Frontal hemodynamic responses to high frequency yoga breathing in schizophrenia: a functional near-infrared spectroscopy study

Hemant Bhargav1*, H. R. Nagendra1, B. N. Gangadhar2 and Raghuram Nagarathna1

1 Division of Yoga and Life Sciences, Swami Vivekananda Yoga Anusandhan Samsthana, Bangalore, India
2 National Institute of Mental Health and Neurosciences, Bangalore, India

INTRODUCTION

*Kapalabhati kriyā (KB), also known as the breath of fire or the skull shining breath, involves rapid breathing consisting of active expiration with the help of abdominal muscles and passive automatic inspiration taking place during relaxation (1). Experimental data show that KB affects a broad scale of physiological processes such as respiration and cardiovascular system (2), biochemical parameters, (3) and central nervous activity (4, 5). Traditionally also, KB practice is believed to increase the blood flow to the brain (6). Immediately after the practice of KB the performance in a cancelation task (7) and auditory P300 odd-ball paradigm task (120 breaths/min for 1 min) improved (8). While performing KB, the most advocated rate of breathing is 120 breaths/min, i.e., a frequency of around 2 Hz (9).

Functional near-infrared spectroscopy (fNIRS) is a new non-invasive optical method that can measure the real time change in oxygenated hemoglobin (oxyHb), deoxygenated hemoglobin (deoxyHb), and total hemoglobin (totalHb) or blood volume concentration was tapped for 5 min before, 1 min during, and for 5 min after KB. This was obtained in a quiet room using a 16-channel functional near-infrared system (FNIR100-ACK-W, BIOPAC Systems, Inc., USA). The average of the eight channels for each side (right and left frontals) was obtained for the three sessions. The changes in the levels of oxyHb, deoxyHb, and blood volume for the three sessions were compared between the two groups using independent samples t-test. Within group comparison showed that the increase in bilateral oxyHb and totalHb from the baseline was highly significant in healthy controls during KB (right oxyHb, p = 0.00; left oxyHb, p = 0.00 and right totalHb, p = 0.01; left totalHb, p = 0.00), whereas schizophrenia patients did not show any significant changes in the same on both the sides. On the other hand, schizophrenia patients showed significant reduction in deoxyHb in the right pre-frontal cortex (right deoxyHb, p = 0.00). Comparison between the groups showed that schizophrenia patients have reduced bilateral pre-frontal activation (right oxyHb, p = 0.01; left oxyHb, p = 0.03 and right total Hb, p = 0.03; left total Hb, p = 0.04) during KB as compared to healthy controls. This hypo-frontality of schizophrenia patients in response to KB may be used clinically to support the diagnosis of schizophrenia in future.

Keywords: kapalabhati, schizophrenia, pre-frontal cortex, high frequency yoga breathing, fNIRS, optical topography, cerebral blood flow, near-infrared spectroscopy
KB practice has been shown to affect pre-frontal hemodynamic responses in healthy subjects using fNIRS (13). KB is a simple physical breathing technique that does not require any equipment or skilled staff, can be taught easily, can be administered in less than 1 min, and is cost effective. Since this practice does not involve any word or symbol, it can be used on any individual who can learn the breathing practice irrespective of his geographic, educational, ethnic, or cultural background.

Thus, this study was planned with two major objectives: (1) to assess the pre-frontal hemodynamic responses to KB practice performed at 2 Hz frequency in healthy subjects and schizophrenia patients and (2) to check whether schizophrenia patients differ in their pre-frontal hemodynamic responses to KB from healthy age, gender, and education matched controls.

MATERIALS AND METHODS

PARTICIPANTS

We enrolled 18 (14 males and 4 females) schizophrenia patients and 18 (14 males and 4 females) healthy subjects, who had no general medical disease, substance abuse, head injury, or diseases such as hypertension, epilepsy and ischemic heart disease where KB is contraindicated. The age of patients and controls was $28.9 \pm 3.5$ [mean $\pm$ standard deviation (SD)] and $26.35 \pm 3.53$ years, respectively, and the duration of education of patients and controls was $14.37 \pm 3.8$ and $15.5 \pm 3.34$ years, respectively (Table 1). There were no significant differences between the two groups in age, gender, and duration of education. All the subjects were right handed.

Patients were recruited from inpatients and outpatients of Holistic Health Home – Arogyadhama, Bangalore, India and were diagnosed as having schizophrenia (14 paranoid, 2 disorganized, and 2 undifferentiated) according to DSM-IV criteria through clinical interviews by two independent psychiatrists. All patients were on antipsychotic medications by consultant psychiatrist. The duration of illness was $8.37 \pm 5.6$ years. All patients were medicated with antipsychotics at the examination (17 atypical and 1 typical antipsychotics) with mean chlorpromazine equivalent dosage of $289 \pm 133$ mg/day (22). Six out of 18 patients were medicated with anticholinergics drugs (Table 1). Both schizophrenia patients and healthy controls had no previous exposure to KB practice before

Table 1 | Demographic and clinical characteristics of subjects.

| S. no. | Healthy individuals | Schizophrenia patients | $p$ Value |
|--------|---------------------|------------------------|-----------|
| 1 | n | 18 | 18 | 0.13 |
| 2 | Sex | 14 Males, 4 females | 14 Males, 4 females |
| 3 | Age$^a$ (years) | $28.35 \pm 3.53$ (mean $\pm$ SD) | $28.9 \pm 3.5$ |
| 4 | Handedness | All right handed | All right handed |
| 5 | Education$^a$ (years) | $15.5 \pm 3.34$ | $14.37 \pm 3.8$ |
| 6 | Mean age of onset of illness (years) | – | $21.68 \pm 2.36$ |
| 7 | Duration of illness (years) | – | $8.37 \pm 5.6$ |
| 8 | Medications | Nil | 13 Patients on risperidone alone; 2 on depot preparations; 2 on risperidone plus quetiapine; 1 on aripiprazole; 1 on clozapine and 1 on fluoxetine; six patients were taking anticholinergics (Tab trihexyphenidyl 2 mg BD) |

$^a$Independent samples t-test; *$p < 0.05$.
(for more than a month in the last 1 year), all of them were trained by a certified yoga trainer to perform KB till they could perform it correctly (i.e., 120 ± 10 breaths/min for 1 min) and comfortably. The training was given for a period of 10–15 days before the assessments were taken. A chest pressure transducer was used to monitor the frequency and intensity of the practice. Recordings were taken only when the subject performed the practice correctly and comfortably. All subjects gave written informed consent before participating in the present study. The study was approved by the ethics committee of SVYASA University, Bangalore, India.

INIRS DEVICE
The system (FNIR100-ACK-W, BIOPAC Systems, Inc., USA) is a continuous wave device, which measures changes in attenuation at two wavelengths (730 and 850 ± 15 nm), sampling at 25 kHz, and hence allows for the differentiation of two dynamic absorbers (oxyHb and deoxyHb). Equipped with 4 light emitting and 10 detector probes, 16 channels can be measured quasi simultaneously. Concentration changes in oxyHb and deoxyHb were calculated based on a modified Beer–Lambert approach (23). With an optode probe set consisting of 10 photo-detectors and 4 light emitters, 16 channels were measured. The optodes were affixed to a probe set with an inter-optode distance of 2.5 cm covering an area of ~6 cm × 18 cm. The probe set was fastened to the participant’s head by elastic straps. For horizontal fixation, the lower edge of the probe set was fixed 1 cm above the nasion.

PROCEDURE
The participants reported for the assessment at morning 7:00 a.m. on different days. All recordings were taken in empty stomach, in a dark room. The subjects wore a flexible headband over pre-frontal and comfortably. All subjects gave written informed consent before participating in the present study. The study was approved by the ethics committee of SVYASA University, Bangalore, India.

INIRS DEVICE
The system (FNIR100-ACK-W, BIOPAC Systems, Inc., USA) is a continuous wave device, which measures changes in attenuation at two wavelengths (730 and 850 ± 15 nm), sampling at 25 kHz, and hence allows for the differentiation of two dynamic absorbers (oxyHb and deoxyHb). Equipped with 4 light emitting and 10 detector probes, 16 channels can be measured quasi simultaneously. Concentration changes in oxyHb and deoxyHb were calculated based on a modified Beer–Lambert approach (23). With an optode probe set consisting of 10 photo-detectors and 4 light emitters, 16 channels were measured. The optodes were affixed to a probe set with an inter-optode distance of 2.5 cm covering an area of ~6 cm × 18 cm. The probe set was fastened to the participant’s head by elastic straps. For horizontal fixation, the lower edge of the probe set was fixed 1 cm above the nasion.

RESULTS
oxyHb CHANGES
We observed a highly significant increase in bilateral oxyHb (in micromoles per liter) from the baseline during the practice of KB in normal healthy individuals; right side (p = 0.00) and left side (p = 0.00). Whereas, no significant change was found in schizophrenia patients on both the sides; right side (p = 0.92) and left side (p = 0.62) (Table 2; Figures 1–4).

Between group comparisons showed that oxyHb levels were significantly higher in healthy controls as compared to schizophrenia patients.
FIGURE 1 | Oxygenated hemoglobin changes in healthy subjects and schizophrenia patients in left pre-frontal cortex before (pre), during, and after (post) KB practice. Abbreviations: oxyHb, oxygenated hemoglobin; deoxyHb, deoxygenated hemoglobin; totalHb, total hemoglobin; PFC, pre-frontal cortex.

FIGURE 2 | Oxygenated hemoglobin changes in healthy subjects and schizophrenia patients in right pre-frontal cortex before (pre), during, and after (post) KB practice. Abbreviations: oxyHb, oxygenated hemoglobin; deoxyHb, deoxygenated hemoglobin; totalHb, total hemoglobin; PFC, pre-frontal cortex.

patients during the practice of KB on both the sides; right side \( p = 0.01 \) and left side \( p = 0.03 \) (Table 3).

deoxyHb CHANGES
Schizophrenia patients showed significant reduction in deoxyHb (in micromoles per liter) during the practice of KB in right hemisphere \( p = 0.00 \), whereas healthy comparison subjects showed no significant change \( p = 0.09 \). No change was found in deoxyHb levels on the left side of the brain in both healthy volunteers and schizophrenia patients (Table 2; Figures 3 and 4). Between groups comparison for deoxyHb changes did not show any significant difference between the two groups (control and patient) during the practice of KB (Table 3).

totalHb CHANGES
Significant increase was seen in bilateral blood volume (totalHb in micromoles per liter) from the baseline during the practice of KB in healthy controls; right side \( p = 0.01 \) and left side \( p = 0.00 \). On the contrary, totalHb levels reduced in schizophrenia patients but did not reach the level of significance; right side \( p = 0.06 \) and left side \( p = 0.77 \) (Table 2; Figures 3 and 4).

Between group comparisons showed that totalHb levels were significantly higher in healthy controls as compared to schizophrenia patients during the practice of KB on both the sides; right side \( p = 0.03 \) and left side \( p = 0.04 \) (Table 3).

DISCUSSION
We found that there was a highly significant increase in oxyHb and totalHb in healthy subjects during the practice of KB, which was not observed in schizophrenia patients. Schizophrenia patients showed reduction in deoxyHb in the right PFC within the group \( p = 0.01 \); Table 1 but it was not significant between the groups. Frontal hemodynamic responses of schizophrenia patients to the practice of KB were different as compared to healthy age, gender, and education matched controls. Since, oxyHb is considered as the most sensitive indicator of changes in regional cerebral blood flow in NIRS measurements (26, 27), we observed that schizophrenia patients had significantly lesser PFC activation or blood flow as compared to healthy controls during the practice of KB in terms of oxyHb changes. This suggests that the effect of KB on pre-frontal hemodynamics is similar to that of a cognitive task, which can activate this region of the brain.

Some significant immediate effects of KB practice on frontal hemodynamics in long term yoga practitioners have already been demonstrated recently (13). There was a reduction in bilateral pre-frontal oxyHb and increase in deoxyHb during KB. These findings appear contradictory to what we have found. But our study differs from this study in terms of the experience of the subjects in performing KB as well as the intensity and duration of the KB practice that was administered. Study by Telles et al. (13) involved long term practitioners of KB who had 8–36 months experience of practicing KB whereas in our study we involved KB naïve subjects. Secondly, in the study by Telles et al., KB was practiced at the rate of 60 breaths/min for a total duration of 18 min in three epochs of 5 min separated by a gap of 3 min. And the average of the three epochs was taken to assess the hemodynamic responses during KB. Whereas, we administered KB for the duration of 1 min at double the frequency (120 breaths/min) and took the average of 1 min. Thus, there may be two possible explanations for the contradictory findings in the two studies: (1) subjects who were experts and were practicing KB for a longer duration may have got desensitized to this practice (similar to the practice effect seen with repeated administration of neuro-psychological tests) and thus were more relaxed during the practice thereby showing PFC deactivation instead of activation, whereas those who are performing this breathing for the first time may still remain sensitive; (2) the intensity of practice given by Telles et al. (13) was not sufficient to produce PFC activation. Pre-frontal hemodynamic responses may have a threshold below which PFC activation may not take place and this threshold may be somewhere between 60 and 120 breaths/min. In future studies, it would be interesting to
Frontal hemodynamic responses to yoga breathing

Assess hemodynamic responses in KB naïve subjects with gradually increasing dosage (rate of breathing) of KB and try to generate a dose–response curve along with the threshold point in oxyHb and total Hb levels.

Detailed mechanism as to how the practice of KB affects frontal hemodynamics and why schizophrenia patients respond differently from healthy subjects are yet to be understood, but as it is known that PFCs are involved in the pathology of schizophrenia (14), we may hypothesize that because of the abnormality in PFCs, schizophrenia patients have responded differently. All schizophrenia patients were taking antipsychotic medications, which make it difficult to disentangle drug effects from disease effects. A review suggested that treatment with antipsychotic medication seemed to normalize brain function and to make the brain function of schizophrenia patients more similar to that of healthy individuals (21). Therefore, the results of our study may be more because of this disease rather than the medication, although we cannot eliminate completely the medication effects. Future studies with drug naïve patients are required to discard the medication effects and confirm the findings of this study. In future studies, it would be interesting to assess and compare the hemodynamic responses to KB in patients suffering from other neuro-psychiatric disorders where PFCs are reported to be involved.

In the present study, we believe that the performance of KB practice by schizophrenia patients was comparable to healthy controls because, first, the practice was monitored objectively using a chest pressure transducer for the frequency and depth, and secondly, the patients have been adequately trained by a certified trainer and the recordings were taken only when the trainer was satisfied that the schizophrenia patients performed the practice well enough to match healthy controls. Those patients who could perform the practice as per the standards were only selected in the study. Thus, assuming that schizophrenia patients performed KB as correctly as the healthy controls, we found that the increase in frontal lobe circulation during KB is not seen in schizophrenia patients, which means that the effects of KB such as increased attention and relaxation at the subjective level (7, 8) may be lesser in schizophrenia patients as compared to healthy individuals, which we did not check in the present study. We should have assessed immediate effect of KB practice on clinical parameters and cognitive performance in schizophrenia patients simultaneously, which we plan to do in our future studies. Secondly, because of the limited number of channels, the area of measurement in NIRS was restricted to the PFC. Simultaneous measurements by NIRS and other neuro-imaging methodologies

Table 3 | Means and standard deviations of frontal hemodynamic responses in patients and controls during KB practice.

| Variable   | Side | Patient (mean ± SD) | Control (mean ± SD) | Effect size | p Value |
|------------|------|---------------------|---------------------|-------------|---------|
| oxyHb      | Left | 1.48 ± 8.62         | 9.87 ± 11.04        | 0.84        | 0.03*   |
|            | Right| 0.72 ± 5.20         | 12.48 ± 17.29       | 1.03        | 0.01*   |
| deoxyHb    | Left | 0.69 ± 11.32        | -2.76 ± 7.79        | 0.21        | 0.57    |
|            | Right| -3.29 ± 4.40        | -4.32 ± 8.12        | 0.15        | 0.69    |
| totalHb    | Left | -0.38 ± 13.40       | 8.10 ± 11.07        | 0.69        | 0.04*   |
|            | Right| 4.02 ± 5.15         | 8.16 ± 17.75        | 0.93        | 0.03*   |

oxygenated hemoglobin; deoxyHb, deoxygenated hemoglobin; totalHb, total hemoglobin.

*Independent samples t-test; *p < 0.05.
might be used to clarify the association of the PFC with other brain regions (27).

Future studies should perform a diagnostic validity of KB technique in cases of schizophrenia. Future studies should also check whether KB practice performed over a longer duration can modify pre-frontal hemodynamic responses in schizophrenia patients and whether this modification correlates with the clinical outcome.

CONCLUSION

This study uses fNIRS to demonstrate that schizophrenia patients differ significantly from healthy individuals in terms of their bilateral pre-frontal hemodynamic responses to Kapalabhati kriya. Healthy individuals show significantly greater activation and schizophrenia patients show relative hypo-activation of bilateral PFCs during KB. KB practice may serve as a potential diagnostic tool to assess pre-frontal hemodynamic responses. Future studies should assess diagnostic validity of KB in schizophrenia patients.

ACKNOWLEDGMENTS

We thank all subjects who participated in the study. Further, we would like to thank Deepeshwar Singh and Varsha C. Shekhar for supporting fNIRS technicalities.

REFERENCES

1. Bhole MV. Study of respiratory functions during kapalabhati – part I. Yoga Rev (1982) 2(4):211–22.
2. Stancák A Jr, Kuna M, Srinivasan MA, Dostálek C, Vishnudevananda S. Kapalabhati – yoga cleansing exercise. II. EEG topography analysis. Homeost Health Dis (1991) 33(4):182–9.
3. Desai BP, Gharote ML. Effect of kapalabhati on blood urea, creatinine, and tyrosine. Act Nerv Super (Praga) (1990) 32(2):95–8.
4. Stancák A Jr, Kuna M, Srinivasan MA, Vishnudevananda S, Dostálek C. kapalabhati – yoga cleansing exercise. I. Cardiovascular and respiratory changes. Homeost Health Dis (1991) 33(3):126–34.
5. Boldan E, J. Los, Dostálek C. Frequency characteristics, distribution and dominance of EEG during rest and yogic breathing exercise – kapalabhati. Act Nerv Super (Praga) (1983) 25:197.
6. Niranjanandana SS. Prana, Pranayama Pranavidyada. Munger: Yoga Publication Trust (2002).
7. Telles S, Raghuraj P, Maharana S, Nagendra HR. Immediate effect of three yoga breathing techniques on performance on a letter cancellation task. Percept Mot Skills (2007) 104(3 Pt 2):1289–96. doi:10.2466/pms.104.1289-1296.
8. Joshi M, Telles S. A non randomized non-naive comparative study of the effects of kapalabhati and breath awareness on event-related potentials in trained yoga practitioners. J Altern Complement Med (2009) 15(3):281–5. doi:10.1089/acm.2008.0250.
9. Kuvaylananda S. Kapalabhati. Yoga Mimamsa (1930) 4(2):161–78.
10. Jobis FF. Noninvasive infrared monitoring of cerebral and myocardial oxygen sufficiency and circulatory parameters. Science (1977) 198(4323):1264–7. doi:10.1126/science.929199.
11. Obrig H, Villringer A. Beyond the visible – imaging the human brain with light. J Cereb Blood Flow Metab (2003) 23(1):1–18. doi:10.1097/00004467-200301000-00001.
12. Fuster JM. Executive frontal functions. Exp Brain Res (2000) 133:66–70. doi:10.1007/s002210000401.
13. Telles S, Singh N, Gupta RK, Balkrishna A. Optical topography recording of cortical activity during high frequency yoga breathing and breath awareness. Comment to: non-invasive assessment of hemispheric language dominance by optical topography during a brief passive listening test: a pilot study. Stefano Bembich, Sergio Demarini, Andrea Clarici, Stefano Massaccesi, Domenico Grasso. Med Sci Monit 2011;17(12):CR692-697. Med Sci Monit (2012) 18:LE3–4.
14. Fallgatter AJ, Werner KS. Reduced frontal functional asymmetry in schizophrenia during a cued continuous performance test assessed with near-infrared spectroscopy, Schizophr Bull (2000) 26(4):913–9. doi:10.1093/schbul.a033505.
15. Shinba T, Nagano M, Kariya N, Ogawa K, Shinozaki T, Shimosato S, et al. Near-infrared spectroscopy analysis of frontal lobe dysfunction in schizophrenia. Biol Psychiatry (2004) 58(5):154–64. doi:10.1016/S0006-3223(03)00547-X.
16. Zhu Y, Liu X, Wang J, Jiang D, Fang Y, Hua H, et al. Reduced pre-frontal activation during tower of London in first episode schizophrenia: a multi-channel near infrared spectroscopy study. Neurosci Lett (2010) 487(3):136–40. doi:10.1016/j.neulet.2010.05.003.
17. Penades R, Boget T, Lomena R, Mateos JJ, Catalan R, Gasto C, et al. Could the hypofrontality pattern in schizophrenia be modified through neuropsychological rehabilitation? Acta Psychiatr Scand (2002) 105(3):202–8. doi:10.1034/j.1600-0447.2002.0421.x.
18. Houghton K, Phyepstone B, Soper N, Renzlek I. Single photon emission computed tomography (SPECT) in schizophrenia. Br J Psychiatry (1990) 156:425–7. doi:10.1192/bjp.156.3.425.
19. Chen RY, Chen E, Ho WY. A five-year longitudinal study of the regional cerebral metabolic changes of a schizophrenic patient from the first episode using Tc-99m HMPAO SPECT. Eur Arch Psychiatry Clin Neurosci (2000) 250(2):69–72. doi:10.1007/s0040600070136.
20. Miller DD, Andreasen NC, O’Leary DS, Watkins GL, Boles P, Lichwa RD. Comparison of the effects of risperidone and haloperidol on regional cerebral blood flow in schizophrenia. Biol Psychiatry (2001) 49(8):704–15. doi:10.1016/S0006-3223(00)01001-5.
21. Davis CE, Jeste DV, Eyles LT. Review of longitudinal functional neuroimaging studies of drug treatments in patients with schizophrenia. Schizophren Res (2005) 78(1):45–60. doi:10.1016/j.schres.2005.05.009.
22. Woods SW. Chlorpromazine equivalent doses for the newer atypical antipsychotics. J Clin Psychiatry (2003) 64(6):668–7. doi:10.4088/JCP.v64n0607.
23. Hoshi Y, Tamura M. Dynamic multichannel near-infrared optical imaging of human brain activity. J Appl Physiol (1993) 75(4):1842–6.
24. Faul F, Erdfelder E, Buchner A, Lang AG. Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. Behav Res Methods (2009) 41(4):1149–60. doi:10.3758/BRM.41.4.1149.
25. Ehlis AC, Herrmann MJ, Plichta MM, Fallgatter AJ. Cortical activation during two verbal fluency tasks in schizophrenic patients and healthy controls as assessed by multi-channel near-infrared spectroscopy. Psychiatry Res (2007) 156(1):1–13. doi:10.1016/j-psychres.2006.11.007.
26. Hoshi Y, Kobyayashi N, Tamura M. Interpretation of near-infrared spectroscopy signals: a study with a newly developed perfused rat brain model. J Appl Physiol (2001) 90(5):1657–62.
27. Kleinschmidt A, Obrig H, Requardt M, Merboldt KD, Dernagi U, Villringer A, et al. Simultaneous recording of cerebral blood oxygenation changes during human brain activation by magnetic resonance imaging and near-infrared spectroscopy. J Cereb Blood Flow Metab (1996) 16(5):817–26. doi:10.1097/00004467-199605000-00006.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 31 January 2014; accepted: 08 March 2014; published online: 24 March 2014. Citation: Bhargav H, Nagendra HR, Gangadhar BN and Nagarathna R (2014) Frontal hemodynamic responses to yoga breathing. Frontiers in Psychiatry | Affective Disorders and Psychosomatic Research. March 2014 | Volume 5 | Article 29 | 6.