Rhythmic Breath Holding and Its Effect on Arterial Blood Pressure and Its Correlation With Blood Gases

Bharti Bhandari[1], Manisha Mavai[2], Yogendra Raj Singh[3], Bharati Mehta[4], Omlata Bhagat[4]

[1] *Department of Physiology, Government Institute of Medical Sciences, Greater Noida, Uttar Pradesh, India*

[2] *Department of Physiology, Govt. Medical College, Bharatpur, Rajasthan, India*

[3] *Department of Physiology, All India Institute of Medical Sciences, Raebarelli, Uttar Pradesh, India*

[4] *Department of Physiology, All India Institute of Medical Sciences, Jodhpur, Rajasthan, India*

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Abstract- A single episode of breath-holding (BH) is known to elevate the blood pressure, and regular breathing exercise lowers the blood pressure. This prompted us to investigate how a series of BH epochs would affect the cardiovascular system. To observe arterial blood pressure (ABP) and heart rate (HR) changes associated with a series of "BH epochs" following maximum inspiration and maximum expiration and find the underlying mechanisms for the change by autonomic activity. Thirty-five healthy young adults were instructed to hold their breath repetitively, for 5 minutes, in two patterns, one following maximum inspiration and other following maximum expiration. ABP and ECG (for Heart Rate Variability) were continuously recorded at rest and during both the maneuvers. Capillary blood gases (BG) were zanalyzed at baseline and at the breakpoint of the last epoch of BH. ABP rose significantly at the breakpoint during both the maneuvers. No change in HR was observed. There was significant fall in PO_2 from 94.7 (4.1) mmHg at baseline to 79.1 (9.0) mmHg during inspiratory and 76.90 (12.1) mmHg during expiratory BH. Similarly, SPO2 decreased from 96.3 (1.9) % at baseline to 95.4 (1.5) % and 94.5 (2.7) % during inspiratory and expiratory BH, respectively. Rise in PCO2 from 39.5(3.1) mmHg at baseline to 42.9 (2.7) mmHg and 42.1 (2.8) mmHg during inspiratory and expiratory BH respectively was observed. There was no significant correlation between blood gases and arterial blood pressure. Among HRV parameters, a significant decrease in SDNN, RMSSD, HFnu, total power and SD1/SD2 and the significant increase in LFnu, LF/HF and SD2 were observed during both BH patterns. Rhythmic BH patterns affect the cardiovascular system in similar way as a single episode of BH. Sympathetic overactivity could be the postulated mechanism for the same.

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Introduction

A variety of rhythmic breathing exercises is known to have beneficial health effects. However, there has been little effort to establish the scientific basis of the same. The following study intended to put the breathing exercises on a scientific footing. In our proposed study, we have defined an unconventional rhythmic breathing pattern that is not found in yogic manuals. The rhythmic breathing pattern includes deep inspiratory breaths or deep expiratory breaths with a breath-holding episode in between and is to be carried out for a period of 5 minutes.

Breath-holding (BH) is a voluntary act, but normal subjects are unable to hold breath till the point of unconsciousness. An involuntary mechanism overrides voluntary BH resulting in the resumption of breathing, which is called the break-point. The most likely cause of break-point and the consequent involuntary breathing is the stimulation of chemoreceptors by the fall in the partial pressure of oxygen (PaO_2) below and the rise in the partial pressure of carbon dioxide ($PaCO_2$) above their respective critical partial pressures (1). Breath-holding is known to alter autonomic responses as evinced by the associated rise in arterial blood pressure (2,3). BH also alters blood gas composition. The

Corresponding Author: B. Bhandari
Department of Physiology, Government Institute of Medical Sciences, Greater Noida, Uttar Pradesh, India
Tel: +08003996865, Fax: +91 2341738, E-mail address: drbhartibhandari@yahoo.co.in

cardiovascular effects of BH are meager and contradictory. Breath-holding increases the arterial CO_2 concentration, CO_2 being a mediator of metabolic vasodilation, may induce a fall in BP by decreasing peripheral resistance. Central chemoreceptors are located principally in the ventrolateral medulla and respond to changes in H^+ concentration. Thus they are sensitive to changes in PCO_2. The rise in PCO_2 associated with BH can directly stimulate the chemoreceptors in the vasomotor center in the medulla, thus enhancing the vasoconstrictor response of the peripheral vessels and consequently rise in blood pressure (4,5). We hypothesize that rhythmic breathing, if punctuated by BH episodes, would affect the cardiovascular system differently. Breath-holding is commonly practiced during radiotherapy, certain resistance exercises, and swimming.

In the present study, we intended to record the blood pressure and heart rate changes "immediately following a series of BH epochs," spanning 5 minutes. We also compared their differences, following BH in maximum inspiration *versus* maximum expiration and correlated the findings with the composition of blood gases. To investigate the possible underlying mechanism for the blood pressure changes, we studied the autonomic activity during both the maneuvers.

Materials and Methods

This cross-sectional study was conducted in the Autonomic Function Laboratory of the department of Physiology at our institute. It was commenced after obtaining approval from the Institutional Ethics Committee and informed written consent from all the subjects included in the study.

We recruited thirty-five healthy adult volunteers (20-30 years) of both sexes. The sample size was calculated with reference to the work by Marabotti C *et al*., 2013; using master 2.0 software (CMC, Vellore). The volunteers were selected on the basis of clinical examination, detailed history, including any present medical complaints, past history of any illness pertaining to the cardiovascular, respiratory, musculoskeletal and endocrine system, history of chest pain, or breathlessness and history of smoking, alcohol or tobacco intake. All the participants had normal blood pressure, heart rate, Electrocardiography (ECG) recording and vital capacity. Subjects with any of the above mentioned positive complaints/history or abnormal parameters, athletes and subjects who were trained in yoga were excluded from the study. An athlete was defined as a person who is trained or skilled in exercises, sports, or games requiring physical strength, agility, or stamina.

The subjects were instructed to avoid food at least two hours before the procedure, abstain from coffee, nicotine, or alcohol 24 hours prior to testing and to wear loose and comfortable clothing. All the participants were asked to report at the same time. Their age, height, and body weight were recorded. For short-term analysis of Heart Rate Variability (HRV), ECG was recorded in sitting position for 5 min after 15 min of supine rest. The recording was done in the noise-free room and room temperature was maintained at 24-28° C. Subject was instructed to close the eyes and to avoid talking, sleeping, moving hands, legs and body and coughing during the test.

Electrocardiogram and chest movements were acquired using the computer-based digital data acquisition system Biopac MP 150. Biopac MP 150 was connected to a personal computer by Ethernet interfacing, and signals were acquired using software Acknowledge (BIOPAC Systems Inc., USA) pre-installed in the computer. Lead II ECG was acquired using the bio-potential amplifier ECG BIONOMADIX (BN-TX RSPEC-3.0) with the help of shielded cables and disposable Ag-Ag Electrodes. Chest movements were recorded using the RSP BIONOMADIX (BN-TX RSPEC-3.0) amplifier connected to the sensor for recording expansion.

Sampling rates for acquiring signal was set at 1 kHz in order to have sufficient time precision in detecting the changes in all the parameters. All recordings were done for five minutes in each maneuver for the short-term assessment of HRV. RR intervals from ECG signals were detected using Nevrokard software (Nevrokard, version 6.4.0 Slovenia). HRV was assessed using linear (time, frequency domain) and non-linear (Poincare) analysis.

Continuous Blood pressure was recorded with CNAP-Monitor 500 (CNAP™ Monitor 500, CN Systems Medizintechnik AG, Graz, Austria). The output from this was fed in the Biopac MP 150 (BIOPAC Systems Inc., USA). To stabilize the blood pressure and heart rate, subjects were asked to rest for 15 min before starting the experiment.

Capillary blood was obtained by EPOC® Care-Fill™ Capillary Tube, and capillary blood gases (BG) were assessed using FDA approved EPOC® Point of Care Blood Analysis System (EPOC Reader and HOST mobile computer) based on "smartcard" technology (Epocal, Inc., Ottawa, ON, Canada).

The experiment on each subject comprised two protocols separated by a 1-hour interval during which the subject remained seated comfortably**.** Before starting the recordings, the subjects were familiarized with the experimental setup, the protocol was explained in detail, required instructions were given, and they were systematically trained for the experimental protocol. The protocols followed were:

Protocol 1 (Breath-holding in inspiration)

Capillary blood was withdrawn and analyzed for baseline values of blood gases. The subjects were asked to take deep inspiration, hold the breath as long as they can, and then expire completely. The sequence was repeated for 5 minutes in quick succession. Blood pressure (systolic and diastolic), ECG, and chest movements were continuously recorded at rest and during the maneuvers (Figure 1).

The capillary blood sample was again taken at the breakpoint of the last epoch of BH and analyzed.

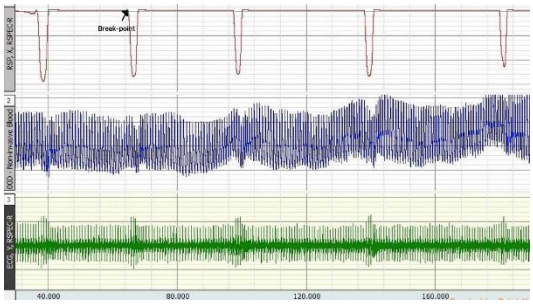

Figure 1. The actual recording of the chest movements, blood pressure, and ECG at rest and during the maneuvers when the breath is held during inspiration

Protocol 2 (Breath-holding in expiration)

The subjects were instructed to expire forcefully and hold their breath in expiration as long as possible. This process was repeated for 5 minutes in quick succession, with continuous blood pressure measurement, recording of ECG, and chest movements (Figure 2). Blood gas analysis was done at the beginning (baseline) and immediately before the breakpoint of the last BH epoch.

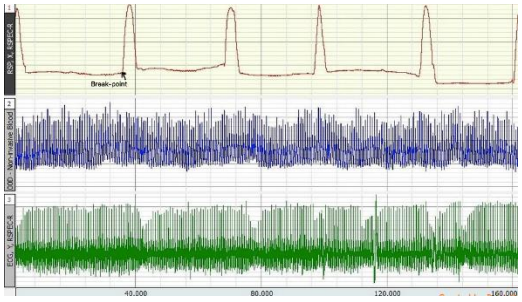

Figure 2. The actual recording of the chest movements, blood pressure, and ECG at rest and during breath-holding in expiration

Statistical analysis

Statistical analysis was done using SPSS version 21 (SPSS Software Inc., Chicago, IL, USA). All the data were presented as mean (SD). The normality of data was tested by the Shapiro-Wilk test. For parametric data, One way repeated measures ANOVA tested the level of significance. For non-parametric data, the Friedman test was used. The correlation between various parameters was assessed by Spearman's rank's correlation test. $P<0.05$ was considered to be statistically significant.

Results

The mean age of the study participants was 24.5 years (SD=4.20), Male: female=2.3:1. The mean inspiratory and expiratory breath-holding durations were 45 s (SD=9.98) and 35.18 s (SD=9.48), respectively ($P<0.05$).

Table 1 shows the cardiovascular parameters at rest and at the breakpoint of the last episode of inspiratory and expiratory breath-holding. A significant rise in systolic, diastolic, and mean blood pressure was observed at the breakpoint in both the maneuvers in comparison to the baseline values.

Table 1. Cardiovascular parameters at rest (baseline) and at the breakpoint of the last episode of inspiratory and expiratory Breath Holding

Parameters	Baseline	Inspiratory BH	Expiratory BH	Overall *P*	*P*(Within baseline, inspiratory and expiratory breath-holding)
HR (bpm)	82.40 (10.30)	83.20 (10.90)	87.98 (7.90)	df = 1.89, *P* = 0.081	0.89*, 0.06**, 0.13#
SBP (mmHg)	124.40 (10.83)	149.60 (18.10)	137.80 (16.90)	df = 1.85, *P* = 0.020	0.008* 0.255**, 0.060#,
DBP (mmHg)	80.90 (8.90)	95.60(10.20)	92.10 (10.90)	df = 1.81, *P* = 0.014	0.040*, 0.438**, 0.111#
MBP (mmHg)	95.40 (8.30)	113.20 (10.40)	110.70 (10.30)	df = 1.82, *P* = 0.018	0.01*, 0.264**, 0.040#

All values are mean (SD). $P<0.05$ were considered as statistically significant. BH: Breath-holding; HR: heart rate; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; MBP: Mean blood pressure. Inter-group (baseline, inspiratory and expiratory breath-holding) comparisons were carried out by One-way repeated measures ANOVA, with post hoc test. Here * = baseline vs inspiration, ** = baseline vs expiration, # = inspiration vs expiration

There was no significant difference in the blood pressure and heart rate between expiratory and inspiratory maneuvers.

Capillary blood gases showed a significant rise in PCO_2 and fall in PO_2 at the breakpoint of the last epoch of BH in both patterns in comparison to the baseline values. Significant decrease in oxygen saturation was observed during expiratory BH when compared to the baseline values (Table 2).

Table 2. Blood gases at rest (baseline) and at the breakpoint of the last episode of inspiratory and expiratory Breath Holding

	Baseline	Inspiratory BH	Expiratory BH	Overall *P*	*P* (Within baseline, inspiratory and expiratory breath-holding)
pH	7.40 (0.02)	7.40 (0.03)	7.39 (0.03)	df = 2.20, *P* = 0.437	0.438*, 0.311**, 0.215#
PCO_2 (mmHg)	39.50 (3.10)	42.90 (2.70)	42.10 (2.80)	df = 1.41, *P* < 0.001	<0.001*, 0.001**, 0.062#
PO_2 (mmHg)	94.70 (4.10)	79.10 (9.00)	76.90 (12.10)	df = 1.42, *P* < 0.001	<0.001*, <0.001**, 0.083#
SPO_2 (%)	96.30 (1.90)	95.40 (1.50)	94.50 (2.70)	df = 1.41, *P* < 0.001	0.037*, 0.002**, 0.006#

Values are mean (SD). *P*<0.05 were considered as statistically significant. BH: Breath-holding; PO2: partial pressure of oxygen; PCO2: partial pressure of carbon dioxide; SPO2: oxygen saturation of hemoglobin. Comparisons within the parameters during different maneuvers were carried out by one-way Repeated Measures ANOVA, with post hoc test, * = baseline vs. inspiration, ** = baseline vs. expiration, # = inspiration vs. expiration

A comparison between the time and frequency domain measures of HRV at baseline, inspiratory, and expiratory BH patterns are shown in table 3. The time-domain indices of HRV, Standard deviation of normal to the normal interval (SDNN), and the square root of the mean of squares of the differences between adjacent NN intervals (RMSSD were significantly decreased during BH episodes as compared to baseline. The spectral parameters of HRV viz. Total power (TP), Normalized high-frequency power (HFnu) were significantly decreased and Normalized low-frequency power (LFnu) and the ratio of LF to HF (LF/HF) was significantly increased during periodic BH when compared to baseline values. Dispersion (standard deviation) of points along the axis of the line of identity (SD2) showed a significant increase and SD1/SD2 showed a significant decrease without significant change in dispersion (standard deviation) of points perpendicular to the axis of the line of identity (SD1) (Table 3).

No significant correlation was found between blood pressure and blood gases (Table 4).

Table 3. Heart rate variability at rest and during inspiratory and expiratory breath holds

Parameters	Baseline	Inspiratory BH	Expiratory BH	Chi-square *P*	Wilcoxon Signed-Rank test	
					Z-value	*P*
SDNN (ms)	72.53 (54.14)	32.4 (4.19)	32.99 (6.66)	9.21, 0.010	-3.78 -3.507 -0.455	<0.001* <0.001** 0.649#
RMSSD (ms)	64.05 (19.42)	28.59 (6.84)	28.52 (9.39)	33.93, <0.001	-4.577 -4.213 -0.114	<0.001* <0.001** 0.909#
pNN50 (%)	10.04 (7.91)	9.90 (1.29)	8.33 (2.05)	5.214, 0.074	-0.023 -1.093 -3.097	0.982* <0.274** 0.002#
TP	3453 (670)	2275 (363)	1908 (353.40)	42.07, <0.001	-4.554 -4.623 -2.95	<0.001* <0.001** 0.004#
LFnu	46.35 (15.40)	53.04 (8.41)	59.05 (9.96)	18.28, <0.001	-3.097 -3.894 -2.573	0.002* <0.001** 0.010#
HFnu	41.27 (11.20)	33.04 (7.05)	27.80 (10.55)	18.5, <0.001	-3.051 -3.848 -2.391	0.002* <0.001** 0.017#
LF/HF	0.89 (0.35)	1.89 (0.55)	2.79 (1.84)	33.02, <0.001	-4.554 -4.554 -2.517	<0.001* <0.001** 0.010#

Continuance of Table 3

SD1	5.43 (1.49)	7.78 (5.29)	6.19 (3.48)	4.07, 0.131	-1.207 -0.228 -2.072	0.227* 0.820** 0.038#
SD2	6.23 (2.54)	15.16 (3.75)	13.91 (6.75)	42.49, <0.001	-4.623 -4.577 -3.541	<0.001* <0.001** <0.001#
SD1/SD2	1.08 (1.35)	0.44 (0.19)	0.46 (0.21)	23.79, <0.001	-4.167 -4.065 -0.046	<0.001* <0.001** <0.964#

Values are Mean (SD). *P* <0.05 were considered as statistically significant. BH: Breath-holding; SDNN: Standard deviation of normal to normal interval; RMSSD: The square root of the mean of squares of the differences between adjacent NN intervals; pNN50: The proportion derived by dividing NN50 by the total number of NN intervals; TP: Total power; LF: Low-frequency power; HF: High-frequency power; LFnu: Normalized low-frequency power; HFnu: Normalized high-frequency power; LF/HF; Ratio of LF to HF. Inter-group comparisons for ESI scores carried out by Freidman test, *P*<0.05 as significant; Wilcoxon signed-rank test was used for comparison between two groups; Bonferroni correction was used for post-hoc analysis, *P*<0.017 is taken as significant. * = baseline vs inspiration, ** = baseline vs expiration, # = inspiration vs expiration

Table 4. Correlation of blood gases with Arterial Blood Pressure

Parameters	Blood gas	Baseline		Inspiratory BH		Expiratory BH	
		r	***P***	**r**	***P***	**R**	***P***
Systolic Blood Pressure	PCO_2	0.34	0.07	-0.24	0.24	-0.30	0.13
Diastolic Blood Pressure		0.21	0.28	-0.19	0.34	-0.05	0.82
Mean Blood Pressure		0.02	0.67	-0.15	0.47	-0.18	0.38
Systolic Blood Pressure	PO_2	0.05	0.12	-0.21	0.29	-0.17	0.42
Diastolic Blood Pressure		0.19	0.31	-0.28	0.17	-0.12	0.56
Mean Blood Pressure		0.28	0.15	-0.21	0.29	-0.04	0.84

P<0.05 were considered as statistically significant. BH: Breath-holding; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; MBP: Mean blood pressure; PO2: Partial pressure of oxygen; PCO_2: Partial pressure of carbon dioxide

Discussion

In this study, we observed the effect of a series of breath-holding epochs," spanning 5 minutes on arterial blood pressure and heart rate. There were two patterns of BH, one following maximum inspiration and the other following maximum expiration. To establish a possible mechanism for the cardiovascular changes, the blood-gas analysis was done and autonomic activity was evaluated. In our study, we found inspiratory breath-holding duration to be significantly longer than expiratory BH duration. Activation of pulmonary stretch receptors during maximal inspiratory breath-hold sends inhibitory signals to the brain, decreasing the drive to breathe. Conversely, expiratory BH decreases the stimulus to stretch receptors, ultimately augmenting the drive to breathe. Furthermore, larger lung volume during inspiratory BH dilutes metabolically derived CO_2 levels (6,7).

We witnessed a significant rise in arterial blood pressure at the breakpoint of the last epoch of BH without any significant change in the heart rate. As expected, PCO_2 rose, and PO_2 dropped significantly at the breakpoint. Oxygen saturation reduced significantly during expiratory BH episodes. The blood gases were not found to correlate with the BP changes, suggesting that BP changes were not possible due to BH-induced hypoxia and hypercapnia. We expected heart rate to decrease with rising in BP attributable to activation of baroreceptors, but no significant changes in heart rate were recorded. The possible explanation for this could be decreased baroreceptor sensitivity during episodic breath-holding.

Hypercapnia (increased levels of carbon dioxide) and/or low levels of oxygen (hypoxia) through chemoreceptor stimulation can influence respiratory and cardiovascular functions (8,9). The influence of hypercapnia and hypoxia on arterial blood pressure is controversial. On the one hand, hypercapnia stimulates chemoreflex leading to sympathetic activation and subsequent vasoconstriction, which raises BP (8). On the other hand, there is a simultaneous dilatory effect of hypercapnia and hypoxia (10).

The literature search revealed various studies in which the effect of BH on BP and associated alterations in blood gas levels were observed, but we cannot retrieve any study investigating the effect of a series of BH episodes. Parkes *et al.*, reported a rise in BP without

any change in HR at the breakpoint of the single episode of BH, this study was also carried out in healthy young subjects. They observed that the participants could prolong breath-hold by pre-oxygenation and hypocapnia but these interventions failed to eliminate the pressure rise (4,11). This is suggestive of a limited role of altered gas composition in blood pressure rise. Similarly, our study also disproves the conventional explanation that the rise in BP is caused by hypoxia and hypercapnia of breath-holding through (peripheral) chemoreceptors (12). Breath-holding in competitive divers (13) and during synchronized swimming (14) have reported a significant fall in alveolar oxygen pressure with minor CO_2 pressure changes. Matheson and McKenzie, 1985 observed significant reductions in arterial pH, arterial PCO2, and arterial HCO_3 at the end of exercise session in trained individuals when breath-holding was done during intense intermittent exercise. (15) Coetsee and Terblanche, 1988 observed similar changes following breath-holding during exercise (5).

The other conceivable mechanism of BP changes with BH could be sympathetic activation. Breath-holding is known to alter autonomic responses. Bhargava *et al.*, have demonstrated a significant increase in blood pressure following breath-holding, which was reduced after certain yogic exercises (2). Numerous works by Indian authors have demonstrated the benefits of breathing exercises on the autonomic nervous system and consequently, on the cardiovascular system. (16-18) Slow rhythmic breathing has shown to improve autonomic functions. But in our study, slow rhythmic breathing pattern *i.e.,* deep breathing punctuated by breath holding increased sympathetic activity as depicted by HRV findings. The parasympathetic withdrawal was also observed. However, no change in heart rate was noticed following BP rise. Overall autonomic variability was significantly decreased due to BH. Contrary to our findings, one of the preliminary studies on the effect of BH on HR has depicted a baroreceptor-mediated large HR deceleration with general autonomic stimulation (19). Recently, Gustavo A. Reyes del Paso *et al*., 2015 postulated breath-holding as a simple manipulation to reduce pain perception (20). Unlike our study, they demonstrated HR deceleration with the increase in BP, which was mediated by the activation of the baroreceptor reflex and its efferent vagal response. Similar to the findings of our study, Parkes MJ *et al*., 2014 & 2016 demonstrated increased BP without associated HR deceleration (4,11). The possible explanation we could contemplate is decreased baroreflex sensitivity during episodic breath holds, but this needs further exploration.

We initiated with the hypothesis that BH, if carried, we rhythmically can lower BP like other slow breathing exercises, but the study has disproved it. Unlike other slow breathing exercises, this breathing pattern was found to raise BP, probably due to sympathetic activation. The associated parasympathetic withdrawal was also observed. However, no change in HR may be due to decreased overall heart rate variability and decreased baroreflex sensitivity. To confirm the cause, we need to extend the study further, focusing primarily on baroreflex sensitivity and blood pressure variability. Keeping in mind the changes in cardiovascular parameters and blood gases associated with repetitive breath-holding, *i.e.,* dramatic rise on blood pressure and fall in oxygen saturation, we suggest that the trainees should be aware of the risks associated with prolonged and repetitive breath holds during exercise sessions and should undergo regular checkup for any cardiovascular morbidity.

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