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The effects of high frequency respiration in yoga practitioners

V. Agostini, D. Paradiso, F. Molinari, D. Rimini, M. Knaflitz
Dipartimento di Elettronica e Telecomunicazioni
Politecnico di Torino
Torino, Italy
valentina.agostini@polito.it

W. Liboni
"Un Passo Insieme" ONLUS Foundation,
Valdellatorre, Torino, Italy

***Abstract*—Near Infrared Spectroscopy (NIRS) allows for assessing brain hemodynamics non-invasively. In NIRS studies, the maneuver of breath holding is frequently used as an activation of the brain autoregulation response. However, breath holding is not always feasible or effective in the clinical practice. We explored the possibility of using kapalabathi, an ancient yoga respiration technique, as an alternate activation maneuver. We studied the brain oxygenation response to kapalabathi, in yoga practitioners, in three different postures. In all the three postures considered Kapalabathi produces a measurable effect on the oxygen availability at the brain cortex level. Remarkable differences were observed in the brain autoregulatory response of smoker and non-smoker practitioners.**

Keywords—Near Infrared Spectroscopy (NIRS); brain hemodynamics; cerebral autoregulation; respiration; kapalabathi; yoga.

I. Introduction

Respiration affects the functioning of the nervous system by regulating the supply of oxygen to the brain tissues. The mechanical properties of cerebral arteries are inherently controlled, to ensure that brain receives oxygen enough and that blood pressure in the brain arteries is kept stable, even when systemic blood pressure changes. This mechanism is known as autoregulation of cerebral blood flow. In our daily life, we often experience the effects of changes of oxygen availability: even a small decrement is known to produce drowsiness, while increments are associated to increased attention levels.

Autoregulation depends on the smoking habits of subjects: smokers, generally, show a markedly decreased autoregulation. This is often associated to their increased risk of cerebral vascular accidents.

In Hatha yoga, Pranayama is the control of the flow of vital energy through the control of breath. There are more than fifty different types of pranayama. yoga practitioners try to achieve, through the control of respiration, a healthy body and mind. The yoga practice Kapalābāthi (KB) is an ancient yoga respiration technique, which literally means "skull shining". It involves short and forceful exhalations, while inhalation happens automatically [1]. Most yoga teachers warn practitioners not to sustain KB respiration for more than 2-3 minutes. A possible justification of this warning is that it is difficult to execute KB in such a way that the expired and inspired air quantities are equal. Beginners, in a single breathing cycle, tend to expire more than they inspire, thus producing a mild hypoxia condition. This is interesting, since even a mild hypoxia induces dilation of the brain arteries, to keep the oxygen concentration in the brain tissue as constant as possible.

The typical manoeuver that allows for inducing a mild hypoxia is breath holding (BH) [2]. However, its effectiveness is limited because it is generally not well tolerated by subjects and difficult to perform for subjects with neurological impairments [3]. Also, its duration is often too short to induce any measurable effect [2]. In this perspective, KB could be thought as an alternate "activation" technique to investigate autoregulation functioning. Near InfraRed Spectroscopy (NIRS) is a non-invasive technique used for real-time monitoring the brain tissue oxygenation [4]. It is based on the principles of optical spectrophotometry. Biological material,

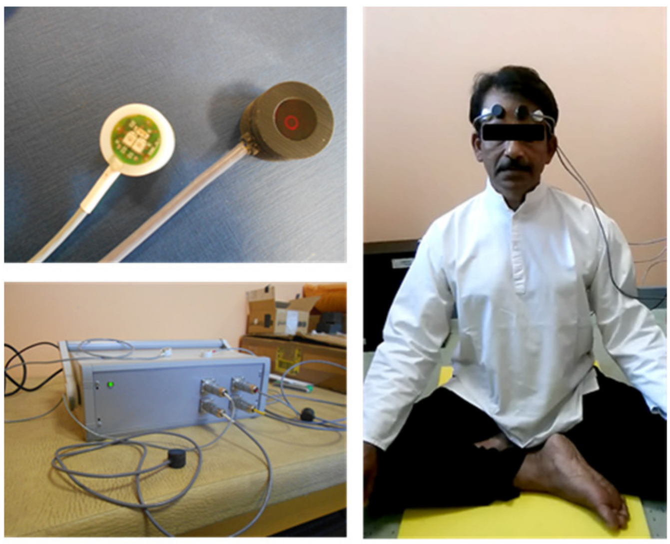

Fig. 1. NIRS developed at Politecnico di Torino with the particular of the emitting and receiving probes. Probe positioning on a subject in sitting position.

including the skull, is relatively transparent in the NIR range (750 nm - 1400 nm) and photons can penetrate within the cerebral cortex for a few millimiters. In reflectance-mode NIRS, the receiving optodes are placed ipsilateral to the transmitter, giving the usual banana-shaped sampling volume. The mean depth of penetration of the light is proportional to the distance between the transmitter and the receiver. To explore the brain cortex beneath the frontal bone, the transmitter and the receiver are generally placed on the forehead from 40 mm to 60 mm apart.

The concentration changes of oxyhemoglobin (O_2Hb), deoxyhemoglobin (HHb), and cytochrome c-oxidase are measured by conventional differential spectroscopy by applying the modified Beer-Lambert law [4]. The absorption spectra of HHb ranges from 650 nm to 1000 nm, O_2Hb shows a broad peak between 700 nm and 1150 nm, and cytochrome c-oxidase shows a peak in the range 820 nm – 840 nm. The photon wavelengths produced by the emitter optode are selected to maximize the separation of these biologically important chromophores, while minimizing the overlap with water [5].

The aim of this study was to evaluate the effects of KB respiration on brain oxygenation with two different purposes: 1) to gain a deeper insight into the effects of this respiration technique in yoga practitioners, and 2) to explore the possibility of using KB as an activation technique in studies of brain autoregulation.

In particular, we analyzed the KB respiration in three different yoga postures: a) crossed-leg sitting (*padmasana*), b) lying supine with legs slightly apart and arms released by the side with palms facing up (*shavasana*), and c) deep backward bending performed in a kneeling position (*ushtrasana* or "camel" pose).

II. Materials and Methods

A. Intrumentation

The NIRS system used in this study was developed at Biolab of Politecnico di Torino (see Fig. 1). It is based on two pairs of emitting/receiving optodes (2 channels). The two channels synchronously record the activity from the left and right brain hemispheres. The emitting probe (white) is constituted by 3 infrared LEDs radiating at different wavelengths (730 nm, 830 nm, 870 nm). The receiving probe (black) is based on an Avalanche Photo Diode (APD). The signals, frequency resolved, are sent to a PC through an USB port. A dedicated Graphical User Interface (GUI) developed in Matlab® allows for controlling the signal acquisition and its real-time representation.

B. NIRS signals

The signals obtained by the system represent the changes of concentration of 1) O_2Hb, 2) HHb, 3) cytochrome c-oxidase. However, in this study only O_2Hb and HHb were considered. We calculated in real-time the TOI (Tissue Oxygenation Index), defined as the ratio of O_2Hb and total hemoglobin:

$$\mathrm{TOI}\ (\%) = \frac{O_2Hb}{O_2Hb + HHb} \times 100$$

Typical TOI values are in the range 60-80% [4]. During the acquisitions, we checked that TOI values lied within the specified range for both channels showing similar values (differences smaller than 10%). The resolution of the system is approximately 0.1 μmol/l.

C. Subjects

We enrolled in the study 18 yoga practitioners (9 males and 9 females) with at least 5 years of experience in the yoga practice. In the group, there were 8 smokers and 10 non-smokers. Four people were long-term practitioners, with a yoga experience of more than 30 years.

Prior to carry out the study, twenty subjects (not practicing yoga) were also enrolled, from the university community, to carry out a pilot study aimed at establishing the physiological changes of O_2Hb and HHb signals in normal resting conditions (with no activation). These subjects were asked to sit quietly on a chair for 6 minutes. The signals recorded in the last minute were used to determine the O_2Hb and HHb spontaneous fluctuations in a minute.

D. Protocol

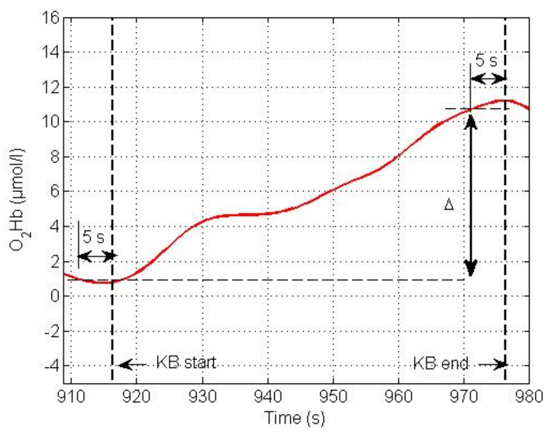

Fig. 2. Example of variation of oxyhemoglobin concentration during kapalabathi.

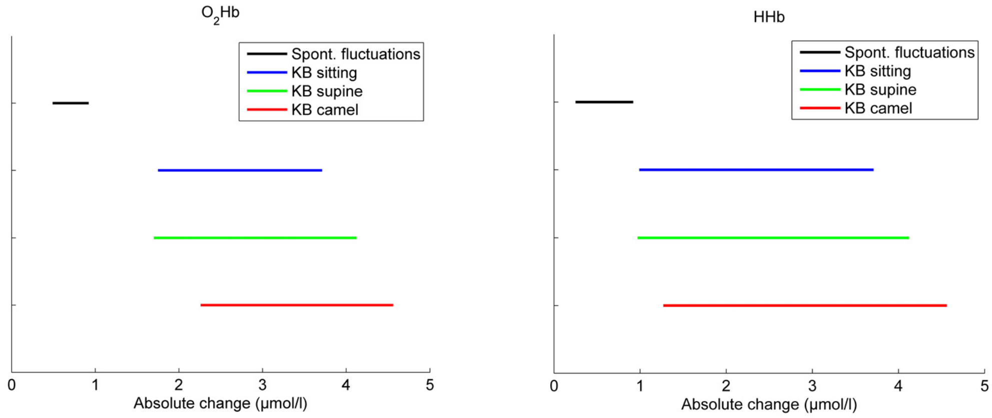

Fig. 3. Absolute changes of oxyhemoglobin (O_2Hb) and deoxyhemoglobin (HHb): spontaneous fluctuations, kapalabathi in sitting position, kapalabathi in supine position, kapalabathi in camel position. Confidence intervals at 95% are represented.

After forehead cleansing, yoga practitioners were asked to sit on the floor in crossed-leg sitting. The emitting and receiving probes were positioned on the forehead in correspondence of each brain hemisphere at a distance of 40 mm from each other (see Fig. 1). Signals were acquired for 2 minutes in a basal condition, to verify that the TOI values lied within the expected range. If this did not happen, the probe position was adjusted until reaching the desired result. Each event start/termination was marked with a mouse click by the experimenter. After 5 minutes of rest in the sitting position, the subjects performed the KB respiration for 1 minute, at their self-selected rhythm (typically between 1-2 cycles per second). Then, they stopped and relaxed for 5 minutes, maintaining the same position. The same procedure was then repeated in the supine position: 5 minutes of rest lying on the floor, 1 minute of KB respiration, other 5 minutes of rest. Then, the subjects reached again the sitting position and, after 5 minutes of rest, they moved to the "camel" pose for 1 minute, maintaining the pose for another minute while practicing KB. Other 5 minutes of rest in the sitting position followed. The entire protocol lasted approximately 45 minutes and was well tolerated by all the yoga practitioners.

E. *Signal processing*

The sampling frequency was 2 Hz. Since we were interested only in the slow fluctuations of the O_2Hb and HHb signals, we applied an anticausal low-pass filter with a cutoff frequency of 70 mHz. The changes produced by KB were evaluated as the difference (Δ) between the mean value of the signal in the last 5 seconds of KB and the 5 seconds preceding it (Fig. 2). The Δ-values of the left and right hemispheres were averaged.

III. RESULTS

Pilot study - In subjects not practicing yoga and resting on a chair, the mean spontaneous variations observed were 0.16±0.97 μmol/l for O_2Hb, and 0.12±0.46 for HHb. More specifically, spontaneous variations were observed in the range ±2 μmol/l for O_2Hb and ±1 μmol/l for HHb.

KB study - We calculated the absolute changes of O_2Hb and HHb in yoga practitioners during KB performed sitting, lying supine, and in camel pose (Fig. 3). In each position, the KB respiration modified O_2Hb and HHb (α=0.05). There are no statistically significant differences among the 3 postures.

Fig. 3 shows the mean absolute changes of the 2 chromophores considered in spontaneous and activated

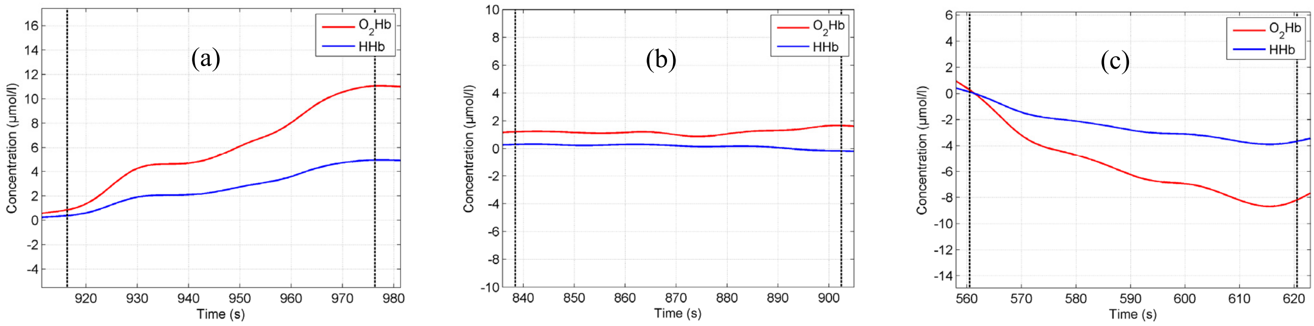

Fig. 4. Examples of NIRS signals with: (a) increasing (b) constant, (c) decreasing trends of oxyhemoglobin (O_2Hb) and deoxyhemoglobin (HHb). The signals were acquired during kapalabathi practiced in sitting position by: (a) a non-smoker yoga practitioner, (b) a (non-smoker) yoga teacher, (c) an ex-smoker yoga practitioner, respectively.

conditions, demonstrating that the KB-respiration has an effect on brain hemodynamics.

Analyzing data, we observed three different trends among yoga practitioners: in particular, we noticed increasing, constant and decreasing trends. Three representative examples are reported in Fig. 4. We classified a trend as “constant” when the variation of the chromophore concentration laid within the range of physiological fluctuations.

On the average, increasing trends were observed, for O_2Hb, in subjects who had no smoking habit, while decreasing trends characterized smokers. Differences between smokers and non-smokers were significant in all the 3 *asanas* considered (see Fig. 5a). The camel pose showed the largest effect size (6.5 μmol/l), with respect to the sitting (4.3 μmol/l) and supine (4.3 μmol/l) poses. For HHb, statistically significant differences between smokers and non-smokers were observed only in the camel pose (see Fig. 5b).

Furthermore, we noticed that long-term practitioners (“yoga teachers”) showed constant trends, for O_2Hb, in the sitting position. However the reduced sample size of this subgroup (n=4) did not allow for exploring this observation in a statistical way.

IV. Discussion and Conclusions

In this study we demonstrated the effects on brain hemodynamics of the kapalabathi respiration in three different yoga postures. These effects were definitely higher than the spontaneous fluctuations observed during normal breathing. In most yoga practitioners with no smoking habit, KB produced a mild hypoxia that was able to elicit a measurable vasodilation effect, with the purpose of assuring sufficient oxygen availability to the brain cortex despite hypoxia. This is in line with what is already known on cerebral autoregulation of the blood flow [2][6]. Practitioners with smoking habits were not able to elicit an effective autoregulation and hence the concentration of O_2Hb on the average decreased. Again, this result is in line with the previous knowledge on brain autoregulation and shows that KB allows distinguishing between the regulatory responses of smokers and non-smokers.

Moreover, it is worth noticing that, although the small number of subjects with an extensive yoga practice (over 30 years) does not allow reaching statistical significance, the general trend shows that they had stable values of O_2Hb and HHb. This finding could be explained by the fact that, due to their familiarity with the KB technique, they are able to inhale and exhale almost the same quantity of air at each breathing cycle, and hence hypoxia is not reached and vasodilation is not elicited.

In conclusion, this study demonstrated that, in the majority of subjects, KB respiration has a measurable effect on the oxygen availability at the brain cortex level. It was also demonstrated that, in most yoga practitioners, the most likely effect of KB is to induce a mild hypoxia. This may be explained by the difficulty of inhaling and exhaling the same air quantity at each breathing cycle. KB was always well tolerated and all the subjects could sustain this kind of respiration for one minute. Differences in the autoregulation of the cerebral blood flow due to the smoking habit are evident in our population, particularly when observing the change of concentration of O_2Hb. In the future, KB could be used as an alternate activation technique in brain hemodynamics studies and, possibly, its effects on oxygen availability could be exploited in clinics.

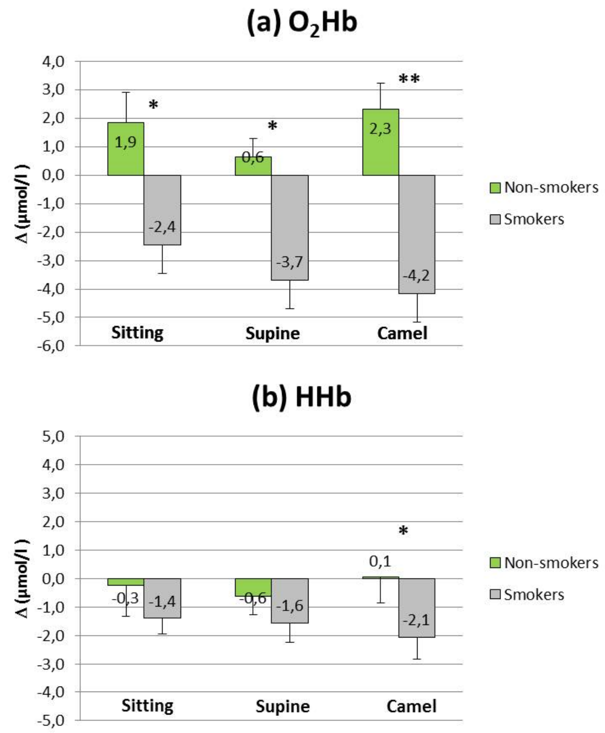

Fig. 5. Average variations of O_2Hb and HHb, during kabalabathi, in non-smokers and smokers. Significant differences between non-smokers and smokers are marked with * ($p<0.05$) or ** ($p<0.005$).

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