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Body Temperature and Energy Expenditure During and After Yoga Breathing Practices Traditionally Described as Cooling

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Background: In traditional yoga texts, *sheetali* and *sitkari pranayamas* are described as cooling. The present study was aimed at recording the surface body temperature, oxygen consumed, and carbon dioxide eliminated before, during, and after performance of *sheetali* and *sitkari pranayamas*.

Material/Methods: Seventeen healthy male volunteers with ages between 19 to 25 years (average age 20.7 ± 1.8 years) were assessed in 4 sessions, viz. *sheetali pranayama*, *sitkari pranayama*, breath awareness and quiet lying, on 4 separate days, in random sequence. The axillary surface body temperature (TRUSCOPE II, Schiller, China) and metabolic variables (Quark CPET, COSMED, Italy) were recorded in 3 periods: before (5 minutes), during (18 minutes), and after (5 minutes), in each of the 4 sessions. The heat index was calculated in the before and after periods, based on recordings of ambient temperature and humidity. Data were analyzed using SPSS (Version 24.0).

Results: Body temperature increased significantly during *sheetali* and *sitkari* ($p < 0.05$, $p < 0.01$; respectively) while it decreased after breath awareness and quiet lying down ($p < 0.01$, $p < 0.001$; respectively) when compared with respective post-exercise states. Oxygen consumption increased by 9.0% during *sheetali* ($p < 0.05$) and by 7.6% during *sitkari* ($p < 0.01$) while it decreased significantly during ($p < 0.05$) and after ($p < 0.01$) quiet lying down compared to respective pre-exercise states.

Conclusions: The results do not support the description of these yoga breathing practices as cooling. These yoga breathing practices may be used to induce a mild hypermetabolic state.

MeSH Keywords: **Body Temperature Changes • Carbon Dioxide • Oxygen Consumption • Yoga**

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Background

In yoga, considerable emphasis is placed on the breath. Yoga breathing techniques are ultimately intended to enhance a practitioner's ability to achieve a calm mental state at will [1]. However, since these practices regulate and modify different aspects of the breath (the rate, depth, or adding a period of breath-holding), they have a direct effect on physiological functions such as oxygen consumption [2].

An early study examined oxygen consumption (VO_2) during 3 yoga breathing practices in a single subject (male, aged 32 years) [2]. The VO_2 increased significantly by (i) 11.9% during high-frequency yoga breathing (*kapalabhati*, at 80 breaths per minute for 30 minutes), (ii) 18.9% during slow deep breathing (*bhastrika* practiced for 24 minutes), and (iii) 18.0% during breathing with retention after inhalation (*ujjayi*, practiced for 22 minutes). All comparisons were made with the previous values. The results of this early study were supported by later research.

High-frequency yoga breathing was found to increase VO_2 compared to the preceding values in at least 2 other studies [3, 4]. Three males (average age 35.7 ± 11.7 years) who breathed at 232 breaths per minute for 30 minutes showed a 203% increase in VO_2 [3]. A slower rate of high-frequency yoga breathing showed a similar trend, but with a smaller magnitude of change; 47 males (average age 23.2 ± 4.1 years) breathed at 60 breaths per minute for 15 minutes, and VO_2 increased by 40% [4].

Similarly, 3 studies found that yoga breathing with a period of breath retention also increased VO_2 compared to the preceding values [5–7]. The findings were as follows: (i) in 10 males (ages 28–50 years), after 15 minutes of practice, there was a 52% increase in VO_2 [5], (ii) in a single subject (male, 26 years of age) with a slow breath rate of 1 breath per minute for 60 minutes, there was an increase of 11% [6], and (iii) in 9 experienced yoga practitioners (5 males, average age 44.0 ± 11.6), yoga breathing with retention practiced for 30 minutes after inhalation increased VO_2 by 20% [7].

Another form of breath regulation involves inhalation through the mouth. This has 2 categories, called *sheetali* (Chapter 2; Verse 57) and *sitkari* (Chapter 2; Verse 54) [1]. These are commonly referred to as cooling *pranayamas*. In Sanskrit, *sheetali* means calming or cooling breath, while *sitkari* is the process of cooling or achieving coolness [1]. In these Sanskrit definitions, the word 'cool' not only indicates a decrease in body temperature, but also signifies a calm mental state.

To the best of our knowledge, there has been no study examining body temperature, oxygen consumption, and energy

expenditure related to the practice of these 2 *pranayamas*, which have been traditionally described as cooling. Hence, the present study aimed to assess the effect of *sheetali* and *sitkari pranayamas* on surface body temperature, energy expenditure, and oxygen consumption, among other variables, in healthy participants compared to breath awareness (which is a part of all *pranayama* practice) as an interventional control and quiet lying down as the control.

Material and Methods

Design of the study

Each participant was assessed in 4 sessions. The 4 sessions were on 4 separate days at the same time of day, with 24 hours between sessions. The 4 sessions were: (i) *sheetali pranayama*, (ii) *sitkari pranayama*, (iii) breath awareness, and (iv) quietly lying down, as a control. The sequence of the sessions was randomized with a standard randomizer (www.randomizer.org), so that the order of the sessions was not the same for the 17 participants. The order of sessions for the first 2 participants is given below as an example. For the first participant, the sequence for the 4 sessions was as follows: (i) *sheetali pranayama*, (ii) breath awareness, (iii) quietly lying down, and (iv) *sitkari pranayama*. For the next participant, the sequence for the 4 sessions was as follows: (i) quiet lying, (ii) breath awareness, (iii) *sitkari pranayama*, and (iv) *sheetali pranayama*. Hence, the sequence differed for the participants.

The sessions were recorded between August and October 2018. For all these sessions, the total duration was 28 minutes (5 minutes before, 18 minutes during, and 5 minutes after). The 18 minutes 'during' consisted of (i) *sheetali pranayama*, (ii) *sitkari pranayama*, (iii) breath awareness, and (iv) quietly lying down. The 18-minute duration of the intervention consisted of three 5-minute epochs with 3 periods of 1-minute rest in between the 3 epochs. In the last 8 years, the authors have found that participants can practice different *pranayamas* effectively and without fatigue if they have rest periods between [8,9]. Three 5-minute epochs were selected as the most practical for participants to include in their daily practice. Hence, this duration is based on laboratory investigations [8,9] and communication with the participants, asking them to self-rate their level of comfort, and practical considerations. This study design is depicted in schematic form in Figure 1.

Experimental conditions

The participants maintained the same duration after a meal for all 4 sessions. The minimum gap was 2 hours after a meal for all participants, who were residents of a university campus. The diet was comparable for the participants, consisting of a

Figure 1. The study design is schematically presented here.

lacto-vegetarian meal with an average of 500 to 600 Kcal/meal prior to the recording sessions. The participants wore light, comfortable clothing. Recordings were carried out in a dimly-lit sound-attenuated cabin while the researcher monitored the participants from an adjacent recording room. The participants were not exposed to high external temperatures while coming to the laboratory prior to testing. They were in an indoor environment comparable to that of a laboratory. The participants were asked not to practice any form of exercise including yoga techniques for 24 hours prior to testing. Their compliance to this was checked when they came to the laboratory. In addition, each participant was asked to sit quietly in the laboratory for 10 minutes prior to each of the 4 sessions so that they could adapt to the laboratory conditions. In the experimental room, the ambient temperature and humidity were regulated by air-conditioning; the temperature range was 24.5–25.6°C on all recording days, and humidity was 45–53%. The room temperature and humidity were measured

with a digital wireless electronic hygrometer and a thermometer (HTC-I, China). The thermometer was accurate to 1°C and the hygrometer was accurate to 1% humidity. From the ambient temperature and humidity, the heat index was derived, as described later. Throughout the assessment, the participants were monitored with an infra-red camera and observed on a closed-circuit television by the researcher in the adjacent recording room, and participants were informed of this observation, which allowed the researcher to detect the participants' movement or any episode of sleep or signs of discomfort. No such episodes occurred during the sessions.

Study participants

Seventeen healthy males ages 19–25 years (group average age±SD, 20.7±1.8 years) participated in the study. The sample of 17 participants was drawn from 57 students who were in the final year of a 2-year postgraduate course run by a

Figure 2. Trial profile.

university in northern India. Participants were recruited using flyers on the university and research foundation notice boards. There was no incentive to take part in the study. With a sample size of 17 in a session and with average effect size of 0.69 based on the average change in energy expenditure per hour in these sessions, the study was powered at 0.99 for alpha preset at 0.05 [10].

Inclusion and exclusion

The inclusion criteria were: (i) minimum experience of yoga breathing (*pranayamas*) of 3 months (group average experience $\pm$ SD, 30.3 ± 14.6 months), (ii) ability to practice both *sheetali* and *sitkari pranayamas* according to the standard method [1], and (iii) their availability to come to the laboratory on 4 separate days at the same time of day for the 4 sessions. The participants were not selected based on their: (i) interest in yoga, (ii) their involvement in yoga research, (iii) interest in practicing cooling *pranayamas*, or (iv) any other factor. Hence, all participants had an equal chance of being included in the trial if they met the inclusion criteria mentioned above. The exclusion criteria were: (i) any nervous system disorder or hormonal imbalance that could influence body temperature and thermoregulation, (ii) history of smoking, (iii) any aphthous ulcer or oral lesions that would make the practice difficult, and (iv) taking medication or using other wellness strategies that could influence metabolism and energy expenditure. None of the participants had to be excluded for these reasons. The details of the study were explained to the participants when they were recruited to the study. The actual number of participants at different stages of the trial is detailed in Figure 2. Prior to the experiment, each participant provided signed informed consent. This study was approved by the institution's ethics committee (IEC), following the guidelines of the Indian

Council of Medical Research, which are based on the Helsinki Declaration (IEC approval number: YRD/18/06).

Assessment of body temperature

Body temperature was assessed with a multi-use patient monitor (TRUSCOPE II, Schiller, China) [9]. Before each session, the sensor was cleaned with 2% Savlon™, which contains cetrimide and chlorhexidine gluconate. The sensor was then dried with cotton wool and set aside for 5 minutes before use. For the recording, the sensor was positioned in the left axilla between anterior and posterior axillary folds, at the vertical mid-point of the axilla, and was kept in position with 2 strips of micro-pore plaster. The diameter of the sensor is 9 mm and it measures surface body temperature with an accuracy of 0.1°C. Prior to the study, the sensitivity of the sensor was determined by comparing the values with those of a mercury thermometer, using 7 samples of water at known temperature. The sensor used for the study recorded 0.1°C less than the mercury thermometer. The results were similar to those of another study, which compared a digital temperature sensor with a mercury thermometer in a clinical setting [11]. There have been concerns about the accuracy of surface body temperature recorded from the axilla [12,13]. However, we used the axilla as the recording site due to its ease of access.

During recording, 2 minutes were given for the sensor to stabilize before the actual recording. The body temperature was recorded continuously during 28-minute sessions, noting the reading at the end of each minute.

Assessment of metabolic and ventilatory variables

An open-circuit oxygen consumption analyzer (Quark CPET, COSMED, Italy) was used to assess the metabolic and ventilatory variables [4]. The COSMED Quark CPET (Cardio-Pulmonary Exercise Testing) equipment is designed to evaluate cardio-pulmonary functions. The program algorithm and the presentation of the measured data were developed according to the specifications of the American Thoracic Society (ATS) [14] and European Respiratory Society (ERS) [15]. The equipment has a built-in paramagnetic gas analyzer to evaluate the volume of oxygen consumed (VO_2) and the volume of carbon dioxide eliminated (VCO_2). Prior to acquiring data, the flow or volume calibration of the equipment was performed with a 3-liter calibration syringe, and the gas analyzer was calibrated with atmospheric air and with a cylinder that has a fixed amount of O_2 (16%) and carbon dioxide CO_2 (5%). This calibrates the equipment for ambient temperature, humidity, barometric pressure, flow rate, and gas analysis. The COSMED Quark CPET was used to measure: (i) volume of oxygen consumed (VO_2), (ii) volume of carbon dioxide eliminated (VCO_2), (iii) rate of respiration (RR), (iv) estimated energy expenditure (EE Kcal/day), and (v) the non-protein respiratory quotient (npRQ).

Because the yoga breathing practice (*pranayamas*) involved mouth-breathing with the protrusion of the tongue (*sheetali* and *sitkari pranayamas*), the conventional masks used with the QUARK CPET were not suitable. The participants were fitted with a canopy hood to be able to easily perform the *pranayama* breathing. In the canopy hood, air exhaled by the participants blends with ambient air, and the built-in measurement system calculates partial oxygen consumption, CO_2 production, and other metabolic and ventilatory variables. To fit the canopy comfortably, participants were asked to lie down in supine position. The canopy was fitted around the waist to ensure that it was air-tight.

Interventions

Ideally, all *pranayamas* are practiced in the sitting position with erect spine and straight neck. However, the recording had to be made in the canopy for all 4 sessions (*sheetali pranayama*, *sitkari pranayama*, breath awareness, and quietly lying down). Hence, the supine lying position was used in the 'pre', 'during' and 'post' period of all 4 sessions. Participants were asked to keep their legs extended in this position (lying supine). None of the participants mentioned that they had difficulty in this posture in any particular practice, including maintaining breath awareness and other aspects of breathing. In both practices (*sheetali* and *sitkari*), inhalation is ideally deep and diaphragmatic, while exhalation should be longer than inhalation.

Sheetali pranayama

The participants were asked to keep their eyes closed. To practice oral (mouth) breathing, participants were asked to extrude the tongue comfortably and roll the sides of the tongue up to form a tube and to breathe in slowly and deeply through the tongue. At the end of inhalation, the mouth was closed and exhalation was performed through the nose. This was continued for 18 minutes.

Sitkari pranayama

The upper and lower teeth were clenched together and the lips were drawn aside as much as was comfortable. Participants were asked to breathe in slowly and steadily through the gaps between the teeth. At the end of inhalation, participants were asked to close their mouths and to exhale through the nose. This was continued for 18 minutes.

Breath awareness

Breath awareness (BAW) was practiced with eyes closed. Participants were asked to be aware of their breath but not to modify it in any way. Participants did not perform mouth breathing. They were asked to direct their attention to the flow of air through the nasal passages and respiratory system as much as possible.

Quiet lying

The quiet lying session formed the control session. Participants were asked to keep their eyes closed. Participants did not practice mouth breathing. They were not given any instructions about directing their thoughts or about modifying their breath. Participants were observed on closed-circuit television to ensure that they did not move or fall asleep, which could be detected for example, by nodding movements of the head, for 18 minutes. This was also verified by talking to the participants after the session.

Data extraction

Values of the body temperature were noted every minute from the TRUSCOPE II equipment. The average values were calculated for "5 minutes before", "18 minutes during" and "5 minutes after".

Similarly, average values of the volume of oxygen consumed (VO_2), volume of carbon dioxide eliminated (VCO_2), rate of respiration (RR), estimated energy expenditure (EE Kcal/day), and estimated non-protein respiratory quotient (npRQ) were also calculated for pre-exercise, during exercise, and post-exercise periods. This was done separately for each of the 4

Table 1. Mean, standard deviation, and Cohen's *d*-value of the variables assessed before, during, and after cooling *pranayamas* breath awareness and quietly lying down.

Variables	Sheetali pranayama					Sitkari pranayama				
	Pre (Mean± SD)	During (Mean ±SD)	Post (Mean± SD)	C's <i>d</i> [#]	95% CI (Upper limit, lower limit) ^{##}	Pre (Mean ±SD)	During (Mean ±SD)	Post (Mean ±SD)	C's <i>d</i> [#]	95% CI (Upper limit, lower limit) ^{##}
Surface body temperature (°C)	35.72± 0.52	35.9± 0.53*	35.83± 0.62	0.34	(−0.18, −0.33)	35.79± 0.66	35.96± 0.69**	35.89± 0.76	0.25	(−0.52, −0.29)
VO ₂ (ml/min)	269.05±	293.26±	255.59±	0.46	(−4.53, −43.89)	257.74±	277.23	249.68±	0.57	(−8.79, −30.19)
STPD	53.14	52.51*	48.36***			30.78	±37.23**	36.18*		
VCO ₂ (ml/min)	229.2±	266.82±	183.99±	0.31	(−14.83, 60.42)	189.57±	228.03±	163±	0.69	(−12.76, −64.14)
STPD	112.52	132.14**	120.39**			46.23	65.34**	53.37*		
RR (breath per min)	12.02± 0.01	12.02± 0.01	12.02± 0.01	0.00	(0.004, −0.003)	12.02± 0.01	12.02± 0.01	12.02± 0.01	0.00	(0.003, −0.001)
EE Kcal/day	1873.15± 411.39	2072.01± 448.1**	1719.38± 412.71	0.46	(−63.25, −334.46)	1741.01± 213.12	1915.63± 287.11**	1649.81± 256.3	0.70	(−73.75, −275.49)
npRQ	0.84± 0.41	0.89± 0.41*	0.7± 0.42***	0.12	(−0.004, −0.100)	0.73± 0.18	0.8± 0.20*	0.64± 0.20**	0.37	(−0.010, −0.13)
Heat index ^{###}	25.05± 0.24		25.17± 0.52	0.32	(−0.132, −0.367)	25± 0.35		25± 0.35	0.00	(0.000, 0.000)

Variables	Breath awareness					Quiet lying				
	Pre (Mean± SD)	During (Mean ±SD)	Post (Mean± SD)	C's <i>d</i> [#]	95% CI (Upper limit, lower limit) ^{##}	Pre (Mean ±SD)	During (Mean ±SD)	Post (Mean ±SD)	C's <i>d</i> [#]	95% CI (Upper limit, lower limit) ^{##}
Surface body temperature (°C)	35.56± 0.83	36.82± 3.60	35.92± 0.61**	0.57	(1.47, −3.99)	35.63± 0.70	35.81± 0.85	36.01± 0.54***	0.23	(0.59, −0.41)
VO ₂ (ml/min)	263.24±	257.87±	245.86	0.12	(19.98, −9.23)	265.77±	252.53±	249.49±	0.33	(22.72, 3.76)
STPD	47.57	41.18	±58.08			40.7	39.27*	37.69**		
VCO ₂ (ml/min)	226.47±	218.33±	202.52±	0.06	(23.54, −7.27)	249.25±	229.21±	224.1±	0.14	(36.82, 3.27)
STPD	138.22	140.71	145.9*			142.44	134.25*	129.73*		
RR (breath per min)	12.02± 0.01	12.02± 0.01	12.03± 0.02	0.00	(0.003, −0.003)	12.02± 0.01	12.02± 0.01	12.02± 0.01	0.00	(0.002, −0.005)
EE Kcal/day	1836.71± 427.3	1792.95± 418.78	1699.38± 517.94	0.10	(146.32, −58.80)	1891.02± 428.38	1783.24± 416.76**	1757.61± 402.01**	0.26	(183.85, 31.72)
npRQ	0.84± 0.45	0.81± 0.42	0.78± 0.41*	0.07	(0.06, 0.009)	0.9± 0.44	0.87± 0.40	0.86± 0.39	0.07	(0.085, −0.020)
Heat index ^{###}	24.94± 0.24		24.88± 0.33	0.21	(0.28, −0.16)	25.17± 0.39		25.05± 0.55	0.26	(0.37, −0.13)

* $p < 0.05$; ** $p < 0.01$, *** $p < 0.001$; post hoc analyses with Bonferroni adjustment, during and post compared with respective pre periods. [#] Cohen's *d* values for during vs. pre comparisons; ^{##} 95% confidence interval for during vs. pre differences; ^{###} Heat index was calculated using pre and post conditions.

sessions (*sheetali pranayama*, *sitkari pranayama*, breath awareness, and quietly lying down).

Statistical analysis

The group average values±SD for oxygen consumption (VO₂), carbon dioxide eliminated (VCO₂), rate of respiration (RR),

estimated energy expenditure (EE Kcal/day), and estimated non-protein respiratory quotient (npRQ) are provided in Table 1.

A repeated-measures analysis of variance (RM-ANOVA) was performed with SPSS (version 24.0). There were 2 within-subject factors: Sessions with 4 levels (*sheetali pranayama*, *sitkari pranayama*, breath awareness, and quietly lying down

Table 2. ANOVA table for the variables.

S. No.	Variables	Factors	F-value	Degrees of freedom (df)	Partial eta squared	Huynh-Feldt ϵ	p-Value
1	Surface body temperature (°C)	States	2.94	1.08, 17.25	0.155	0.55	0.102
		Sessions×States (interaction)	1.01	1.02, 16.25	0.6	0.17	0.33
2	Volume of oxygen consumed [VO ₂] (ml/min) STPD	States	16.28	1.86, 29.77	0.5	0.93	<0.001
		Sessions×States (interaction)	5.85	3.20, 51.19	0.27	0.68	0.001
3	Volume of carbon dioxide eliminated [VCO ₂] (ml/min) STPD	States	38.01	2.00, 32.00	0.7	1	<0.001
		Sessions×States (interaction)	11.67	3.02, 48.32	0.42	0.63	<0.001
4	Rate of respiration (breaths/min)	States	2.66	1.59, 25.54	0.14	0.87	0.1
		Sessions×States (interaction)	0.89	1.73, 27.65	0.05	0.32	0.41
5	Estimated energy expenditure (Kcal/day)	States	24.99	1.98, 31.76	0.61	0.99	<0.001
		Sessions×States (interaction)	7.9	3.23, 51.68	0.33	0.69	<0.001
6	Non-protein respiratory quotient (npRQ)	States	39.56	1.98, 31.71	0.71	0.99	<0.001
		Sessions×States (interaction)	9.75	2.97, 47.63	0.38	0.62	<0.001
7	Heat index	States	0.09	1.00, 16.00	0.01	1	0.77
		Sessions×States (interaction)	1.06	2.25, 35.99	0.06	0.88	0.36

sessions) and States (pre, during, and post). This had 2 levels (pre and post) for the heat index and 3 levels for all other variables (pre, during, and post).

Multiple comparisons were carried out with Bonferroni adjusted post hoc tests.

Results

Repeated-measures analyses of variance (RM-ANOVA)

There was a significant difference between States for: (i) oxygen consumption (VO₂), (ii) carbon dioxide eliminated (VCO₂), (iii) estimated energy expenditure (EE Kcal/day), and (iv) non-protein respiratory quotient (npRQ).

We also found significant interaction between States and Sessions for: (i) oxygen consumption (VO₂), (ii) carbon dioxide eliminated (VCO₂), (iii) energy expenditure (EE Kcal/day), and (iv) non-protein respiratory quotient (npRQ). A significant interaction between States and Sessions for any variable suggests that they are interdependent.

The F, df, Huynh-Feldt epsilon, and p values are provided in Table 2.

Post hoc analyses

- Sheetali pranayama*. The following variables were significantly increased during *sheetali pranayama*: body temperature, oxygen consumption (VO₂), carbon dioxide eliminated (VCO₂), estimated energy expenditure (EE Kcal/day), and non-protein respiratory quotient (npRQ).
- Sitkari pranayama*. The following variables were significantly increased during *sitkari pranayama*: body temperature, oxygen consumption (VO₂), carbon dioxide eliminated (VCO₂), estimated energy expenditure (EE Kcal/day), and non-protein respiratory quotient (npRQ).
- Quiet lying down: The oxygen consumption (VO₂), carbon dioxide eliminated (VCO₂) and estimated energy expenditure (EE Kcal/day) were significantly decreased during quiet lying down.

The changes in the post-exercise and during-exercise periods compared to the respective pre-exercise period, the level of significance for both during and post comparisons,

the Cohen's *d* (for during vs. pre comparison), and 95% confidence intervals for during vs. pre differences are presented in Table 1.

Discussion

The axillary surface body temperature increased significantly during the practice of both *sheetali* and *sitkari pranayamas*. These results do not support the traditionally accepted idea that these *pranayamas* are 'cooling'. Changes in body temperature are known to occur with simultaneous changes in oxygen consumption ('At a temperature of 32°C (89.6°F), oxygen consumption decreases as a function of hypometabolism...') [16]. During *sheetali* and *sitkari pranayamas*, there was a significant 9% increase in oxygen consumption (VO_2), (*sheetali pranayama*) and 7.6% (*sitkari pranayama*), compared to the preceding value. The carbon dioxide elimination also increased significantly during both *sheetali* (16%) and *sitkari* (20%) *pranayamas*.

The non-protein respiratory quotient increased during both *pranayamas*; this was significant for *sitkari pranayama* (with a 10% increase). The respiratory quotient gives an indication of the macronutrients metabolized. There was a significant decrease in the percentage of fats utilized during *sheetali pranayama*, and the percentage of carbohydrates metabolized increased significantly during *sitkari pranayama*. Apart from the increased oxygen consumption being related to the respiratory quotient and the metabolism of macronutrients, the increase in oxygen consumption and hence in energy expenditure could be related to other factors as well.

Sheetali and *sitkari pranayamas* involve mouth breathing, not nasal breathing. Nasal breathing is the physiological mode of breathing in all humans, irrespective of age [17,18]. Breathing through the nose facilitates filtering, heating, and humidification of inhaled air [18]. Nasal obstruction due to mechanical factors, inflammatory conditions, tumors, and congenital malformations lead to non-physiological mouth breathing. Hence, most studies on mouth breathing are carried out in persons who are forced to breathe through the mouth due to nasal obstruction and the results may not be directly applicable to the participants in the present study who chose mouth breathing as a part of *pranayama* practice. All the same, the findings in cases of mouth breathing are relevant and are presented here. After reviewing 18 articles from a total of 378 abstracts from PubMed and Web of Science, which described the implications of mouth breathing, the authors concluded that in long-term mouth breathing, a cycle is established with altered respiratory functions, involvement of the accessory muscles of respiration, and postural compensations, which in turn further perpetuate the respiratory changes [19]. Therefore, mouth breathing can be expected to increase the work of breathing. This could

explain the increase in oxygen consumption and increased energy expenditure during *sheetali* and *sitkari pranayamas*.

Another possible mechanism which could explain the increase in oxygen consumption (VO_2) during both *sheetali* and *sitkari pranayamas* is that *pranayama* breathing involves the diaphragm [1]. A previous study enrolled 38 healthy participants randomly assigned to a feedback breathing exercise group or a diaphragmatic breathing exercise group; while the metabolic and respiratory responses of both groups were assessed [20]. The diaphragmatic breathing group showed a 19% increase in oxygen consumed (VO_2) as a short-term effect of the practice, whereas the feedback breathing exercise showed only a 10% increase in oxygen consumption (VO_2). Diaphragmatic breathing activates the muscles of respiration and thus increases the oxygen consumed and energy spent [20]. This increase in oxygen consumption (VO_2) during diaphragmatic breathing may explain the increase in oxygen consumed in high-frequency yoga breathing (10–14%) [4], as well as in other *pranayamas* [21].

The contribution of environmental physical factors to this increase in surface body temperature was also ruled out. The room temperature and humidity were maintained at fairly constant levels during the recording sessions. The heat index was obtained from the recorded room temperature and humidity was derived using an algorithm [22]. The heat index indicates the level of thermal comfort and is often used in environmental health research [23,24]. There was no change in the heat index after any of the sessions in post-pre comparisons.

The participants were covered with the canopy in the 'pre', 'during' and 'post' states of all 4 sessions (*sheetali pranayama*, *sitkari pranayama*, breath awareness, and quiet lying down). Thus, the recording conditions were the same for all 4 sessions. If being in the canopy had resulted in warming, it would be expected that the surface body temperature would have steadily increased during the 3 states (pre, during, and post) in all 4 sessions. If this was the case, the highest surface body temperature would have been recorded in the post period. It was apparent that the surface body temperature only increased steadily in the quiet lying down session. In the (i) *sheetali pranayama*, (ii) *sitkari pranayama*, and (iii) breath awareness sessions, the surface body temperature increased in the 'during' period and decreased in the 'post' period. This suggests that wearing the canopy was not warming.

In previous studies on yoga breathing, the magnitude of percentage increase in oxygen consumption (VO_2) was more than the increase found during *sheetali pranayama* (9.0%) and *sitkari pranayama* (7.6%) in the present study. High-frequency yoga breathing at 232 breaths per minute increased VO_2 by 208% [3], while breathing at 60 breaths per minute increased VO_2 by 40% [4]; which could be attributed to increased work of

breathing. This difference could not be related to the method of measuring VO_2 , which differed between the studies, in which some used the Douglas bag method as well as closed and open-circuit methods. No relationship could be found with the method and the increase in VO_2 . Similarly, the increase in VO_2 during yoga breathing with a period of breath-holding following inhalation was greater than the increase during *sheetali* and *sitkari pranayamas* in the present study [5–7]. This greater magnitude of increase in VO_2 may also be attributed to the greater work of breathing associated with yoga breathing, which included a period of breath-holding.

There was a significant decrease in VO_2 after quiet lying down, suggesting that this recumbent position, without specific instructions about the breath or about awareness, was relaxing. There was no change in VO_2 during or after breath awareness exercises. Possibly, the awareness paid to the breath prevented the decrease in oxygen consumption seen in quiet lying down. The increase in body temperature in the post periods of these sessions is more difficult to explain.

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Conclusions

The increase in VO_2 which occurred during the 2 mouth-breathing yoga practices could be the basis of using these practices as a form of mild exercise, especially since the oxygen consumption decreased (though not significantly) after both *sheetali* and *sitkari pranayamas*. Further assessments are required to understand the psychophysiological mechanisms involved in the changes occurring with these yoga breathing practices, which could involve the autonomic nervous system, the endocrine system, and top-down cortical regulation of these systems. At present this remains a speculation.

Conflicts of interest

None.