Appl Psychophysiol Biofeedback
DOI 10.1007/s10484-008-9055-0

Immediate Effect of Specific Nostril Manipulating Yoga Breathing Practices on Autonomic and Respiratory Variables

P. Raghuraj · Shirley Telles

Abstract The effect of right, left, and alternate nostril yoga breathing (i.e., RNYB, LNYB, and ANYB, respectively) were compared with breath awareness (BAW) and normal breathing (CTL). Autonomic and respiratory variables were studied in 21 male volunteers with ages between 18 and 45 years and experience in the yoga breathing practices between 3 and 48 months. Subjects were assessed in five experimental sessions on five separate days. The sessions were in fixed possible sequences and subjects were assigned to a sequence randomly. Each session was for 40 min; 30 min for the breathing practice, preceded and followed by 5 min of quiet sitting. Assessments included heart rate variability, skin conductance, finger plethysmogram amplitude, breath rate, and blood pressure. Following RNYB there was a significant increase in systolic, diastolic and mean pressure. In contrast, the systolic and diastolic pressure decreased after ANYB and the systolic and mean pressure were lower after LNYB. Hence, unilateral nostril yoga breathing practices appear to influence the blood pressure in different ways. These effects suggest possible therapeutic applications.

Keywords Right nostril yoga breathing · Left nostril yoga breathing · Alternate nostril yoga breathing · Unilateral nostril yoga breathing · Autonomic and respiratory variables

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Introduction

In 1895 Kayser first described 'changes in the amount of blood flowing through the cavernous tissues of the nasal conchae'. This has come to be called the nasal cycle. The cycle was considered an ultradian rhythm during which the patency and efficiency of the right and left nostrils changed alternately with varying periodicity (Stoksted 1953). However the earlier accepted view that 80% of healthy individuals have a regular nasal cycle was re-examined by a study which used numerical measures of reciprocity and quantified the division of airflow between the nasal passages over time (Flanagan and Eccles 1997). Hourly measurements of unilateral nasal airflow were made for 8 h in 52 volunteers. A numerical definition of the nasal cycle was derived based on (i) the correlation between unilateral airflows and (ii) an airflow distribution ratio between the two nasal airways. Only 11 of the 52 volunteers had patterns of nasal airflow which met this definition. This was 21% of the volunteers studied. This suggested that earlier descriptions of the nasal cycle as being a regular cyclical phenomenon in most healthy individuals required further understanding.

In a different kind of investigation, the time periods of multiple systems during sleep and waking rest were studied in three healthy adults, assessing ten variables which included the nasal cycle (Shannahoff-Khalsa and Yates 2000). Time series analysis detected periods at 115–145, 70–100 and 40–65 min across all variables. Hence at present the concept of spontaneous changes in nasal patency in humans remains a possibility, though the physiological mechanisms underlying this cycle are not clear (Okhi et al. 2005). It is recognized that nasal blood vessels influence nasal airflow and hence nasal airflow is regulated by autonomic and central controls (Eccles 2000).

This is related to the fact that sympathetic nerves supplying the nose are regulated by the hypothalamus and vasomotor areas of the brainstem. Despite this need for clarity in understanding the nasal cycle there is an interest in understanding the physiological changes associated with spontaneous changes in nasal patency and those associated with unilateral forced nostril breathing.

For example unilateral forced nostril breathing (UFNB) through the right nostril significantly increased blood glucose while left nostril breathing lowered it (Backon 1988). In a single subject it was seen that right UFNB reduced the involuntary blink rate whereas left UFNB increased involuntary blink rates (Backon and Kullock 1989). Also, right UFNB decreased the intraocular pressure whereas left UFNB increased it.

These findings suggested that right unilateral forced nostril breathing is associated with a generalized increase in sympathetic tone, and can hence be correlated with the 'active phase' of the basic rest activity cycle (Werntz et al. 1983). Another study examined the effects of UFNB on the functioning of the heart (Shannahoff-Khalsa and Kennedy 1993). This involved three experiments. For two of them the subjects breathed at the rate of 6 breaths per minute and for the third their breath rate was rapid (i.e., 2–3 breaths/s). Using impedance cardiography it was shown that at a breath rate of 6 per minute, right UFNB increased the heart rate compared to left UFNB, which lowered the heart rate. Also the stroke volume was higher with left UFNB and left UFNB also increased the end diastolic volume.

Apart from the lateralized effects on the autonomic nervous system, recordings of the electroencephalogram (EEG) suggested that nasal patency was inversely coupled to alternating dominance of activity in the two cerebral hemispheres, mediated through the autonomic nervous system (Werntz et al. 1983). However this was not seen in another study. In ten untrained subjects nasal decongestion was altered by having the subjects lie in the lateral recumbent position, occluding the contralateral nostril (Velikonja et al. 1993). Cortical activation and laterality were estimated based on ratios of low beta and high alpha bandwidths, relative to each other and between hemispheres. The study did not support the hypothesis of hemispheric activation correlated with nasal patency in subjects untrained in breathing techniques. Similarly, as for unilateral forced nostril breathing, a study on the immediate effects of uninostril yoga breathing related to the performance in a hemisphere-specific task, also did not support the description of nasal patency being coupled with lateralization of cerebral function. Hence the effects of nostril patency on cerebral hemispheric activation remain unresolved.

In addition to spontaneous shifts in nostril patency and unilateral forced nostril breathing, changes in nostril patency have been induced through yoga practice. The ancient Indian science of Yoga uses voluntary regulation of the breathing to make breathing rhythmic, facilitate relaxation and induce a state of mental calmness (Swami Vivekananda 1973). Some of these breathing techniques involve inhalation and exhalation through one nostril selectively (Swami Muktibodhananda 1999). These yoga breathing techniques allow the effects of selective nostril breathing to be studied, when carried out presumably without effort, for specified periods.

One month of right nostril yoga breathing practiced for a few minutes at a time, four times a day, increased the baseline oxygen consumption by 37% (Telles et al. 1994). Left nostril yoga breathing and alternate nostril yoga breathing also increased baseline oxygen consumption, but the magnitude of change was lesser than for right nostril yoga breathing (i.e., 24 and 18%, respectively). Left nostril yoga breathing also increased the volar galvanic skin resistance (suggestive of a decrease in sympathetic activity). The immediate effects of 45 min of right nostril yoga breathing were compared to those of an equal duration of normal breathing, in another study (Telles et al. 1996). Right nostril yoga breathing increased systolic blood pressure by 9.4 mm Hg, increased oxygen consumption by 17%, and decreased digit pulse volume (suggestive of an increase in vasomotor sympathetic activity) by 45%.

There has been no study comparing the immediate effects of right, left and alternate nostril yoga breathing practiced by the same individuals on different occasions. Hence, the present study was planned to study the effects of these three yoga breathing practices, compared to breath awareness and normal breathing, on autonomic and respiratory variables in normal volunteers.

Methods

Participants

Twenty-one male volunteers with ages ranging between 18 to 45 years (group mean ± *SD*, 27.5 ± 6.3 years) participated in the study. Autonomic and respiratory variables have been shown to vary with the phases of the menstrual cycle (Yildirir et al. 2002), hence the study was restricted to males. The participants were undergoing training at a yoga center. They had experience of practicing the three yoga breathing techniques (i.e., right nostril yoga breathing, left nostril yoga breathing and alternate nostril yoga breathing) ranging between 3 and 48 months (group mean ± *SD*, 14.6 ± 10.7 months). All of them had completed a residential training course in yoga which was for 3 months During the three months the training was intensive, i.e., for 8 h each day and included training in yoga postures (*asanas*), voluntarily regulated breathing (*pranayamas*), meditation, and yoga philosophy. It also included the practice of the yoga breathing techniques mentioned here (viz., RNYB, LNYB, ANYB and BAW), as well as instruction on the theory of yoga breathing and descriptions from traditional texts about the effects of the practices based on experiences of yoga practitioners. The 3 month training also included a single session of 60 min of theory on the physiological effects of different yoga practices citing published research.

Following the 3 months of intensive training participants continued to stay at the yoga center to receive training in philosophical aspects of yoga. They continued to practice yoga unsupervised and reported practicing yoga breathing practices other than those reported here for approximately 10 min a day, at least 3 times in a week. In addition to this all the participants included in the study were given a month of training in the breathing practices assessed in the present study for 30 min each day for a month before the study began as a refresher course. This one month of supervised practice was to attempt to reduce the differences between subjects due to their wide range of experience in yoga practice.

All of them were in normal health based on a routine clinical examination and none of them had a history of smoking or respiratory ailments including nasopharyngeal abnormalities. They were all right handed dominant based on their response to the Edinburgh handedness inventory (Oldfield 1971). Handedness was assessed as there is a report supporting a handedness by nostril interaction (Searleman et al. 2005). Also none of them were taking medication and they did not use any other wellness strategy. The variables to be recorded and the study design were described to the participants after which their signed consent to participate in the study was obtained. None of them was aware of the hypothesis of the study. The project had the approval of the Institutional Review Board.

Design

The participants were assigned to five sessions as five possible sequences. These were (i) Sequence 1: right nostril yoga breathing, left nostril yoga breathing, alternate nostril yoga breathing, breath awareness, and normal breathing; (ii) Sequence 2: left nostril yoga breathing, alternate nostril yoga breathing, breath awareness, normal breathing, and right nostril yoga breathing; (iii) Sequence 3: alternate nostril yoga breathing, breath awareness, normal breathing, right nostril yoga breathing, and left nostril yoga breathing; (iv) Sequence 4: breath awareness, normal breathing, right nostril yoga breathing, left nostril yoga breathing, and alternate nostril yoga breathing, and (v) Sequence 5: normal breathing, right nostril yoga breathing, left nostril yoga breathing, alternate nostril breathing, and breath awareness.

For each sequence the five sessions (of 40 min each) were conducted on five different days. Each 40 min session consisted of 30 min during which subjects practiced any one of the four breathing techniques (RNYB, LNYB, ANYB, and BAW) or did not do any breath manipulation (in the control session). The 30 min period was preceded and followed by 5 min periods which were 'rest periods' without breath manipulation. Hence each subject had a 40 min session each day. This was for 5 days keeping the time of the day constant for each subject. In the 30 min segments during which subjects practiced different breathing techniques, there were four 7.5 min epochs.

Participants were randomly assigned to these five possible sequences using a random number table. Hence, each participant was assessed in five sessions on five different days at the same time of the day, with the assignment of participants to different session-sequences being random. Assessments were done throughout a session. HRV data were recorded in Epoch 3 and Epoch 4, each of 7.5 min duration. Five minutes of each epoch were analyzed for HRV. In each epoch of 7.5 min, HRV data were recorded in the last 5 min, hence the first 2.5 min of each epoch were not included for analysis. Each session lasted for 40 min of which 30 min was spent in the respective breathing practices, preceded and followed by 5 min of sitting quiet. This 30-min 'during' period was considered as four epochs (Epoch 1–4), of 7 min 30 s each. The assessments' schedule during a session has been presented schematically in Fig. 1.

Assessments

Autonomic and respiratory variables were acquired using a four channel polygraph (Medicaid, Chandigarh, India). The EKG was acquired using Ag/AgCl electrodes with conducting gel (Electrode Gel, Medicaid Systems, Chandigarh, India), fixed at mid-clavicular points bilaterally and with a third electrode 1 cm above the left lower costal margin. These three positions were selected to simulate standard electrode positions to record the three limb leads with minimal risk of movement artifact (Thakur and Webster 1985). This precaution was needed as participants used their right hand to manipulate the nostrils. The EKG was digitized using a 12 bit analog-to-digital converter (ADC) at a sampling rate of 1,024 Hz and was analyzed off-line to obtain the heart rate variability (HRV) spectrum. The skin conductance level was recorded with two contoured silver electrodes in contact with the volar pads of the distal phalanges of the index and middle fingers of the left hand. Using a low level DC amplifier a current of 0.5 V was passed through the electrodes. The finger plethysmogram was recorded using a photoelectric transducer kept at the base of the nail of the left thumb. The respiration was

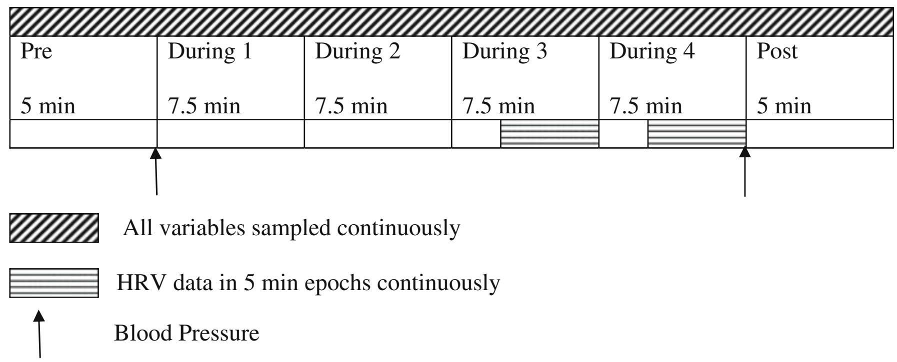

Fig. 1 Schematic presentation of the timing of assessments during a session

recorded using a stethograph connected to an AC amplifier and fixed around the trunk approximately 8 cm below the lower costal margin as the participants sat erect (Telles et al. 1996). The blood pressure was recorded before and after each session with a standard mercury sphygmomanometer, auscultating over the right brachial artery. The diastolic pressure was noted as the reading at which the Korotkoff sounds appeared muffled. The mean pressure was derived as follows: mean pressure = diastolic pressure + 1/3 X Pulse pressure, where the pulse pressure is the difference between the systolic and diastolic pressure (Ganong 1999).

Yoga Breathing Practices

There were three yoga breathing (*pranayama*) sessions and two control sessions one of breath awareness (BAW) and the other of normal breathing (CTL) given to each subject. The sessions were for 30 min on five separate days at the same time of the day. The five practices are described below. (1) Right nostril yoga breathing (RNYB) or *Suryanuloma viloma pranayama* practice involves breathing exclusively in and out through the right nostril while the left nostril is gently occluded. (2) Left nostril yoga breathing (LNYB) or *Chandra anuloma viloma pranayama* practice involves breathing through the left nostril exclusively while the right nostril is occluded. (3) Alternate nostril yoga breathing (ANYB) or *Nadisuddhi pranayama* practice involves breathing through left and right nostrils alternately. Throughout these practices the awareness is directed to the breath and breathing. During breath awareness, the participants maintained awareness of the breath without manipulation of the nostrils (Visweswaraiah and Telles 2004). During the normal breathing session the participants sat at ease without specific instructions about their breathing. In the three nostril manipulating *pranayamas* the thumb and the ring finger of the right hand were used to manipulate or occlude the nostrils. This is a characteristic yoga gesture (*nasika mudra* in Sanskrit) prescribed during *pranayama* practice to manipulate the nostrils with ease (Swami Niranjananda Saraswathi 1994). During the different practices (except for the normal breathing session) the participants were asked to remain in a mental state characterized by relaxation and internal awareness. This is the mental state adopted during meditation and voluntary regulated yoga breathing (*pranayama*). Also, the participants' attention was directed to the movement of air into and out of their nostrils. They also attempted to be aware of the air as it moved through their nasal passage.

Data Extraction

The following data were extracted from the polygraph records. The heart rate in beats per minute (bpm) was obtained by continuously counting the QRS complexes in successive 60 s periods. The breath rate (in cycles per minute) was calculated by counting the breath cycles in 60 s epochs, continuously. The skin conductance level (in micro Siemens) and finger plethysmogram amplitude (in cm) were sampled at 30 s intervals.

Frequency domain analysis of the heart rate variability data was carried out for 5 min recordings, in the following 5-min epochs for each of the five sessions: pre, epoch 3 (E3), epoch 4 (E4), and post. The EKG data were visually inspected offline and those EKG records which had artifacts were not included for analysis. In the records of eight participants the EKG record in the first during state (i.e., 'epoch 1') had muscle artifact. This was also seen in the second during state (i.e., 'epoch 2' in another three subjects. The third and fourth during states (i.e., 'epoch 3' and 'epoch 4') were noise-free in all subjects and hence were used for analysis. Fourier analysis of the R-R interval series was done using the HRV analysis software version 1.1 developed by the Biomedical Signal Analysis Group, University of Kuopio, Finland (Niskanen et al. 2004).

Hence, the HRV was sampled in two 'during' epochs, i.e., E3 and E4. The energy in the HRV series in the following specific frequency bands was studied viz., the very low frequency band (0.0–0.05 Hz), low frequency band (0.05–0.15 Hz), and high frequency band (0.15–0.50 Hz). The low frequency and high frequency band values were expressed as normalized units (Task force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology 1996).

Data Analysis

Statistical analysis was done using SPSS (Version 10.0) package. Repeated measures analyses of variance (ANOVA) were performed with two Within Subjects factors, i.e., (i) Sessions with five levels; right nostril yoga breathing, left nostril yoga breathing, alternate nostril yoga breathing, breath awareness, and normal breathing and (ii) States with six levels; i.e., pre, epoch 1 (E1), epoch 2 (E2), epoch 3 (E3), epoch 4 (E4), and post. For variables such as low frequency (LF) power, high frequency (HF) power and LF/HF ratio of the HRV spectrum the Within Subjects factor (States) had four levels; i.e., pre, epoch 3 (E3), epoch 4 (E4) and post. For systolic blood pressure, diastolic pressure and mean pressure the Within Subjects factor (States) had two levels; i.e., pre and post.

Post-hoc tests with Bonferroni adjustment for multiple comparisons were used to detect significant differences between mean values.

Results

The groups mean values ± *SD* for heart rate, skin conductance level, finger plethysmogram amplitude and breath rate for all five sessions are given in Table 1. The groups mean values ± *SD* for low frequency (LF) power, high frequency (HF) power, and ratio of low frequency to high frequency (LF/HF) power for all five sessions are given in Table 2, and for systolic blood pressure, diastolic blood pressure and mean pressure for all five sessions are given in Table 3. In addition, for greater clarity the HRV (along with breath rate data for comparison) are provided as line graphs in Fig. 2 and the systolic, diastolic and mean pressure values are given as bar graphs in Fig. 3.

There was a significant difference between Sessions for (i) heart rate [$F = 3.47$, for $df = 3.74, 74.74$, $p < .05$, Huynh-Feldt $\varepsilon = .934$]; (ii) breath rate [$F = 16.70$, for $df = 3.30, 66.02$, $p < .001$, Huynh-Feldt $\varepsilon = .825$]; (iii) systolic blood pressure [$F = 11.93$, for $df = 3.39, 67.74$, $p < .001$, Huynh-Feldt $\varepsilon = .847$]; (iv) diastolic blood pressure [$F = 5.21$, for $df = 3.04, 60.77$, $p < .01$, Huynh-Feldt $\varepsilon = .760$]; and (v) mean pressure [$F = 9.98$, for $df = 3.41, 68.18$, $p < .001$, Huynh-Feldt $\varepsilon = .852$].

Table 1 Heart rate, skin conductance level, finger plethysmogram amplitude and breath rate in all five sessions

Variables	Sessions	States					
		Pre	Epoch 1	Epoch 2	Epoch 3	Epoch 4	Post
Heart rate (bpm)	RNYB	74.20 ± 9.69	76.85 ± 9.51	77.01 ± 10.55	78.18 ± 9.83	77.87 ± 9.52	77.20 ± 11.04
	LNYB	73.50 ± 8.25	75.66 ± 8.16	76.60 ± 8.45	77.19 ± 8.75	76.90 ± 8.75	77.76 ± 11.05*
	ANYB	75.78 ± 9.11	78.96 ± 9.55**	79.67 ± 8.77***	78.89 ± 12.54	80.51 ± 9.36**	80.61 ± 10.61*
	BAW	72.98 ± 9.01	71.07 ± 7.12	72.84 ± 8.01	73.02 ± 8.02	73.52 ± 7.97	74.98 ± 8.12
	CTL	78.13 ± 8.48	74.36 ± 7.53	74.27 ± 7.65	75.50 ± 7.63	75.68 ± 7.92	77.30 ± 7.35
Skin conductance level (μS)	RNYB	1.58 ± 1.89	2.08 ± 2.23	2.34 ± 2.40	2.35 ± 2.43	2.43 ± 2.44	2.74 ± 2.85*
	LNYB	2.89 ± 3.29	2.56 ± 2.71	2.00 ± 2.39	2.30 ± 2.61	2.40 ± 2.59	2.66 ± 2.97
	ANYB	1.85 ± 2.47	2.32 ± 2.86	2.55 ± 2.88	2.59 ± 2.80	2.79 ± 2.93	3.11 ± 2.85*
	BAW	1.18 ± 1.43	1.26 ± 1.42	1.21 ± 1.47	1.30 ± 1.67	1.35 ± 1.67	1.62 ± 1.82
	CTL	1.57 ± 2.03	1.44 ± 1.89	1.54 ± 2.14	1.49 ± 1.98	1.71 ± 2.44	1.87 ± 2.68
Finger plethysmogram amplitude (cm)	RNYB	0.59 ± 0.29	0.46 ± 0.22*	0.45 ± 0.22	0.41 ± 0.19*	0.38 ± 0.20**	0.33 ± 0.14***
	LNYB	0.59 ± 0.31	0.56 ± 0.30	0.50 ± 0.24	0.46 ± 0.22	0.51 ± 0.28	0.48 ± 0.29
	ANYB	0.53 ± 0.29	0.47 ± 0.25	0.49 ± 0.24	0.42 ± 0.22	0.38 ± 0.17*	0.41 ± 0.21
	BAW	0.66 ± 0.31	0.56 ± 0.31	0.48 ± 0.25***	0.49 ± 0.38	0.46 ± 0.31*	0.36 ± 0.18***
	CTL	0.67 ± 0.41	0.57 ± 0.30	0.53 ± 0.28*	0.51 ± 0.26*	0.43 ± 0.25**	0.43 ± 0.23*
Breath rate (cpm)	RNYB	17.28 ± 2.85	12.29 ± 4.94**	12.41 ± 5.55**	12.23 ± 5.04***	12.07 ± 4.99***	16.03 ± 3.86
	LNYB	17.02 ± 3.21	11.11 ± 4.93**	11.39 ± 5.28**	11.71 ± 5.51**	11.85 ± 5.45**	15.67 ± 3.85
	ANYB	17.19 ± 4.04	9.08 ± 3.09***	9.33 ± 2.86***	9.45 ± 3.52***	9.49 ± 3.21*	13.98 ± 4.73*
	BAW	16.45 ± 3.69	16.26 ± 3.37	16.32 ± 3.63	16.25 ± 3.73	16.10 ± 4.02	15.90 ± 3.54
	CTL	16.75 ± 3.79	16.95 ± 3.79	17.14 ± 3.63	16.97 ± 3.87	17.00 ± 3.69	16.83 ± 3.97

Values are group mean ± *SD*

* $p < .05$, ** $p < .01$, *** $p < .001$, post-hoc tests with Bonferroni adjustment, compared with respective 'Pre' values

Table 2 LF power, HF power, LF/HF ratio of the HRV spectrum in all five sessions

Variables	Sessions	States			
		Pre	Epoch 3	Epoch 4	Post
Low frequency (LF) power (n.u.)	RNYB	39.87 ± 6.18	45.22 ± 9.88	44.38 ± 11.68	40.21 ± 10.18
	LNYB	39.94 ± 3.19	43.42 ± 8.85	40.74 ± 7.13	39.82 ± 8.62
	ANYB	40.07 ± 5.66	45.23 ± 11.37	47.23 ± 10.57*	41.56 ± 8.50
	BAW	40.57 ± 5.02	43.03 ± 6.91	38.88 ± 8.39	42.04 ± 7.19
	CTL	40.49 ± 14.27	38.43 ± 6.46	41.62 ± 9.38	41.64 ± 10.23
High frequency (HF) power (n.u.)	RNYB	60.15 ± 6.15	56.49 ± 10.72	58.52 ± 8.28	59.84 ± 10.11
	LNYB	61.12 ± 9.49	55.26 ± 8.98	54.94 ± 7.96	59.30 ± 8.38
	ANYB	59.93 ± 5.66	56.35 ± 15.13	52.01 ± 12.93*	58.44 ± 8.50
	BAW	59.73 ± 5.37	57.77 ± 7.65	59.15 ± 10.92	57.89 ± 7.20
	CTL	62.01 ± 7.53	61.13 ± 6.63	58.82 ± 9.95	58.36 ± 10.23
LF/HF ratio	RNYB	0.67 ± 0.18	0.83 ± 0.36	0.74 ± 0.28	0.74 ± 0.45
	LNYB	0.68 ± 0.37	0.86 ± 0.32	0.85 ± 0.27	0.70 ± 0.28
	ANYB	0.68 ± 0.17	0.77 ± 0.38	1.11 ± 0.64*	0.73 ± 0.32
	BAW	0.69 ± 0.16	0.76 ± 0.25	0.77 ± 0.47	0.76 ± 0.25
	CTL	0.64 ± 0.22	0.66 ± 0.19	0.77 ± 0.43	0.78 ± 0.39

Values are group mean ± *SD*

* $p < .05$, post-hoc tests with Bonferroni adjustment, compared with respective 'Pre' values

Table 3 Systolic and diastolic blood pressure and mean pressure in all five sessions

Variables	Sessions	States	
		Pre	Post
Systolic blood pressure (mm Hg)	RNYB	110.57 ± 6.52	116.67 ± 5.41***
	LNYB	110.38 ± 6.53	106.19 ± 6.51**
	ANYB	109.81 ± 6.19	108.67 ± 6.43*
	BAW	111.33 ± 5.88	111.24 ± 6.23
	CTL	112.48 ± 6.84	112.19 ± 6.60
Diastolic blood pressure (mm Hg)	RNYB	72.67 ± 5.30	76.00 ± 5.02***
	LNYB	72.76 ± 4.88	71.62 ± 4.67
	ANYB	73.05 ± 4.27	72.38 ± 3.98*
	BAW	72.67 ± 4.49	72.48 ± 4.51
	CTL	73.05 ± 4.59	72.19 ± 4.47*
Mean pressure (mm Hg)	RNYB	85.30 ± 5.31	89.42 ± 4.63**
	LNYB	85.30 ± 4.87	83.14 ± 4.64**
	ANYB	85.30 ± 4.29	84.47 ± 4.26
	BAW	85.55 ± 4.36	85.39 ± 4.47
	CTL	86.19 ± 4.86	85.52 ± 4.71*

Values are group mean ± *SD*

* $p < .05$, ** $p < .01$, *** $p < .001$, post-hoc tests with Bonferroni adjustment, compared with respective 'Pre' values

There was a significant difference between States for (i) heart rate [$F = 9.59$, for $df = 3.35, 67.13$, $p < .001$, Huynh-Feldt $\varepsilon = .671$]; (ii) skin conductance level [$F = 7.65$, for $df = 56.62$, $p < .001$, Huynh-Feldt $\varepsilon = .566$]; (iii) finger plethysmogram amplitude [$F = 20.04$, for $df = 78.59$, $p < .001$, Huynh-Feldt $\varepsilon = .547$]; (iv) breath rate [$F = 37.69$, for $df = 2.74, 54.69$, $p < .001$, Huynh-Feldt $\varepsilon = .547$; (v) LF power [$F = 3.81$, for $df = 53.32$, $p < .05$, Huynh-Feldt $\varepsilon = .935$]; (vi) HF power [$F = 4.31$, for $df = 57.00$, $p < .01$]; (iv) LF/HF ratio [$F = 5.63$, for $df = 46.64$, $p < .01$, Huynh-Feldt $\varepsilon = .815$].

There was a significant interaction between Sessions and States for (i) skin conductance level [$F = 2.25$, for $df = 5.80, 116.01$, $p < .05$, Huynh-Feldt $\varepsilon = .290$]; (ii) breath rate [$F = 11.09$, for $df = 7.84, 156.82$, $p < .001$, Huynh-Feldt $\varepsilon = .392$]; (iii) systolic blood pressure [$F = 40.12$, for $df = 2.72, 54.36$, $p < .001$, Huynh-Feldt $\varepsilon = .679$]; (iv) diastolic blood pressure [$F = 23.83$, for $df = 3.08, 61.64$, $p < .001$, Huynh-Feldt $\varepsilon = .770$]; and (v) mean pressure [$F = 14.61$, for $df = 1.64, 32.85$, $p < .001$, Huynh-Feldt $\varepsilon = .411$]. This suggested that for all the above mentioned variables the Sessions and States were not independent of each other (Zar 1999).

Post-hoc tests for multiple comparisons were performed with Bonferroni adjustment. All comparisons were made with respective 'pre' states. In the right nostril yoga breathing session there was a significant decrease in the finger plethysmogram amplitude during the E1 ($p < .05$), E3 ($p < .05$), and E4 ($p < .01$) phases and after the practice ($p < .001$). The skin conductance level was increased significantly after the practice ($p < .05$). Both systolic and diastolic blood pressure and mean pressure increased significantly following the practice ($p < .001$, $p < .001$, and $p < .01$, respectively). The breath rate was significantly lower during the E1

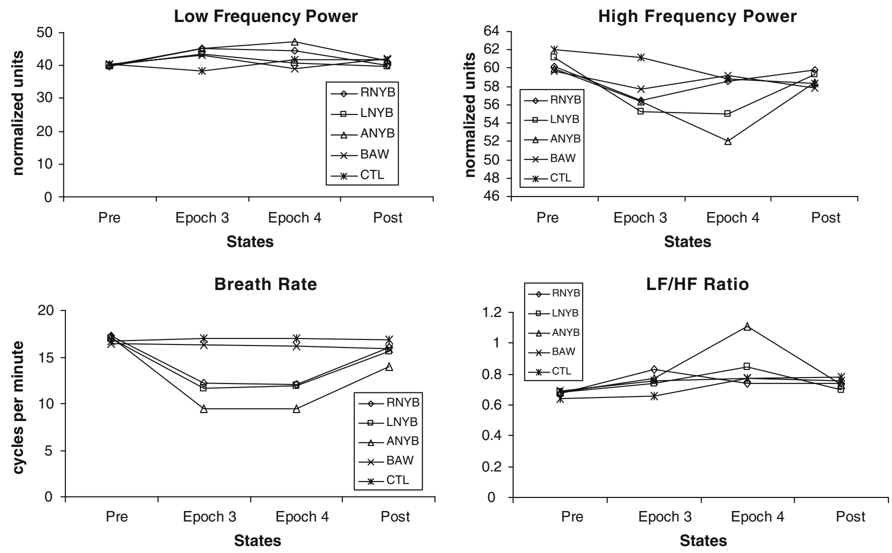

Fig. 2 Low frequency power, high frequency power and LF/HF ratio of heart rate variability spectrum and breath rate in all five sessions

($p < .01$), E2 ($p < .01$), E3 ($p < .001$), and E4 ($p < .001$) phases of the practice.

In the left nostril yoga breathing session there was a significant increase in the heart rate after the practice ($p < .05$). The systolic blood pressure and mean pressure reduced significantly after the practice ($p < .01$, respectively). The breath rate decreased significantly during the E1, E2, E3, and E4 phases of the practice ($p < .01$, respectively).

The alternate nostril yoga breathing session resulted in a significant increase in the heart rate during the E1 ($p < .01$), E2 ($p < .001$), and E4 ($p < .01$) phases and after the practice ($p < .05$). There was a significant increase in both LF power and LF/HF ratio of the HRV spectrum during the E4 phase of the practice ($p < .05$, respectively). In contrast there was a significant decrease in the HF power of the HRV spectrum during the E4 phase of the practice ($p < .05$). The skin conductance level was increased significantly after the practice ($p < .05$). The finger plethysmogram amplitude was reduced significantly during the E4 phase of the practice ($p < .05$). There was a significant reduction in both systolic and diastolic blood pressure ($p < .05$, respectively) after the practice. The breath rate was decreased significantly during the E1 ($p < .001$), E2 ($p < .001$), E3 ($p < .001$), and E4 ($p < .05$) phases, and after the practice ($p < .05$).

In the breath awareness session there was a significant decrease in the finger plethysmogram amplitude during the E2 ($p < .001$) and E4 ($p < .05$) phases and after ($p < .001$) the practice.

In the normal breathing session there was a significant decrease in the finger plethysmogram amplitude during the E2 ($p < .05$), E3 ($p < .05$) and E4 ($p < .01$) phases and after ($p < .05$) the practice. There was also a significant reduction in the diastolic blood pressure and mean pressure after the session ($p < .05$, respectively).

Discussion

The present study evaluated the changes in autonomic and respiratory variables during and after right, left, and alternate nostril yoga breathing compared to an equal duration of breath awareness and normal breathing.

Some of the autonomic variables which were assessed in the present study directly indicate the level of activity in different subdivisions of the sympathetic nervous system whereas others indicate autonomic balance. The heart rate for example, is regulated by dual innervation (sympathetic and vagal) as well as humoral factors (Andreassi 2000). This also applies to the heart rate variability (HRV) components. The low frequency (LF) band of the HRV is mainly related to sympathetic modulation when expressed in normalized units (Task force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology 1996) while the efferent vagal activity is a major contributor to the high frequency (HF) band. The LF/HF ratio is correlated with the sympathovagal balance (Malliani et al. 1991).

A decrease in finger plethysmogram amplitude is correlated with increased noradrenergic vasomotor sympathetic control of the cutaneous blood vessels (Delius and Kellerová 1971). The skin conductance level is an indicator of the level of activity in the cholinergic sudomotor sympathetic nerves supplying the eccrine sweat glands (Shields et al. 1987), which is believed to be the major contributor to changes in the spontaneous electrodermal activity (Fowles 1986). The blood pressure depends on two main factors viz., the cardiac output and the peripheral vascular resistance. The systolic blood pressure varies more within a short period than the diastolic blood pressure. Also the systolic blood pressure is usually determined by the cardiac output while the diastolic blood

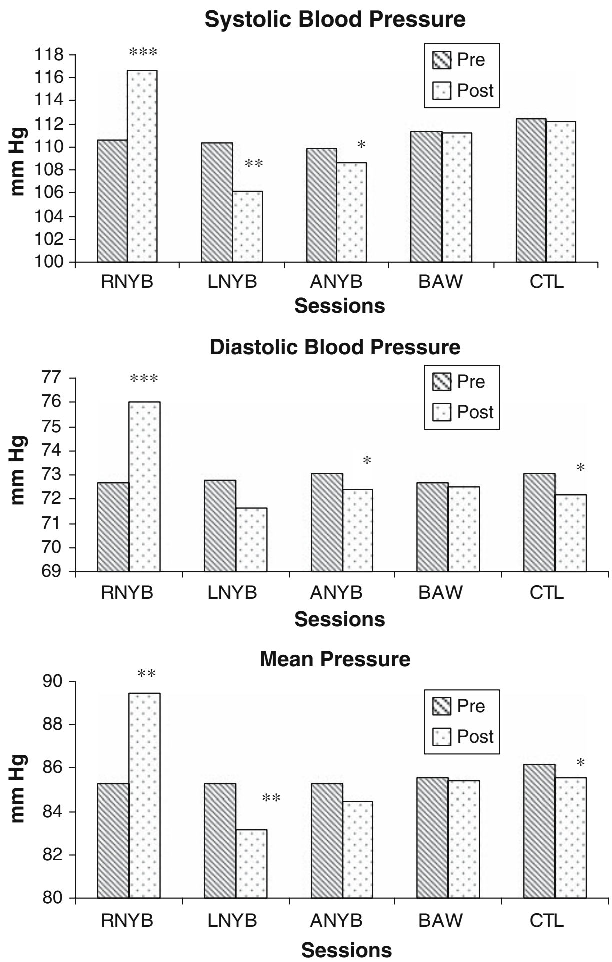

Fig. 3 Systolic, diastolic and mean blood pressure before and after the five sessions

pressure is more closely related to the peripheral vascular resistance (Franklin 2004) and the mean pressure signifies the average pressure throughout the cardiac cycle (Ganong 1999). Unlike these variables, it is well established that the breath rate depends upon numerous factors ranging from physical activity to psychological stressors (Stevenson and Ripley 1952).

A summary of inferences for the three experimental interventions i.e., right nostril yoga breathing, left nostril yoga breathing, and alternate nostril yoga breathing and the two control sessions (breath awareness, and normal breathing) is given below.

Right nostril yoga breathing practice increased the skin conductance level and in contrast reduced the finger plethysmogram amplitude. This may be mediated by an increase in sympathetic activity in the sudomotor and cutaneous vasomotor subdivisions, respectively. However these findings could have been influenced by the slower rate of breathing during RNYB described below as well as other confounding factors such as the fixed session sequence, which has also been described below. There was also an increase in blood pressure (both systolic and diastolic blood pressure). The increase in blood pressure following right nostril yoga breathing may be related to peripheral vasoconstriction as the finger plethysmogram amplitude was lower. These results suggest that right nostril yoga breathing practice increases sympathetic tone in some subdivisions of activity. However the skin conductance 'pre' values for the right nostril yoga breathing session differed from the 'pre' SC values of the left nostril yoga breathing session. Though the difference was not statistically significant these differences in 'pre' values, and the fact that 'post' heart rate data, (also of right nostril yoga breathing and of left nostril yoga breathing sessions), were not different, make it difficult to state that right nostril yoga breathing increased sympathetic activity. However earlier studies have shown a trend of sympathetic activation following breathing exclusively through the right nostril.

Right unilateral forced nostril breathing increased the heart rate compared with left unilateral forced nostril breathing (Shannahoff-Khalsa and Kennedy 1993) suggesting an increase in cardio-sympathetic activity. Previous studies on right nostril yoga breathing have also showed similar results. A month of right nostril yoga breathing practice compared to alternate nostril yoga breathing resulted in a significant increase in the heart rate and oxygen consumption and a decrease in the body weight (Telles et al. 1994). Another study which compared the immediate effects of right nostril yoga breathing with normal breathing, both practiced for 45 minutes, showed a reduction in skin resistance, digit pulse volume (45%) and an increase in systolic blood pressure (9.1 mm Hg) following right nostril breathing (Telles et al. 1996). In the present study also, the finger plethysmogram amplitude reduced and systolic blood pressure increased following the practice.

Left nostril yoga breathing practice resulted in a significant reduction in both systolic blood pressure and mean pressure, and possibly increased activity in some other subdivisions of sympathetic nervous system activity. The reduction in systolic blood pressure following left nostril yoga breathing may be related to a combination of effects such as changes in cardiac output, peripheral vascular resistance, and humoral factors.

The practice of alternate nostril yoga breathing resulted in more changes than either uninostril yoga breathing. There was a decrease in both systolic and diastolic blood pressures and in the finger plethysmogram amplitude. In contrast, there was an increase in the heart rate, skin conductance level, LF power and LF/HF ratio of the HRV spectrum. The changes in heart rate and HRV, skin conductance level and finger plethysmogram amplitude could have been influenced by the slower breath rate during alternate nostril yoga breathing.

During all three nostril manipulating yoga breathing practices there was a significant decrease in the breath rate. This may be related to consciously regulating and slowing down the breathing while practicing the respective breathing techniques. However after alternate nostril yoga breathing practice the breath rate further reduced compared to the baseline. This may be due to breathing through both nostrils alternately.

The breath rate was considerably slower during ANYB (approximately 9 cpm) compared with RNYB and LNYB. During all three of them the respiratory rates were slower than spontaneous breathing at rest (approximately 17 cpm). Also throughout LNYB the breath rate was lower than in RNYB (ranging from 0.2 to 1.2 cpm). Given the fact that a reduction in breath rate is associated with reduced arousal, the lower breath rates in these yoga breathing practices could be expected to have influenced most, if not all variables as described below, with the possible exception of the blood pressure.

In order to prevent changes in breath rate influencing the outcome it would have been ideal to have had the subjects breathe at predetermined rates in all sessions. However in order to study the effect of the *pranayama* techniques practiced as naturally as possible, subjects were not given specific instructions about the breath rate as such instructions are not a part of the traditional descriptions of the yoga techniques studied here. The disadvantage of this is that the increase in the LF power of the HRV during alternate nostril yoga breathing could have been related to the slower breath rate. This does not permit an interpretation of the changes in the heart rate variability as being due to shifts in autonomic balance. This is related to a link between respiration and heart rate variability. It was shown that biofeedback training to increase the amplitude of respiratory sinus arrhythmia maximally, increases the amplitude of heart rate oscillations only at approximately 0.1 Hz. (Lehrer et al. 2000). To achieve this, breathing is slowed to a point at which resonance occurs between respiratory induced oscillations and oscillations that naturally occur at this rate. Also, in another study it has been shown that any changes in breathing frequency that almost coincide with spontaneous Mayers wave frequency (6 breath per mintue) such as regulated slow breathing or chanting *Ave Maria* or yoga *mantra* enhances heart rate variablity and baroreflex sensitivity by synchronising inherent cardiovascular rhythms (Bernardi et al. 2001). This may explain the changes in increase in heart rate and heart rate variablity components which occurred during the practice of RNYB, LNYB or ANYB practice when the rate of breathing was slower.

The very low frequency power (VLF) did not change significantly during or after the breathing techniques, or in the control session. The VLF accounts for more than 90% of the total power in the 24 h heart rate power spectrum, however the physiological mechanisms underlying the VLF power have not been determined. The VLF power partially reflects thermoregulatory mechanisms, fluctuation in activity of the renin–angiotensin system, and the function of peripheral chemoreceptors (Malliani et al. 1991; Parati et al. 1995). Also both the respiratory pattern and level of physical activity modulate VLF power. Hence there are several possible physiological mechanisms for the VLF power which is the reason why the VLF power values have not been detailed in the present study.

The changes in the normal breathing session were a decrease in finger plethysmogram amplitude and a decrease in blood pressure, which are contrary to each other. In this session, the participants were asked to sit at ease without specific instructions about breathing. These changes could be related to the fact that the participants might have felt a sense of monotony and boredom. It has been shown that such a state influences changes in autonomic indices resulting in increased sympathetic activity (Ohsuga et al. 2001). However, it is difficult to explain the reduction in the diastolic blood pressure and mean pressure while there was a simultaneous reduction in the finger plethysmogram amplitude indicative of peripheral vasoconstriction.

The effects of uninostril breathing have been described in ancient Indian yoga texts, where the flow of air through the nostrils is in the form of energy and is called *swara* (=sound in Sanskrit) (Swami Muktibodhananda 1999). Hence, *Swara Yoga* explains how the flow of subtle energy through the nostril changes at regular intervals and also describes its' importance. When the breath flows through the left nostril (lunar *swara*), it is said that the energy is flowing through the left subtle energy channel (*ida nadi*), while when breathing through the right nostril (solar *swara*), it flows through the subtle energy channel on the right (*pingala nadi*), and when breathing through both nostrils, it flows through the middle channel (*sushumna*). These subtle energy channels (*nadis*) are not anatomically distinct entities but were described based on experiential observations of the ancient sages. Energy flow through *ida* is supposed to be 'heat dissipating (cooling)' whereas energy flow through *pingala* is 'heat generating'. *Swara Yoga* specifically mentions that when the breath flows through *ida*, one should carry out 'passive activities', such as rendering service and performing religious rites (*Shiva Swarodaya, V: 102–113*). When the breath flows through *pingala*, one should perform 'energetic' activities, such as studying scriptures, hunting and controlling an elephant, horse or chariot (*Shiva Swarodaya, V: 114–123*). When the breath flows through both nostrils (*sushumn*a), it has been mentioned to avoid activity and remain relaxed (*Shiva Swarodaya, V: 128*) (Raghuraj and Telles 2003).

The way in which unilateral breathing influences the central nervous system and other systems has not been conclusively proven. It seems possible that mechanical receptors in the nasal mucosa are activated with airflow into the nostril, and this signal is unilaterally transmitted to the hypothalamus (Shannahoff-Khalsa 1991). The hypothalamus is considered the highest center for autonomic regulation. A similar mechanism may explain the effects seen here.

The present study suggests that breathing through the right, left or through both nostrils alternately produces distinct autonomic changes. However there are certain methodological limitations to the study which do not allow definite inferences to be made. One of the main drawbacks is the method of randomization. Participants were randomly assigned to five possible sequences, with the five sessions on separate days. At the time the fixed sequences were planned so as to follow the order in which the yoga breathing techniques (i.e., right nostril yoga breathing, left nostril yoga breathing, alternate nostril yoga breathing, or breath awareness) are taught during a typical yoga session. Due to these fixed-session sequences there is an inherent confounding bias in the results so that changes which occur in a preceding session could possibly have carryover effects to the session which follows it.

Other limitations of the study are related to the practice of yoga breathing techniques. Since all participants were right hand dominant they all used their right hand to manipulate the nostrils. For this reason, recordings of skin conductance and finger plethysmogram amplitude were from the left hand. There is a possibility that there may be differences between the two hands in levels of skin resistance and blood volume pulse. Kennedy et al. (1986) showed widely differing sympathetic tonus between the two sides of the body. Autecubital venous blood was sampled in both arms simultaneously every 7.5 min for periods of 3 to 6 h and assayed for epinephrine, nonepinephrine and dopamine levels. Fluctuations in the nasal cycle were shown to correlate significantly with the alternating levels of nor-epinephrine.

Also, it could be expected that using the right hand to do all the manipulations may have contributed to the changes observed during the three yoga breathing techniques. There was no attempt to control for this. Also, since the participants had received theory and practical instruction about the effects of the *pranayama* practices, they may have been aware about what effects to expect by practicing the yoga techniques, even though they were not told the hypothesis of the study. It is possible that by knowing the effects they were able to induce them inadvertently, since experience in yoga has been shown to facilitate control over functions earlier considered to be involuntary. Further studies controlling for these factors would be worthwhile given the possible therapeutic applications of these practices.

Clinical studies have been conducted to understand the efficacy of unilateral nostril breathing. In 1948, Friedell reported the first clinical trial using alternative nostril breathing for symptoms of angina pectoris on 11 patients. It was shown that 'diaphragmatic breathing with attention to both phases of respiration and the intervening pauses' coupled with 'alternately closing one nostril while inhaling slowly through the other' had profound effects on relieving symptoms of angina pectoris and eventually the patients were able to curtail the use of nitroglycerin. It was speculated that alternate nostril breathing directly affects the lateralized sympathetic and vagal input to the heart, hence inducing a balance in autonomic nervous system activity. More recently, a study was conducted to evaluate the comparative effects of yogic and conventional treatment in diarrhea-predominant irritable bowel syndrome (IBS) in a randomized control design (Taneja et al. 2004). It was shown that the patients who received yoga practice (a combination of physical postures along with right nostril yoga breathing), practiced two times a day for two months showed a significant decrease in bowel movements (measured by standard electrophysiological recordings) and state anxiety.

Hence, the physiological effects of yoga breathing practices on autonomic activity suggest therapeutic applications in conditions affecting autonomic balance. However, further studies are essential to substantiate the findings and understand the underlying mechanisms.

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