressed. It has been suggested that the HRV LF/HF value does not accurately measure sympathovagal balance and that its correspondence with psychological and physiological conditions is not unique.^{27,28} Although there are ongoing efforts to resolve the interpretive ambiguity of LF/HF,²⁹ this issue requires more recognition and future research.

In this study, no significant findings were observed until 12 minutes after starting Okinaga. The lack of significance may relate to the small sample size; however, it may also indicate that participants require time to adapt to very prolonged expiration. It is possible that long expiration may create stress owing to oxygen deficiency in the initial period of Okinaga.

Deep breathing may be beneficial for alleviating anxiety. Research on deep breathing is insufficient, although many studies on mindfulness suggest that deep breathing is an important factor. Although this study investigated Okinaga, a special skill developed by ninjas in ancient Japan, the findings clarify the effects of deep breathing more generally. Studies on meditation have emphasized its hypoarousing and relaxing effects, but the arousing and alertness-promoting effects of meditation have been relatively ignored.^{18,21} As ninjas regularly faced dangerous, life-threatening situations, vigilance to their surroundings was essential. It seems reasonable to argue that Okinaga leads to relaxed alertness, but further examination of its effects is necessary. Moreover, there are some limitations of the present study, such as the small sample size, and the fact that methodological issue of EEG measurements was only taken from the forehead. Further research in this field is required.

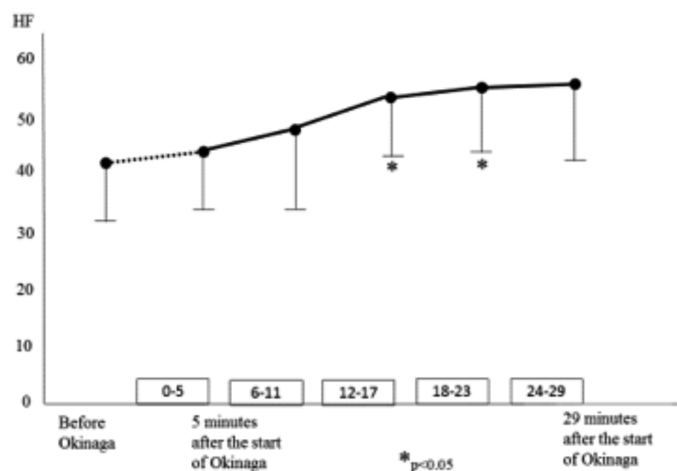


Figure 3. Changes in HF value over the time course of Okinaga.

Conclusions

This study investigated a breathing method known as Okinaga, in which expiration may reach one breath per minute. The effects of Okinaga deep breathing on brain waves and autonomic nervous system function were examined. Theta and alpha 2 waves increased and beta waves decreased as Okinaga progressed. Parasympathetic dominance was observed as Okinaga progressed. These findings suggest that deep breathing is relaxing and relieves anxiety. Future research should build upon the methodology used here to advance our understanding of the effects of deep breathing.

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