

## Oxygen consumption during pranayamic type of very slow-rate breathing

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To determine whether the yogic Ujjayi pranayamic type of breathing that involves sensory awareness and consciously controlled, extremely slow-rate breathing including at least a period of end-inspiration breath holding in each respiratory cycle would alter oxygen consumption or not, ten males with long standing experience in pranayama, and volunteering to participate in the laboratory study were assessed. These subjects aged 28-59 years, had normal health appropriate to their age. Since Kumbhak (timed breath holding) is considered as an important phase of the respiratory cycle in the pranayama, they were categorised into two groups of five each, one group practising the short Kumbhak varieties of pranayama, and the other the long Kumbhak varieties of pranayama. The duration of Kumbhak phase was on an average 22.2 per cent of the respiratory cycle in the short Kumbhak group and 50.4 per cent in the long Kumbhak group. The oxygen consumption was measured in test sessions using the closed circuit method of breathing oxygen through the Benedict-Roth spirometer. Each subject was tested in several repeat sessions. Values of oxygen consumption of the period of pranayamic breathing, and of post- pranayamic breathing period, were compared to control value of oxygen consumption of the pre-pranayamic breathing period of each test session. The results revealed that the short Kumbhak pranayamic breathing caused a statistically significant increase (52%) in the oxygen consumption (and metabolic rate) compared to the pre-pranayamic base-line period of breathing. In contrast to the above, the long Kumbhak pranayamic breathing caused a statistically significant lowering (19%) of the oxygen consumption (and metabolic rate). The values returned to near normal in the post-pranayamic periods. The data provide a basis to indicate that different types of pranayamic breathing may lead to different types of alterations in the oxygen consumption and metabolic rate.

The nature of physiological alterations that possibly occur with different types of yogic practices is not well understood. The present study was aimed to determine whether oxygen consumption and metabolism would be altered or not in practitioners of Yoga during the consciously regulated, extremely slow-rate, Ujjayi pranayamic type of timed breathing that includes breath- holding phase (Kumbhak) in each cycle of respiration. It was aimed to assess this in two variants of the pranayama that differed in the ratio of duration of the Kumbhak phase in the breathing cycle, one being short and the other long.

It was reported in two earlier studies<sup>1,2</sup> involving only one subject in each, that oxygen consumption during Ujjayi pranayama, when compared to the preceding period, increased in one of the subjects by +19 per cent and in the other subject by +9 per cent. It is necessary however, to examine more subjects practising pranayama to check whether such an impression of increase which is based on the data of only two subjects will be generally valid. Therefore, the present study was undertaken on ten subjects to assess the effects of two pranayamic variants on oxygen consumption of subjects under each variant. Further, it was aimed to obtain data of each subject as averages of several repeat test sessions (over 7) to improve reliability.

### **MATERIALS & METHOD**

Ten healthy male subjects of the age range of 28-59 years were selected out of the volunteers who responded to our initial contact. A subject was chosen on the following criteria: (i) pranayamic experience of sufficiently long duration, preferably for some years; (ii) normal health appropriate to age and having not suffered from any major illness; and (iii) willingness to attend a large number of test sessions without dropping out. A full explanation about the study was given to each subject and informed consent obtained. The peak flow rates of the subjects were in the normal range (for Indians) of 390-510 l/min, mean and SD being 451 + 42 l/min (determined with Wright's mini peak flow meter).

All subjects had been practising the Ujjayi pranayama with different ratios of the phase durations of the respiratory cycle. In the typical Ujjayi pranayama 3,4 the respiratory rate is markedly reduced volitionally and each cycle includes successively (i) the phase of inhalation while the glottis is kept partially closed; (ii) the phase of Kumbhak or holding of breath (retention of the inhaled air) during which the glottis is fully closed, and (iii) the phase of a steady exhalation. There may also be a phase of end-expiration Kumbhak or breath-holding in exhaled state, before beginning the next cycle. The cycles were repeated regularly while keeping respective durations of the phases similar in all the cycles of the pranayamic breathing. In typical ratio, the expiration phase is twice that of inspiration while the duration of Kumbhak in end of inspiration is twice that of expiration phase, i.e., 1:4:2 for inspiration: hold: expiration. However, different types of Pranayama differ widely in the ratios of the phase durations. The Kumbhak is to be done in ease and not to be prolonged as in breath-holding for breaking point test. During pranayama, the subject is required to become aware of sensations of passage of air through nasal passages and of filling up of lungs. The entire process of breathing is to be executed without stress and strain, under conscious control, maintaining the ratio of phase durations of each cycle of respiration, carrying on rhythmically, steadily and without jerking movements. In the end-inspiration Kumbhak phase, the perineal muscles are held in contraction, and chin lowered on to the manubrium of sternum (mulabandha, and jalandara bandha). In the end- expiration Kumbhak phase, the abdomen is drawn inwards and backwards with diaphragm in raised position (uddiyan bandha).

Since the duration of the inspiratory Kumbhak is known to be an all-important variable of the Ujjayi Pranayama, we have categorised the ten subjects into two groups of five each, viz., long and short Kumbhak types. In the long Kumbhak group (LK), the Kumbhak (in inspiration) phase duration was  $50.4 \pm 6.6$  per cent of the total duration of respiratory cycle. In the short Kumbhak group (SK) the Kumbhak phase was only about  $22.2 \pm 10.6$  percent of the total cycle duration. The inspiration-Kumbhak-expiration duration's ratio was about 1:4:2 in the long Kumbhak group, and about 1:1 (or less):1 in the short, Kumbhak group. Three subjects in each group also had the end- expiration Kumbhak. However, there were no differences in other respects, i.e., in the base-line values of the two groups of subjects. Their average ages were not significantly different (Student's 't' test), the values being  $45.2 \pm 7.4$  years for the SK group and  $38.4 \pm 13.9$  years for the LK group. Besides, the pre-pranayamic base-line values of pulmonary ventilation were not different, the value of the SK group was  $15.0 \pm 5.8$  l/min BTPS and of the LK group was  $10.3 \pm 2.5$  l/min. BTPS (Table 1). The base-line oxygen consumption also, of the two groups was not different (Student's 't' test), the average values being  $269.6 \pm 127$  ml/min STPD for the SK group and  $320.8 \pm 96.7$  ml/min STPD for the LK group (Table II).

The oxygen consumption was recorded using the closed circuit method of the Benedict-Roth apparatus<sup>5</sup>. In this method the subject breathes into an oxygen tank, the exhaled carbon dioxide having been excluded from entering the tank by absorbing it in soda lime.

**Table I**

Pulmonary ventilation (l /min BTPS)  
(Data are mean  $\pm$  SD)

Subjects	Short Kumbhak pranayama				Long Kumbhak pranayama				
	Repl-ication	Before Pranayama	During Prana-yama	After Prana-yama	Subj-ects	Repl-ication	Before Prana-yama	During Prana-yama	After Prana-yama
STY	14	$15.8 \pm 2.8$	$7.4 \pm 1.9$	$12.8 \pm 2.0$	NA	13	$6.6 \pm 2.2$	$4.5 \pm 1.0$	$6.2 \pm 1.4$
VIS	10	$15.0 \pm 3.9$	$6.9 \pm 1.0$	$14.5 \pm 2.6$	RJ	12	$9.5 \pm 2.5$	$6.2 \pm 1.2$	$10.8 \pm 2.5$
NAR	12	$7.7 \pm 2.8$	$5.3 \pm 2.3$	$7.2 \pm 2.3$	SW	15	$13.7 \pm 4.9$	$4.0 \pm 0.8$	$13.6 \pm 4.2$

AI	7	23.7 ± 6.7	8.3 ± 2.0	22.9 ± 7.3	SN	10	10.7 ± 6.7	2.5 ± 0.7	11.9 ± 2.9
Paired 't' test against 'before'			P < 0.025	Not significant	10.3 ± 2.8			P < 0.025	Not Significant
Mean ± SD		15.0 ± 5.8	7.2 ± 1.2	14.8 ± 5.7			10.3 ± 2.5	1.6 ± 1.5	10.7 ± 2.7
% of 'before'		(100.0%)	(48.0%)	(98.6%)			(100.0%)	(46.6%)	(103.8%)

Difference between 'before' values of the two pranayama types was not significant (Student's 't' test; P>0.1)

<b>Table II</b>									
Oxygen consumption									
(ml/min STPD) Data are mean ± SD									
Short Kumbhak pranayama					Long Kumbhak pranayama				
Sub-jects	Repli-cation	Before< Prana-yama	During Prana-yama	After Prana-yama	Sub-jects	Repli-cation	Before Prana-yama	During Prana-yama	After Prana-yama
STY	14	255 ± 85.0	405 ± 273.3	330 ± 171.6	NA	13	179 ± 65.2	104 ± 40.3	131 ± 63.8
VIS	10	321 ± 87.9	390 ± 129.2	238 ± 119.0	RJ	12	286 ± 138.7	190 ± 71.9	205 ± 84.9
NAR	12	442 ± 154.9	715 ± 286.7	379 ± 101.0	SW	15	432 ± 224.6	342 ± 132.8	355 ± 121.0
VJ	10	236 ± 67.4	339 ± 58.0	268 ± 179.9	STH	11	325 ± 176.9	310 ± 149.7	373 ± 164.1
AI	7	94 ± 53.4	205 ± 169.0	118 ± 75.0	SN	10	382 ± 100.0	349 ± 84.2	320 ± 120.0
Paired 't' test			P<0.05	Not significant	10.3 ± 2.8			P < 0.025	Not Significant
Mean ± SD		269.6 ± 127	4.10 ± 187.4	266.6 ± 99.4			320 ± 96.7	259.0 ± 107.6	276.8 ± 104.4
% of 'before'		(100%)	(152%)	(98.8%)			(100.0%)	(81%)	(86%)

Difference between 'before' values of the two pranayama types was not significant (Student 't' test; P>0.4)

The difference between the initial and final volumes of oxygen in the tank is the oxygen consumed by the subject in a given period of breathing. In normal tidal type of breathing, the end-expiratory points can be joined into a slanted straight line, and the difference between the two ends of the line gives the value of oxygen consumed. In the present study involving a specialized type of pranayama breathing also, the same method is useful if the line is drawn as a best-fitting average connecting the end-expiratory points. The accuracy of this value compared well (90%) against a value obtained by summing the oxygen values calculated separately for individual breaths during the period. When the amplitudes of breaths varied much more, that session was not included in the analysis. Moreover, the value for each individual being the mean of data of several test sessions, even the small errors of individual sessions would get evened out in this study. In each experimental (test) session, oxygen consumption assessments were made for the three periods:

The pre or before, the during, the post or after pranayamic practice, as illustrated in Figs 1 and 2. Each of these test periods was of about 4 min duration. The recording laboratory was air conditioned to about 27°C with relative humidity of 50 per cent. Since the subjects had to wear the face mask and breathe through the valves of the closed circuit apparatus they had not used the nostril manipulations and full chin-lock position. In between the three periods (before, during, and after) a pause or an interruption for 30 sec with breathing air was allowed while replenishing oxygen in the spirometer bell and readjusting the writing pen level. The spirometer record provided the values of tidal volume, respiratory rate and also the oxygen consumption of each of the periods. From these, the volume of gas ventilated was calculated. The oxygen values having been obtained under room temperature and pressure, they were corrected for standard temperature and pressure. Whether a change occurred in oxygen consumed during the test period of pranayama and in the period after pranayama, was assessed by comparing with the control value obtained in

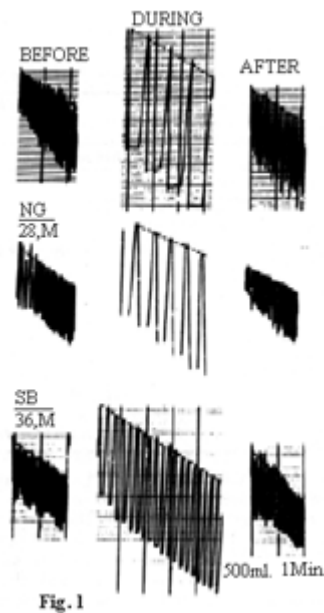


Fig. 1

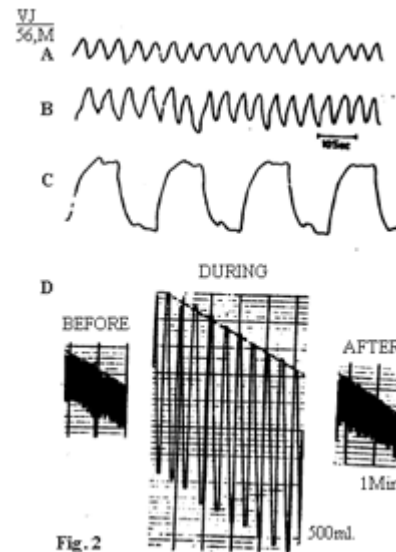


Fig. 2

**Fig. 1.** Representative record made on a polygraph with mercury strain gauge connected to the chest, and subject parallelly connected to the Benedict-Roth spirometer while, (A) breathing air with face mask valve opened to outside air, (B) breathing oxygen through the closed circuit system of the spirometer during pre-pranayamic control period, and (C) during the pranayamic practice period (inspiration recorded upwards), (D) records made on the Benedict-Roth spirometer (expiration is upwards), before, during, and after the pranayama, this case being of short kumbhak type and having both inspiratory and expiratory kumbhak phases.

**Fig. 2.** Examples of short and long kumbhak types of records of pranayamas on Benedict-Roth spirometer. Pranayama lower two subjects have both inspiratory and expiratory kumbhak phases, SB of short type, and NG of long type. (top figure) practices long type with only the inspiratory. Kumbhak phase.

The period preceding (before) the pranayama of the same experimental session, so that the status of diet or metabolism and other unknown variables prevailing on that day and time of recording would be common for both control and test data thereby not affecting the inferences. On each subject several test sessions were repeated and the average of these repeated measurements was considered as the value for that subject. Such averaged values of the three test conditions of the five subjects of the group were averaged and treated statistically 6-8. Statistical significance of difference of oxygen consumption of the pranayamic breathing, or of post-pranayamic period, from the pre-pranayamic value was assessed by the matched pairs 't' test. Comparisons across groups were made by Student's 't' test. The significance of effects of the three treatment conditions (before, during, after) for the five subjects of the group were also assessed by the method of analysis of variance 6 i.e., two-way ANOVA.

## RESULTS

The short kumbhak group (Table II) showed significant increase (52%) of oxygen consumption during the pranayamic practice period over that of pre-pranayamic control value (paired 't' test;  $P < 0.025$ ). The value returned to normal in the post-pranayamic period. Out of the total amount of oxygen consumed in the entire experimental session, 43.56 per cent was consumed during the period of pranayamic practice (paired 't' test;  $P < 0.01$ ) in contrast to only 27.7 per cent in the pre-pranayamic period, and 28.58 per cent in the post-pranayamic period. ANOVA revealed (Table III) that the effect of treatments was significant ( $P < 0.01$ ; 8.7 df 2.8).

Table iii. Analysis of variance of oxygen amounts consumed

Source	Short Kumbhak pranayama					Long Kumbhak pranayama			
	Df	SS	MS	F	P	SS	MS	F	P
Between subjects	4	213496.7	533374.2	13.7	0.001	20548.4	30137.1	0.01	
Between 'treatments'	2	67900.1	33950.1	8.7	0.01	10120.1	5060.1	5.8	0.03
Residual	8	31112.5	3889.1			6923.2	865.4		
Total	14	312509.3	22322.1			137591.7	9827.9		

The long kumbhak group (Table II) showed a significant decrease (19%) in oxygen consumption during the pranayamic practice period from that of pre-pranayamic control value (paired 't' test;  $P < 0.05$ ). Out of the total amount of oxygen consumed in the entire experimental session, 29.4 per cent only was consumed during the pranayamic period in contrast to 36.3 per cent in the pre-pranayamic period, this difference was significant (paired 't' test;  $P < 0.05$ ). ANOVA (Table III) showed that the treatments effect was significant ( $P < 0.03$ ; F 5.8, df 2.8).

If it is assumed that the respiratory quotient (RQ) is 0.82 and the kcal / 1 oxygen is 4.825, application of the DuBois formula indicates that the metabolic rate in the short kumbhak type of pranayamic breathing period will be +70 per cent higher than that of the pre-pranayamic base-line breathing, in contrast to the reduction by -20 per cent in the long kumbhak type of pranayamic breathing. Since a variation of RQ between 0.71 and 1.0 contributes to not more than a maximum of 6 per cent error, the above derivations of metabolic rate are reliable

enough to understand the effect of Pranayama.

There was no significant difference between the two groups (Student's 't' test) in the base-line pre- pranayamic pulmonary ventilation (Table 1), or in the base-line oxygen consumption values (Table II). There was a difference (Student's 't' test) only in the base-line respiratory rate, the short kumbhak group having  $13.1 \pm 2.5$ /min and the long kumbhak group having  $7.9 \pm 1.61$  /min. During pranayama the respiratory rate was lowered to 24.42 and 27.84 per cent in the short and long kumbhak types, respectively; the corresponding pulmonary ventilatory values were 48 and 46.6 per cent. During post-pranayamic period, pulmonary ventilation was restored to pre- pranayamic levels in both groups.

During both short and long kumbhak types of pranayamic breathing periods, the pulmonary ventilation (Table I) was lower than in the pre-pranayamic breathing periods (control values), but interestingly the oxygen consumption (Table II) significantly (paired 't' test) exceeded the pre- pranayamic control value in one type of pranayama (SK type), whereas it decreased significantly in the other type of pranayama (LK type). Thus the oxygen consumption was not correlated to ventilation, but the duration of kumbhak phase on the other hand, seems to play a major role.

## DISCUSSION

This type of a detailed and differential study has not been reported previously on the subject of changes of oxygen consumption during the subtypes of kumbhak-pranayamic breathing. Miles<sup>1</sup> reported data using the oxygen estimation method similar to the one used in the present research, on a single subject who practised a slow breathing, kumbhak- pranayama (Ujjayi type, but time ratios not specified), and also two non-kumbhak types of rapidly (80/min) breathing varieties of pranayamas, namely, the kapalabhati and bhastrika. In the single subject study, all the three types of Pranayama caused an increase in oxygen consumption varying from +12 to +35 per cent. Rao<sup>2</sup> also reported data on one subject, showing a 7-9 per cent increase in oxygen consumption during Ujjayi type of pranayama having time ratios of 1:4:2. The present results obtained from larger number of subjects differed from those of single subject studies<sup>1,2</sup>, since the data revealed for the first time that there could be effects of not only increase but also decrease in oxygen consumption in different sub- types of the Ujjayi pranayamas. Hence our study points out the need for a change in the perspective of understanding of effects of pranayamas.

The present study offers an indication, on the basis of the data of several test sessions conducted on a larger number of subjects, that the Ujjayi types of pranayamic practice could cause either an increase or a decrease in the oxygen consumption, depending on variations in the duration of kumbhak or the ratios of durations of different phases of the respiratory cycle.

Although the oxygen consumption was altered during both the pranayamic types, it returned after the Pranayama to pre-pranayamic levels. There was no evidence of increased consumption of oxygen following the long kumbhak pranayama, thereby indicating that no debt had been incurred during such a pranayama or that the low oxygen consumption would have matched to a lowered metabolic state during the long kumbhak pranayama. Also, there seems to be no gross lowering of PO<sub>2</sub>, or rise of Pco<sub>2</sub>, since no effects expected of arterial anoxemia and respiratory chemoreceptor stimulation were apparent as the post-pranayamic ventilation was at the same level as pre-pranayamic level. Contrary trends of oxygen consumption (implying corresponding trends to be occurring in the status of metabolism) observed during the two types of pranayamas may be related to the differences in their effects on skeletal muscular relaxation or activity, on variations of autonomic nervous system discharges altering regional blood flows and metabolism, and even on adrenal cortico-medullary secretions. The two types of Pranayamic procedures having differing patterns of consciously controlled execution of respiratory rhythms with different time ratios of their phases, and differing in experiences of resulting sensations, could have led to either increase or decrease of arousal or relaxation states and associated shifts in muscular

activities and metabolism. The differences in oxygen consumption in the two pranayamas may also be partly related to changes in brain blood flow and metabolism due to differences in intensities of regional activities of neurons in the cerebrum under differences in the nature of conscious control of the respiratory rhythm, and in the experiencing of sensations of breathing in the two pranayamas.

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