Is Man Able to Breathe Once a Minute for an Hour?:
The Effect of Yoga Respiration on Blood Gases

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Abstract: The ventilatory response to hypercapnia and arterial blood gases during ujjai respiration of once per minute for an hour were determined in a professional hatha yogi. The results suggest that lower chemosensitivity to hypercapnia in yoga practitioners may be due to an adaptation to low arterial pH and high $P_{a\text{CO}_2}$ for long periods. [Japanese Journal of Physiology, 52, 313–316, 2002]

Key words: yoga respiration, blood gases, hypercapnic ventilatory response.

Yoga, which means a union or a joining together of the body, emotion, and mind, is considered to have originated in the northern part of India around 500 BC [1]. Although yoga was divided into several branches, hatha-yoga has recently been practiced by many people for the maintenance and promotion of health, since it has shown many beneficial effects for the body and mind by regular practice. Udupa and Singh [2] have conducted physiological, endocrine, metabolic, and neuropsychological studies in a group of normal male volunteers undergoing a 6-month training course of hatha-yoga. They observed reduction in body weight, increased rate of chest expansion, vital capacity and breath-holding duration. They also described that the practice of yoga appears to make an individual more mentally competent. Furthermore, Ray et al. [3] concluded that selected hatha-yoga exercises can improve muscular endurance and delay the onset of fatigue in middle-aged men.

On the other hand, the practice of hatha-yoga consists of the control of posture (asana) and the manipulation of respiration (pranayama). The control of posture aims at developing a stable and effortless position that involves stretching, balancing in a supine position, sitting, standing, and even maintaining a head-down posture. A voluntary control of breathing plays a central role in hatha-yoga. It is well known that practitioners of yoga, known as “yogi,” have more tidal volume and less respiratory frequency [4] than untrained subjects do. Stanescu et al. [1] found that the ventilatory response to hypercapnia was significantly lower in Belgian subjects who had made an intensive practice of hatha-yoga in comparison with an untrained group. Although they speculated that these changes were due to a chronic manipulation of respiration, arterial blood gases during the voluntary control of breathing (ujjai, a branch of respiratory manipulation of pranayama) were not measured in their study.

The purpose of this study, therefore, was to determine the ventilatory response to carbon dioxide at rest and to arterial blood gases during ujjai breathing in a professional male yogi, and to learn about the involvement of changes in blood gas status in the altered ventilatory response, if any.

Methods

In the present study, we examined a healthy Japanese man who had made an intensive practice of asana and pranayama for 19 years and is capable of slower deeper breathing at a low respiratory frequency of once per minute, so-called ujjai respiration, for 1 h. He was born and educated in the northern part of Japan. After graduation from high school, he visited
India a few times to learn hatha-yoga. He was 26 years old when he started the regular practice of hatha-yoga every day for 2–2.5 h/d. When beginning this laboratory test his age was 45, height 164.3 cm, and weight 59 kg, and he was living on a mixed diet. The subject was informed of the experimental protocol and possible risks involved in this study before he was asked to consent. The protocol of this study was approved by the Human Research Committee of the Research Center of Health, Physical Fitness and Sports of Nagoya University.

The subject came to our laboratory twice on separate days. On the first day, pulmonary ventilation and oxygen uptake at rest were measured for 10 min by means of the Douglas bag method in the control and ujjai respirations. Furthermore, the ventilatory response to carbon dioxide was obtained by the rebreathing method according to Read [5]; the subject rebreathed a gas mixture (7% CO\textsubscript{2} in O\textsubscript{2}) of 5 l for 4 min. During rebreathing, pulmonary ventilation (V\textsubscript{E}) and end-tidal PCO\textsubscript{2} (PET\textsubscript{CO}\textsubscript{2}) were determined by means of a respirometer (Fukuda, Tokyo, Japan) and a CO\textsubscript{2} analyzer (Godart, Utrecht, Holland), respectively. The slope of the ventilatory response curves, S, and the intercept on the PET\textsubscript{CO}\textsubscript{2} axis, B, were calculated by the method of least squares.

On the second day, arterial blood gases were determined by the use of a catheter during control and ujjai respirations. Although a manipulation of respiration plays an important role in hatha-yoga, the respiration for ujjai consists of slow and ample near-vital capacity maneuvers accompanied by apnea at the end of inspiration and expiration. Ujjai is a thoracic type of breathing; abdominal muscles play a passive role. In this routine a very deep inspiration is taken slowly with the glottis partially closed and the head erect. When the lungs seem full, the head is bent forward until the chin touches the jugular notch firmly. After this routine a very deep inspiration is taken slowly through a sampling tube connected to the mask. End-tidal carbon dioxide and oxygen concentration in the expired gas were monitored by means of CO\textsubscript{2} (Godart) and O\textsubscript{2} (Morgan, London, England) gas analyzers during the experiment. The heart rate was also continuously recorded by a three-lead electrocardiogram (Nihon Kohden, Tokyo, Japan). These gas analyzers were calibrated with a known gas concentration before testing. Arterial blood sampling during ujjai respiration was carried out in a quiet room at constant temperature (25°C) in the sitting position called the “lotus pose.” An arterial catheter was inserted into the radial artery at the wrist of the left hand. Under the normal conditions of respiration, a few milliliters of arterial blood sample were taken gradually in a heparinized syringe extending over 1 min. This procedure was repeated 3 times to obtain the average values of blood gases during controlled breathing. Furthermore, an arterial blood sample was collected in a heparinized syringe 5 or 6 times (about once every 10 s) during one cycle of ujjai respiration. This continuous sampling was also repeated 3 times with appropriate intervals over 1 h. Arterial blood CO\textsubscript{2} and O\textsubscript{2} partial pressure (Pa\textsubscript{CO}\textsubscript{2}, Pa\textsubscript{O}\textsubscript{2}), oxygen saturation (Sa\textsubscript{O}\textsubscript{2}), and hydrogen ion concentration (pH) were determined with an automatic blood gas analyzer (Acid-Base Analyzer ABL 30, Radiometer, Copenhagen, Denmark). Bicarbonate concentration [HCO\textsubscript{3}⁻] was calculated by means of this equation, [HCO\textsubscript{3}⁻] = 0.0306 × Pa\textsubscript{CO}\textsubscript{2} × 10 \{(pH−6.161)/0.9524\}, proposed by Siggaard-Andersen [6].

Results

In the present study, minute ventilation, respiratory frequency, oxygen uptake, and heart rate at rest were 3.86 l · min\textsuperscript{−1}, 6 breaths · min\textsuperscript{−1}, 230 ml · min\textsuperscript{−1}, and 69 beats · min\textsuperscript{−1} in the control breathing, and 2.74 l · min\textsuperscript{−1}, 1 breath · min\textsuperscript{−1}, 256 ml · min\textsuperscript{−1}, and 75 beats · min\textsuperscript{−1} in the ujjai breathing. It was found that the slope (S) and intercept (B) of the hypercapnic ventilatory response curve measured by the rebreathing method in this subject was 0.26 l · min\textsuperscript{−1} · torr\textsuperscript{−1}, and −10.2 l · min\textsuperscript{−1}, respectively.

End-tidal PO\textsubscript{2} and PCO\textsubscript{2} (PET\textsubscript{O}\textsubscript{2} and PET\textsubscript{CO}\textsubscript{2}) oscillated simultaneously with each respiration cycle during ujjai breathing (Fig. 1). In the study, PET\textsubscript{O}\textsubscript{2} and PET\textsubscript{CO}\textsubscript{2} reached about 62 torr and 48 torr, respectively, at the end of expiration when the subject performed ujjai respiration at a frequency of once per minute.

On the other hand, the average values (±SD) of Pa\textsubscript{O}\textsubscript{2}, Pa\textsubscript{CO}\textsubscript{2}, Sa\textsubscript{O}\textsubscript{2}, and pH during control breathing were 95.0 (±2.4) torr, 40.0 (±1.1) torr, 97.0 (±0.25)%, and 7.393 (±0.008), respectively. Figure 2 indicates the relationship between arterial blood pH and bicarbonate ion concentration obtained during ujjai breathing with a respiratory frequency of 1.0/min. Although changes of blood gas during one cycle of ujjai breathing determined 3 times differed more or less as shown in Fig. 2, arterial pH decreased to 7.319 and Pa\textsubscript{CO}\textsubscript{2} increased 51.3 torr.
Discussion

The physiological benefits of exercise are highly accepted. The hatha-yoga exercise is considered to improve body functions through the manipulation of cardiovascular, respiratory, metabolic, and other control mechanisms [7]. Ray et al. [3] concluded that the practice-selected hatha-yoga exercises can improve muscular endurance and delay the onset of fatigue in middle-aged man. Berger and Owen [8] also reported the possibility that hatha-yoga is associated with reductions in psychological stress.

Miles [9] has determined respiratory frequency and minute ventilation in Indian male subjects who had been trained in yoga breathing. In his experiments, the average values of minute ventilation and respiratory frequency during ujjai respiration for 20 min were 3.53 l·min⁻¹ and 1.26 breaths·min⁻¹. In the present study, minute ventilation, respiratory frequency, and oxygen uptake at rest were 3.86 l·min⁻¹, 6 breaths·min⁻¹, and 230 ml·min⁻¹ in the control breathing, and 2.74 l·min⁻¹, 1 breath·min⁻¹, and 256 ml·min⁻¹ in the ujjai breathing, respectively.

In regard to the respiratory adaptation of yoga training, Karambelkar et al. [10] have reported that a professional yogi could stay in an airtight pit until CO₂ reached 7.7%, probably because of being long habituated to a situation of this kind; but an untrained subject felt great discomfort when CO₂ reached a level of about 7%, and the experiments had to be discontinued. It has hitherto been reported that hypoxic and hypercapnic ventilatory responses were significantly lower in athletes than in untrained subjects [11]. In the previous study we also found that the mean slope of the hypercapnic ventilatory response curve at rest was significantly (p<0.05) lower in endurance runners (1.12 l·min⁻¹·torr⁻¹) and long-distance swimmers (1.43 l·min⁻¹·torr⁻¹) in comparison with untrained subjects (1.86 and 2.03 l·min⁻¹·torr⁻¹) [12, 13]. Stanescu et al. [1] observed that the mean slope (±SD) in the yoga group, 0.70±0.29 l·min⁻¹·torr⁻¹, was significantly (p<0.01) lower than in the control group (1.73±0.84 l·min⁻¹·torr⁻¹). These results were confirmed in this study, i.e., the slope of hypercapnic ventilatory response (S) measured by the rebreathing method in this subject was 0.26 l·min⁻¹·torr⁻¹. This corresponds to 37% of Stanescu et al.’s value [1].

As described previously, the subject of this study has for more than 19 years been continuing an intensive practice of a special kind of physical training that...
Involves a control of posture (asana) and of respiration (pranayama) every day for 2–2.5 h/d. The control of posture aims at developing a stable position, which may be held supinely, while seated or standing, or even in a head-down posture [1]. Furthermore, ujjai respiration consists of slow and near-vital capacity maneuvers that use not only the diaphragm and costal muscles, but also the accessory respiratory and abdominal muscles. In other words, it is possible to assume that an intensive and prolonged practice of various postures and of ujjai respiration may have elements in common with the adaptation of aerobic work capacity and respiratory chemosensitivity to endurance training for long periods, even though maximum oxygen uptake was not determined for this professional yogi. This assumption, however, needs further investigation.

On the other hand, Stanescu et al. [1] argued that lower hypercapnic ventilatory response observed in the yoga group is due to a chronic manipulation of respiration and that the decreased hypercapnic drive allowed the yoga practitioners to maintain a lower respiratory flow rate. Since Stanescu et al. [1] did not measure blood gases in their experiments, however, we determined $P_{aO_2}$, $P_{aCO_2}$, and pH during control and ujjai respiration at a frequency of once per minute to account for lower chemosensitivity to CO₂ in the professional yogi. It has hitherto been reported that blood gases do not change much with physical exercise under a moderate workload, but average arterial pH decreased to 7.24 and $P_{aO_2}$ decreased to 68.3 torr at exhaustion during maximal exercise in the trained cyclists [9]. In the present study, the average values (±SD) of $P_{aO_2}$, $P_{aCO_2}$, $S_aO_2$, and pH of 3 samplings during control breathing were 95.0 (±2.4) torr, 40.0 (±1.1) torr, 97.0 (±0.25)%s, and 7.393 (±0.008), respectively. On the other hand, during ujjai breathing, arterial pH decreased to 7.319, and $P_{aCO_2}$ increased to 51.3 torr at the end of ujjai expiration (Fig. 2). Furthermore, $P_{aO_2}$ decreased to about 76 torr at the end of the expiration of ujjai breathing. In other words, this professional yogi in daily life seems to have been exposed intermittently to mild respiratory acidosis and hypoxemia by means of yoga respiration, especially ujjai respiration, during the hatha-yoga training. From these results it is possible to hypothesize that intermittent respiratory acidosis and hypoxemia from ujjai respiration in daily life may influence the hypercapnic and hypoxic drives of the respiratory control system, which allow respiration at a frequency of 1 breath per minute over an hour in this professional yogi. This possibility, however, remains unconfirmed.

In conclusion, it was suggested that reduced hypercapnic chemosensitivity in the well-trained yogi may be related to an adaptation to low arterial pH and/or to high $P_{aCO_2}$.

REFERENCES