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Review Article

Alternate nostril breathing: a systematic review of clinical trials

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ABSTRACT

Anulom-vilom Pranayama/ alternate nostril breathing (ANB)/Nadi-suddhi pranayama is one of the common yogic breathing techniques and involves breathing through one nostril at a time while closing the other nostril manually. This study aimed to summarize effects of independent ANB on various physiological parameters, to evaluate safety issues in clinical populations and collect published primary scientific evidence on the benefits of ANB. PubMed/Medline, Cinahl, Web of Science and Google Scholar were searched using the following terms: Alternate nostril breathing, Anulom-vilom/ anuloma-viloma pranayama, Nadi-shodhan/Nadi-shodhana pranayama. Forty-four randomized controlled trials were included in this review paper. These studies evaluated the effects of alternate nostril breathing on parameters of the autonomic nervous system, cardiopulmonary system, cognitive functioning, problem solving and motor memory retention. Of the studies, ten showed a high level of bias; twenty-nine showed a low level of bias and five showed an unknown level of bias as per Cochrane systemic review guidelines. Most of the studies included healthy subjects and age range was eight to seventy years. Alternate nostril breathing has few variations and standardization of the technique is yet to be established. This technique provides high level evidence for positive outcomes for the autonomic nervous and cardiopulmonary systems. There is also high level of evidence regarding improvement in cognitive functioning with regular practice of alternate nostril breathing. More clinical trials are required to evaluate the effects of alternate nostril breathing in clinical populations and to synthesize effective frequency and duration parameters.

Keywords: Alternate nostril breathing, Anulom-vilom pranayama, Cardio-pulmonary and autonomic function, Slow breathing exercises, Systemic review, Yoga

INTRODUCTION

The focus of this research paper is to evaluate independent effects of the yogic breathing exercise, alternate nostril breathing (ANB), on human physiological and cognitive functions. Currently, there is developing interest in using alternative and complementary therapies to manage chronic ailments and debilitating diseases. Among alternative and complementary therapies, yoga is widely used to improve quality of life. The Yoga Sutras compiled by Indian philosopher Maharshi Patanjali includes Ashtanga yoga which has eight limbs/components: Yama (form of moral imperatives), Niyama (virtuous habits and behavior), Asana (postures), Pranayama (control of breath), Pratyahara (withdrawal of senses), Dharana (concentration and introspective focus), Dhyana (profound meditation), Samadhi (state of trance/meditative consciousness).[1] Pranayama includes various techniques to regulate breathing by altering rhythm, rate, phase duration, depth; and by consciously controlling nostril use with awareness and precision. Mental status (anxious versus calm) is reflected by breathing pattern and it is believed that conscious regulation is key to achieving control over mind/mental status.

Anulom-viloma Pranayama/ alternate nostril breathing (ANB)/Nadi-suddhi pranayama is one of the common yogic breathing techniques and involves breathing through one nostril at a time while closing the other nostril manually. The normal nasal cycle consists of alternating phases of congestion and decongestion of nasal tissue based on predominance of parasympathetic or sympathetic tone.[2] Breathing alternately through each nostril helps to restore autonomic nervous system balance. In the past two decades, there has been an increase in the practice and studies of alternate nostril breathing. Potential benefits of regular practice of ANB include modulation of sympathovagal balance, improved cardiac function, refined metabolism, stress relief, increased cognitive acumen, and the attenuation of normal aging, among others. ANB is easy to learn, cost-effective and does not require any equipment or major time investment. Though there are few review articles on various types of yoga including pranayama are available, to the best of author's knowledge there is no known review article on effects of ANB. Therefore, the current review paper aims to summarize the effects of independent ANB on various physiological parameters, to evaluate safety issues in clinical populations and collect published primary scientific evidence on the benefits of ANB.

METHODS

This paper is a systematic literature review of primary research of alternate nostril breathing on physiological variables.

The search included English language literature from 1996 to present (as per 03/27/17). The following databases were used: PubMed/Medline, Cinahl, Web of Science and Google Scholar, using the following terms: Alternate nostril breathing, Anulom-vilom/ anulom-viloma pranayama, Nadi-shodhan/Nadi-shodhana pranayama. A separate search was conducted for each of these terms. The following inclusion criteria were used: primary research; on alternate nostril breathing/Anulom-vilom Pranayama/ Nadi-shodhana Pranayama. Studies were excluded: if not primary research; if ANB was not the sole intervention and if results were reported of multiple interventions instead only of ANB. This review paper aimed to collect published primary scientific evidence on the benefits of this specific yogic breathing technique so studies involving only unilateral nostril breathing is not included in this review paper.

One reviewer reviewed each paper using a standardized data extraction form as per guidelines from Cochrane Handbook for Systematic Reviews of Interventions (Version 5.1.0).[3] Extracted data included authors, year of publication, sample size, interventions, main outcomes, and salient features. The data extraction process is detailed in Figure 1. Different studies have used various terms for ANB and certain physiological parameters. To maintain consistency, more accepted, or whenever possible, standard terms are used throughout this paper. For example, ANB has been described as Anulom-vilom or AV or AVP (Anulom-vilom Pranayama) or Nadi-shuddhi in different studies.

Cochrane Handbook for Systematic Reviews of Interventions (Version 5.1.0) was used to assess quality and risk of bias. The domains of bias reviewed are: random sequence generation, allocation concealment, blinding of participants and personnel, incomplete outcome data, selective reporting and other sources of bias.[3]

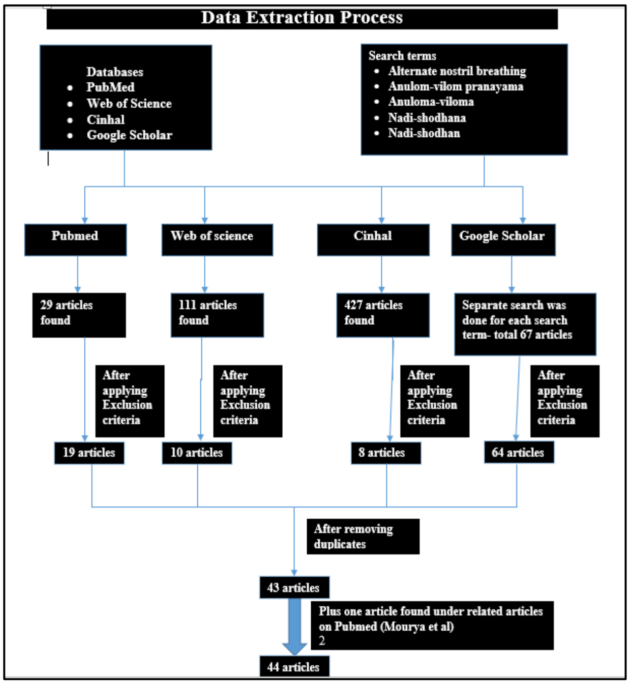

Figure 1: Data extraction process.

RESULTS

This review includes 44 randomized controlled studies. The year of publication and authors, study design, sample size, age of participants, previous yoga experience, ANB dosage, outcome measures, results and salient findings for each study are reported in Table 1. Thirty-nine studies had healthy persons as subjects; two studies included hypertensive patients as subjects; one study included pre-hypertensive obese patients as subjects; one study included females suffering from premenstrual syndrome and one study had asymptomatic alcoholics.

Results of risk level of bias are presented for each study in Table 2. Ten studies showed a high level of bias, while twenty-nine studies had a low level of bias and five had an unknown level of bias due to insufficient details available.

Participants characteristics

Participant age ranged from 8-70 years. Three studies included children as participants.[4-6] Seven studies included subjects with no prior yoga/breathing exercise experience.[7-13] Eleven studies included subjects who were practitioners of breathing exercises and other components of yoga.[14-24] Their experience ranged from seven days to eighty-six months. Twenty-six studies did not provide details regarding prior yoga experience. Thirteen studies exclusively used male subjects as participants; two studies had only female subjects as participants and the other studies tested males and females.[14,15,17,19,21,22,24-31,46]

Table 1: Summary of primary studies examining the effects of alternate nostril breathing.

Study	Sample size	Study design	Age (years)	Prior yoga practice	Intervention dosage	Outcome parameters	Results	Salient features
Telles et al[14]	N=26 M (study group) N=15 M (control group)	Randomized-controlled study	23.8±3.5 26.1±4.0	6-72 months None	ANB: 15 min BAW: 15 min None	HRV, BP, HR, RR interval (Pre, during and post)	During and Post ANB: ↑ RMSSD, ↑NN50, ↑RR interval, ↓ BR, ↓SBP. BAW: ↓BR Control: ↑ BR	BR: ANB:11.96±2.12 BAW:13.88±1.97 Conrol:16.35±1.98
Telles et al[15]	N=20 M	Randomized-Control trial	27 ± 4.9	30.2±24. 4 months	ANB: 40 min BAW: 40 min	P300 task elicited with simple oddball paradigm. Peak amplitude and latency of P300 at Fz, Cz and Pz sites	ANB: ↑ peak amplitude at Fz, Cz and Pz sites ↓ peak latency Fz BAW: ↑peak amplitude at Cz	-
Subramanian et al[7]	N=25 BMI < 26	Crossover study	17-35	None	5 min ANB @ 6 & 12 breaths/min	HRV before and after	For both: ↑ LF, ↑LF: HF, ↓HF	-
Garg et al[30]	N =51 F Postmenstrual phase	Randomized-control trial	21.71±3.1	-	ANB, RNB, LNB 45 min for 1 week	Wechsler Adult Intelligent Scale	ANB, RNB, LNB: ↑ in digit span forward and backward, associate learning, spatial memory	-
Yadav et al[8]	N= 16 (study group) N=14 (control) N=10 (breathing late group)	Randomized control trial	18-27	None	Study: 30 min ANB Control : none Breathing late ANB after first retention test	Testing of newly learnt motor skill immediately and 24 hours after 30 min of intervention	Improved motor memory in immediately and after 24 hours in breathing immediate and late group	BR 8-10/min Inhalation for 2 sec, hold for 2 sec, exhalation for 4 sec
Telles et al[16]	N= 90 3 groups	Randomized controlled study	49.7±9.5 With Essential hypertension	Minimum 6 months	ANB:10 min BAW: 10 min control: 10 min	BP Purdue pegboard score	ANB: ↓ SBP, ↓ DBP, ↑ score for both hands; BAW ↓ SBP, Control: ↑ score (at dominant hand)	Right handed subjects
Telles et al[17]	N=29 or 39 M	Crossover study	26.0 ± 5.5	25.5 ± 5.0 months	45 min RNB, LNB, ANB,BAW, control.	The P300 event related potential using an auditory oddball paradigm from C3 and C4 sites	Post RNB: lower P300 peak latency at l C3 (left scalp) compared to C4 (right scalp)	Difference of details in abstract and main text
Bhavanani et al[18]	N=20	Crossover study	34.10 ± 13.62	> 3 months	9 rounds of RNB, LNB, SB,CB, ANB , NB on 6 separate days (definition below)	HR, BP, Reaction time	RNB: ↓ ART,↓VRT LNB: ↓ HR, ↑ ART SB: ↑ DBP, ↑ MAP, ↓ ART, ↓VRT CB: ↓ HR, ↓	BR:5-6/min Right handed subjects

							SBP, ↓ MAP, ↓ RPP, ↓ double product, ↑ ART, ↑VRT ANB: ↓ SBP, PP, RPP	
Ghiya et al[9]	N=20	Crossover study	22.3±2.9	None	30 min ANB PB (normal breathing @ 5/min	MAP, HRV before and after	ANB and PB: ↑ ln TP, ↑ ln LF, ↑ ln HF	BR:5/min
Sinha et al[44]	N=25	Self-controlled study	18.48 ± 0.55	-	15 min ANB for 6 weeks.	Deep breathing test and Orthostatic tolerance test	Both test improved/ increase in parasympathetic activity	-
Turankar et al[41]	N=6 (ANB group) N= 5 (control)	Randomized controlled study	27.83 ± 0.91	-	ANB 20 min Rest 20 min Twice/day for 7 days	PR, GSR (at rest, after standing, after stepping), PFTs, BP	ANB: ↓ resting GSR, ↓ resting pulse rate, ↓ GSR drop after standing Control: ↓ PR	6 sec inhalation 6 sec hold 6 sec exhalation 30 cycles twice/day
Bhardwaj et al[47]	N=40	Self-controlled study	16-70	-	30 min ANB For 40 days	Clinical endoscopic, radiological parameters, MCC test (see footnotes)	Improved all parameters	Vit A as supplement during the study
Dhungel[32]	N=36 32 M, 4 F	Self – controlled study	24.67±2.35	-	15 min ANB For 4 weeks	RR, PR, BP, PEFR, Pulse pressure	ANB: ↓ RR, ↓PR, ↓DBP, ↑ PEFR,↑ Pulse pressure	-
Srivastava et al[43]	N= 40 20 F, 20 M	Self-controlled study	17-22	-	15 min ANB for 8 weeks of 8 weeks	BR, BP, HR, PEFR, GSR, Before, at 15 min, at 2 weeks and at 8 weeks	After 15 min: ↓ BR, ↓SBP, ↑ PEFR (for only F) After 8 weeks: ↓ BR, ↓ HR, ↓ SBP, ↓DBP (for only F), ↑PEFR	-
Naveen et al[6]	N= 27 in each of five groups	Randomized controlled trial	10-17	-	27 rounds, 4X/day, for 10 days of RNB, LNB, ANB, BAW, control	Verbal and spatial memory scores	RNB, LNB, ANB, BAW: ↑ spatial memory score	Rt hand dominant subjects
Telles et al[19]	N= 20 M Rt handed	Crossover study	28.4 ± 5.7	39. 3 ± 33.2 months	30 min RNB, LNB, ANB, BAW. 1 session/day	Letter cancellation task	ANB, RNB: Improved letter cancellation task	Rt hand dominant Subjects
Raghuraj et al[20]	N=12	Crossover study	25.6±3.1	19.7± 12.8 months	15 min ANB 1 min Kapalbhati Either session on two separate days	HRV	ANB: No changes Kapalbhati: increased sympathetic activity	-
Raghuraj et al[4]	N=130	Crossover study	11-18	-	27 rounds 4X/day RNB, LNB, ANB, BAW, Mudras for 10 days	Hand strength	ANB, RNB, LNB: ↑ hand strength	Right hand dominant.
Raghuraj et al[22]	N=21 M	crossover study	27.5 ± 6.3	14.6 ± 10.7 months	30 min RNB,LMB, ANB, BAW, Control 5 separate days for each session	Before/ during and after the session HRV, BR, BP, skin conductance, finger plethysmograph amplitude (FPA)	ANB: ↓ BR, ↑ HR , ↓ SBP & ↓DBP (after practice), ↑HRV in during practice:(↑ LF, ↑ LF/HF, ↓HF), ↑ skin conductance, ↓ FPA	Right hand dominant; 3 months yoga training + 1 month breathing practices

Pal et al[27]	N= 60M Slow & Fast breathing group	Randomized control trial	17.65 ± 0.15	-	3 months twice/d Slow breathing 30 min ANB Fast breathing group 30 min fast breathing	HR response to standing HR response to deep breathing Valsalva ratio Bradycardia ratio Tachycardia ratio	ANB:↓ in resting HR, Improved parameters for the test HR in response to standing, Improved parameters for the test HR response to deep breathing	6 sec inhalation, 6 sec hold, 6 sec exhalation; 15days of training prior to study
Dullo et al[42]	N=40 M=20, F=20	Self-controlled study	17-22	-	4 months: twice/d 10 min ANB	PEFR $FEF_{25-75\%}$	ANB: ↑ PEFR, $FEF_{25-75\%}$	-
Mourya et al[37]	N=60 Stage I hypertension	Randomized control study	20-60	-	3 months twice/d Slow breathing 15 min ANB Fast breathing: 15 min	BP, Standing to lying ratio (S/L ratio) Immediate heart rate response to standing (30:15 ratios) Valsalva ratio Heart rate variation with respiration (E/I ratio) Hand grip test Cold pressor response	ANB: ↑(S/L ratio), ↑ (30:15 ratios), ↑ Valsalva ratio, ↑ E/I ratio, ↑ diastolic BP increase in hand grip test, and both diastolic and systolic BP increase in cold pressor test, ↓ SBP, ↓ DBP Fast breathing: ↓ SBP, ↓ DBP	For ANB:6 sec inhalation, 6 sec exhalation BR 5-6 b/min Two weeks of training prior to study
Thakur et al[36]	F=12, M= 18	Crossover study	25.83±3.41	-	2 weeks: 30 m/d RNB, LNB, ANB, BAW; 4 separate days for each session	Wechsler memory scale Before and after intervention at end of 2 weeks	ANB: ↑ Digit span forward RNB: ↑ Digit span forward and ↑ Digit span backward	2 weeks of practice prior to study
Bhavanani[23]	N=16 F= 11, M= 5	Crossover study	31.06 ± 8.96	> 2 months	27 rounds ANB (Rt nostril initiated): NS (Lt nostril initiated ANB)	HR, BP, ART (Auditory reaction time), VRT visual reaction time)	ANB: ↑ HR, ↑ SBP, ↑ DBP, ↓ ART, ↓ VRT NS: ↓ HR, ↓ SBP, ↓ DBP, ↑ ART, ↑ VRT	BR: 5-6/min; Right hand dominant for all subjects
Joshi et al[21]	N=21 M	Crossover study	26 ± 5.5	39.4 ± 57.3 months	20 min; RNB, LNB, NB, BAW, Control.	Hand grip strength	No changes before and after	Right hand dominant for all subjects
Sivapriya et al[5]	N=115	Self-controlled	8-14	-	30 min 45 days	PEFR, FVC, FEV_1, BR	ANB: ↓BR, ↑ all PFTs	10 days of training
Gupta et al[24]	N=30 M	Self-controlled study	60-70	7 days of training	3 months ANB	Beck Depression Inventory, Sinha W-Aself-analysis form	↓ depression and ↓ anxiety score	ANB session duration not mentioned
Malhotra et al[38]	PR: N=66 Reaction time N=30	Self-controlled study	-	-	ANB 12 cycles	PR, Online reaction time test	↓ PR, ↓ reaction time	-
Sharma et al[31]	60 F with Premenstrual syndrome (3 groups) + 30 F age matched control	Randomized control study	18-40	-	3 menstrual cycle Group A control Group B ANB 8-10 min Group C Yogic asanas Control	BR, HR, BP, GSR, T, EMG	Group A: ↓SBP, ↓ GSR, ↓ BR,↑ T Group B (ANB): ↓ HR, ↓SBP, ↓DBP, ↓ EMG, ↓ GSR, ↓ BR, ↓ T Group C:↓SBP, ↓DBP, ↓ EMG, ↓ GSR, ↓ BR, ↓ T	Inspiration:hold: expiration ratio – 2:8:4
Jain[28]	N=60 M	Self-	17-25	-	ANB 15 min	HR, BP, CO,	↓ all CV	-

	Pre-hypertensive Obese	controlled study			6 weeks	SV, CI, SVI, SPR, SVR	parameters,	
Singh et al[29]	Study: 15 M Control:15 M	Randomized controlled	18-24	-	6 weeks ANB 30 min/day,	HR, BP, VC	↓ HR, ↓ SBP, ↑VC	With breath hold 1-2 sec
Dhanvijay et al[33]	N=60	Self-controlled study	17-25	-	ANB 15 min 12 weeks	PR, BP, BR, PEFR	↓SBP, ↓DBP, ↑ PEFR	1 cycle/ min
Kumari et al[45]	N= 100 Hypertensive patients;	Randomized controlled trail	-	-	ANB 15 min Control: None	HR, BP	↓SBP, ↓DBP, ↓ BR	-
Mohan et al[46]	N=60 M Group A BMI < 25, Group B BMI >30	Self-controlled study	25-35	-	ANB 15 min	HR, BP	Group A and Group B: SBP, ↓DBP, ↓ HR	-
Jain et al[25]	N=100 M	Self - controlled	17-23	-	ANB for 15 minutes	HR, BP, CO, SV, CI, SVI, SPR, SVR, SVRI	↓ all CV parameters	-
Kumar[40]	28 asymptomatic alcoholics, 28 age matched control]	Randomized controlled study	-	-	10 rounds ANB 10 days Both groups	GSR	ANB: ↓ GSR in both alcoholics and nonalcoholics	Inspiration :retention - 1:2 at the beginning progressed to 1:4.
Malhotra et al[39]	N= 66	Self-controlled study	-	-	ANB 12 cycles	Reaction time	ANB: ↓ Reaction time	With breath hold
Dhanvijay et al[44]	N= 60	Self-controlled study	17-25	-	12 weeks: ANB 15 min	Valsalva Ratio Blood pressure response to isometric Hand grip test	ANB: ↓ DBP in response to isometric hand grip test	1 cycle/min
Goel et al[35]	N=30	Self-controlled study	18-40	-	10 min ANB (Nadishuddhi Pranayama)	HR, BP, RPP,PR. QTc, QRS interval	ANB: ↓ HR, ↓ PR, ↓ SBP, ↓ RPP	-
Dhadse et al[11]	Study N=30 control N= 30	Randomized controlled study	18-22	None	8 weeks 20 minANB Control: none	Visual reaction time for green and red light	ANB: ↓ VRT for red and green light	Inhalation: hold: exhalation 2:8:4.
Dhadse et al[10]	Study N=30 control N= 30	Randomized controlled study	18-22	None	8 weeks 20 min ANB Control: none	Auditory reaction time for high and low tone	ANB: ↓ART for high and low tone	Inhalation: hold: exhalation 2:8:4.
Garg et al[12]	N= 30	Self-controlled study	17-21	None	12 weeks 25 min ANB	VC, PEFR, MVV before, at 6 and 12 weeks of intervention	After 12 weeks ANB: ↑ VC, ↑ PEFR, ↑ MVV	Inhalation: hold :exhalation: 3 sec:6 sec:3 sec
Shubba laxami[13]	N=30	Randomized control trial	17-20	None	Study: 20 min Group A: rest Group B:quiet breathing	HR, BP, PEFR, Time for simple problem solving	ANB: ↑ PEFR, ↓ HR, ↓ SBP, ↓ time for simple problem solving	1-2 sec breath hold
Jain[26]	N = 60 M Obese BMI ≥ 30	Self-controlled study	22.3-2.4	-	before, immediately after and 5 min after of cold pressure test(CPT) with and without ANB	HR, BP, SVR, SVRI, SV, SVI, CO, CI, CPT	Without ANB:↑CV parameters (DBP, HR, SPR, SVRI) immediately and 5 min after CPT, With ANB practice CV parameters increased but came to baseline after 5 min of CPT	-

The outcome parameters which did not show any significant changes are not mentioned under the results column. ANB- alternate nostril breathing, M- male, F-female, BAW-breath awareness (participants pays conscious attention to natural flow of breath),HRV-heart rate variability, BP-blood pressure, ↑- increase, ↓-decrease, PR- pulse rate interval-systolic blood pressure, DBP-diastolic blood pressure, BR-breathing rate,NN50-the number of interval differences of successive normal to normal intervals greater than 50 ms, RMSSD-the square root of the mean of the sum of squares of differences between adjacent NN intervals, LF-low frequency on HRV,HF-high frequency on HRV,RNB- right nostril breathing, LNB-left nostril breathing, Fz-frontal site, Pz- parietal site, Cz-vertex site for electrode position as per Jasper et al. 1958, Right UNB (SN)- right nostril breathing, Left UNB (CN)- Left nostril breathing, SB- Breathing in through right nostril and out through the left, CB- Breathing in through left nostril and out through the right NS- Breathing in through left nostril and out through right followed by breathing in through right and out through left NB - Performance of normal breathing through both nostrils, PP-pulse pressure SBP-DBP, MAP/MP- mean arterial pressure = DBP + 1/3 pulse pressure, GSR-galvanic skin resistance double product- HR × MAP/100,RPP- rate pressure product = HR × SBP/100, E:I ratio = longest RR interval during expiration/Shortest RR interval during inspiration, 30:15 ratio = interval of 15th and 30th beats (Bannister et al. 1992), MCC test- Saccharin mucociliary clearance test, PFTs- pulmonary function tests, PEFR-pulmonary expiratory flow rate, VC-vital capacity, MVV-maximum voluntary ventilation, FEF 25%-75%-Forced expiratory flow 25–75%, FEV1- forced expiratory volume at one second, Kapalbhati -breathing technique which involves inhaling deeply and start exhaling forcibly at the rate of 120 breath cycles per min (2.0 Hz frequency). The rapid active exhalations are accomplished by rapid, forceful movements of the abdomen followed by passive, effortless inhalation, Valsalva ratio- a measure of the change of heart rate that takes place during a period of forced expiration against a closed glottis or mouth piece, Bradycardia ratio - (from ECG recording of Valsalva maneuver) Longest R-R interval shortly after the strain/ Mean R-R interval of the period of 30 sec before the strain, Tachycardia ratio - (from ECG recording of Valsalva maneuver)Shortest R-R interval during the strain/Mean R-R interval of the period of 30 sec before the strain, Standing to lying ratio (S/L ratio)- the ratio of longest R-R interval during the 5 beats before lying down to shortest R-R interval during 10 beats after lying down , Immediate heart rate response to standing (30:15 ratios)- ratio of R-R interval at beat 30 and at beat 15 after standing, Heart rate variation with respiration (E/I ratio) - the sum of the six longest R-R intervals divided by the sum of the six shortest R-R intervals (Bannister et al. 1992), FPA-Finger plethysmograph amplitude, DBD- Heart rate response to deep breathing, ART-auditory reaction time, VRT-visual reaction time, T-body temperature, CO- cardiac output, SV- stroke volume, CI-cardiac index, SVI- stroke volume index, SPR/SVR- systemic vascular resistance, SVRI- systemic vascular resistance index, QTc-QT interval, QRS-QRS intervalDifferent studies have noted different acronyms for same terminology (mean arterial pressure as MAP or MP). To maintain consistency throughout the review paper standard acronym has been used for all the relevant studies

Alternate nostril breathing technique

Alternate nostril breathing involves breathing through one nostril at a time (while manually closing the opposite nostril) while seated in a cross-legged/lotus position or any comfortable erect spine posture. There are variations regarding which nostril to block first, when to switch between nostrils, how long to hold breaths, and duration of inhalation/exhalation, etc. Eighteen studies used technique which requires one nostril to breath in and opposite to breath out (for example, left nostril to breath in and right nostril to breath out, followed by right nostril to breath in and left nostril to breath out).[4,6,14-23,30,32-36] Seven of these studies did not specify which nostril was blocked first or if they started with inhalation or exhalation.[6,15,16,19,22,30,36] In 14 studies, subjects were asked to hold their breath and/or were given specific duration for inhalation, breath retention and exhalation phase (Table 1 for details) while performing ANB.[7-13,27,29,31,37-41] Six studies included the following pattern: breathe out through left nostril, then breathe in through right nostril and repeat this pattern once, twice or three times, before switching the nostrils to breathe out through right nostril, breathe in through left nostril and repeat this once, twice or three times before switching again.[28,42-44,46] Another study involved a mixed pattern of cycles of unilateral nostril breathing, cycles of normal breathing, cycles of opposite unilateral nostril breathing and cycles of alternate nostril breathing.[3] Seven studies instructed subjects to focus on their breath while practicing ANB.[6,12,15-17,19,22]

Intervention dosage

Twenty studies reported acute effects of ANB after a single session with duration ranging from 5-40 minutes.[7-9,13-19,21-23,25,26,35,38,39,45,46] The other studies reported multiple sessions with frequencies ranging from four times per day to a single session for four months. In those studies, duration of a single session ranged from 8-45 minutes. Ten studies reported a session duration in terms of number of breathing cycles, ranging from 9-27 rounds per session.[4,6,12,18,23,33,34,38-40]

ANB and autonomic nervous system

Five studies evaluated the effects of ANB on cardiac autonomic function.[7,9,14,20,22] Ghiya et al, reported improved autonomic modulation of the heart from changes in frequency domain parameters of HRV after a single, low-breathing rate ANB session. In support of this result, Telles et al, reported increased vagal activity via enhanced time domain parameters of HRV after a single session of ANB. By contrast, no changes in HRV occurred in the study by Raghuraj et al, and increased sympathetic activity was noted during and immediately after a single ANB session.[7,22] Five studies evaluated effects of 6-12 weeks of ANB on the autonomic nervous system (except study by Jain et al, which consisted of a single session) by recording heart rate response to the following tests: deep breathing, orthostatic tolerance, HR in response to immediate standing, standing to lying ratio, 30:15 ratios, valsalva ratio, tachycardia ratio, bradycardia ratio, expiration to inspiration ratio, as well as blood pressure response to hand grip and cold pressure tests.[26,27,34,37,44] These studies noticed enhanced autonomic functioning in response to the following tests: deep breathing, orthostatic tolerance, HR in response to immediate standing, standing to lying ratio, 30:15 ratio, Valsalva ratio except for Pal et al, (who reported no significant changes in Valsalva ratio but improved results for other autonomic function tests). Although Mourya et al, reported increased BP in response to the isometric hand grip and cold pressure tests, Dhavijay et al, noticed decreased diastolic blood pressure in response to hand grip test.[34] Three studies reported a reduction while one43 found no changes in GSR.[31,40,41,43]

ANB and cardiovascular system

Fifteen studies found significant decreases in systolic blood pressure and eleven studies marked a significant reduction in diastolic blood pressure after practicing ANB while two studies and reported no changes in blood pressure.[9,13,14,16,18,22,25,28,29,31,33,35,37,41,43,45,46] Eleven studies noted a reduced heart rate and two studies noticed decreased pulse rate and following ANB practice. Bhavanani et al, found that 27 rounds of right nostril-initiated ANB is associated with increased heart rate and blood pressure while 27 rounds of left nostril initiated ANB is associated with decreased heart rate and blood pressure.[13,14,22,23,26-29,31,32,35,38,46]

Table 2: Risk of bias.

Study	Selection bias		Performance bias	Detection bias	Attrition bias	Reporting bias	Other bias	Risk of bias
	Random sequence generation	**Allocation Concealment**	**Blinding of participants and personnel**	**Blinding of outcome assessment**	**Incomplete outcome data**	**Selective reporting**	**Any other concerns**	
Telles et al	Yes (confirmed by author)	Yes	Partially	Yes (confirmed by author via email)	2 subjects dropped out	None		Low
Telles et al	Yes (confirmed by author)	Yes	Partially	Yes (confirmed by author via email)	No	None		Low
Subramanian et al	Not mentioned (Important domain)	Not mentioned	Not mentioned	Not mentioned	None	None	Limited information	Unknown
Garg et al	Yes	Not mentioned	Not mentioned	Not mentioned	None	None		Low
Yadav et al	Randomization done only	Not mentioned	Not mentioned	Not mentioned	None	None	actual mean ± SD is not given	Low
Telles et al	Yes (confirmed by author)	Yes	Partially	Yes	None	None		Low
Telles et al	Yes (confirmed by author)	Yes	Partially	Yes (confirmed by author via email)	None	None		Low
Bhavanani et al	Yes	Not mentioned	Not mentioned	Not mentioned (Objective measurements)	None	None	No actual mean± SD;	Low
Ghiya et al	Yes	Not mentioned	Not mentioned	No	No	None		Low
Sinha et al	N/A	N/A	Not mentioned	Not mentioned	No	None		Low
Turankar et al	Yes	Not mentioned	Not mentioned	Yes	No	None	-	Low
Bhardwaj et al	N/A	N/A	Not mentioned	Not mentioned	6 subjects dropped out	None	Vit A intake Threat to validity	High
Dhungel	N/A	N/A	Not mentioned	Not mentioned	None			Low
Srivastava et al	N/A	N/A	Not mentioned	Not mentioned	None	None		Low
Naveen et al	Yes (confirmed by author)	Yes	Partially	Yes (confirmed by author via email)	None	None		Low
Telles et al	Yes (confirmed by author)	Yes	Partially	Yes (confirmed by author via email)	None	None		Low
Raghuraj et al	Yes (confirmed by author)	Yes	Partially	Yes (confirmed by author via email)	None	Yes No mean ± SD results	Different baseline measurements (HF) between two groups;	High

Raghuraj et al	Yes (confirmed by author)	Yes	Partially	Yes (confirmed by author via email)	None	None	unknown carryover effects	High
Raghuraj et al	Yes (confirmed by author)	Yes	No	Yes (confirmed by author via email)	None	None	Unknown carryover effects; Subjects were aware of hypothesis	High
Pal et al	Yes	Not mentioned	Not mentioned	Not mentioned Objective measurements	None	None		Low
Dullo et al	N/A	N/A	Not mentioned	Not mentioned	None	None		Low
Mourya et al	Yes	Yes	Not mentioned	Yes	12% of subjects dropped out (but statistics adjusted)	None		Low
Thakur et al	Yes	Not mentioned	Not mentioned	Not mentioned	None	None	intervention duration/sequence not mentioned clearly	Unknown
Bhavanani	Partially; Convenient sampling+ randomization	N/A	Not mentioned	Not mentioned	None	None		Unknown
Joshi et al	Yes	Yes	Not mentioned	Not mentioned	None	None		Low
Sivapriya et al	N/A	N/A	Not mentioned	Not mentioned	None	None		Low
Gupta et al	N/A	N/A	Not mentioned	Not mentioned	None	None		Low
Malhotra et al	N/A	N/A	Not mentioned	Not mentioned	Unclear	None	Reliability and validity of Online reaction time testing is questionable; Very limited details	High
Sharma et al	Not mentioned	Not mentioned	Not mentioned	Not mentioned	None	None		Unknown
Jain	N/A	N/A	Not mentioned	Not mentioned	None	None		Low
Singh et al	Yes	Not mentioned	Not mentioned	Not mentioned	None	None		Low
Dhanvijay et al	N/A	N/A	Not mentioned	Not mentioned	None	None		Low
Kumari et al	Not mentioned	Not mentioned	Not mentioned	Not mentioned	None	None	Very limited details; No statistical analysis or no anthropometric data	High
Mohan et al	N/A	N/A	Not mentioned	Not mentioned	None	None		Low
Jain et al	N/A	N/A	Not mentioned	Not mentioned	None	None		Low
Kumar	Not mentioned	Not mentioned	Not mentioned	Not mentioned	Not mentioned	None		Unknown
Malhotra et al	N/A	N/A	Not mentioned	Not mentioned	None	None	Reliability and validity of reaction time testing is questionable	High
Dhanvijay et	N/A	N/A	Not mentioned	Not mentioned	None	None		Low

al								
Goel et al	N/A	N/A	Not mentioned	Not mentioned	None	None		Low
Dhadse et al	Not mentioned	Not mentioned	Not mentioned	Not mentioned	None	None	Reliability and validity of reaction time testing is questionable	High
Dhadse et al	Not mentioned	N/A	Not mentioned	Not mentioned	None	None	Reliability and validity of reaction time testing is questionable	High
Garg et al	N/A	N/A	Not mentioned	Not mentioned	None	None		Low
Kinabalu	No	Not mentioned	Not mentioned	Not mentioned	None	None	some learning effect from practice while assessing problem solving skills	High
Jain	N/A	N/A	Not mentioned	Not mentioned	None	None		Low

N/A: Not applicable due to self- controlled study. It's not possible to blind participants from intervention however bias in this category can be minimized by blinding participants from hypothesis and blinding study personnel. Performance bias was categorized as partially because blinding is not possible due to study type and subjects were unaware of hypothesis), Unknown bias due to fixed sequence of multiple interventions in crossover study so carryover effects are unknown in studies Raghuraj et al.

ANB and pulmonary system

Eight studies evaluated the effects of ANB on pulmonary function tests. Seven studies noted increase in PEFR, while one study reported no changes in PEFR after practicing ANB.[5,12,13,32,33,41,42,43] Other PFTs evaluated were $FEF_{25-75\%}$, FVC and FEV_1[15], VC and MVV[12] - which were improved significantly after regular practice of ANB.[42] Bhardwaj evaluated the effects of ANB in patients suffering from rhinusitis over 40 days. This study found improved clinical, endoscopic, radiological features associated with disease as well MCC tests. However, participants were taking vitamin A during study time so validity of these results are questionable.

ANB and cognitive responses

After 40 minutes of ANB, Telles et al, reported improvement in peak amplitude of P300 at the frontal, cranial and parietal lobes and a reduction in peak latency at the frontal lobe suggesting improved ability of participants to differentiate between auditory stimuli. In another study by the same author, peak amplitude and latencies of P300 were compared for ANB, right uninostril breathing, left uninostril breathing and breath awareness before and after 45 minutes.[15,17] Since left parietal peak latency was significantly slower than on the right, this study concluded that right nostril breathing enhances the activity of the left hemisphere.

Yadav et al, reported ANB facilitated motor memory retention of newly learned motor skills immediately and even after 24 hours. Letter cancellation task score in right-handed adults improved noticeably after practicing both ANB and RNB for 30 minutes in separate sessions.[19] Two studies used the Wechsler adult intelligent scale to assess memory and found ANB improved digit span forward and digit span backward, spatial memory associate learning in adults.[30,36] Naveen et al, reported improved verbal and spatial memory in children after practicing ANB, RNB, LNB and breath awareness. Simple problem-solving skills were improved after practicing ANB for 20 minutes.[13] Four studies recorded the association between ANB and improved reaction time while one study reported no changes in reaction time, and another found increased reaction time in left nostril-initiated ANB.[10,11,18,38,39] However, most studies did not utilize reliable and valid methods for reaction time testing. In one study, authors found decreased self-reported anxiety and depression scores in adults following regular practice of ANB for three months.[24]

ANB and strength

Three studies measured hand grip strength. Two studies reported increased hand strength/dexterity, though both studies had subjects in control groups who showed significant improvement in hand strength/dexterity.[4,16] Conversely, another study (Joshi) found no changes in hand strength after a single session of ANB.[21]

DISCUSSION

This systematic review aimed to summarize the effects of alternate nostril breathing, which is one of the many yogic practices. The positive and negative findings must be scrutinized before reaching any conclusion due to heterogonous studies and methodological biases.

The studies summarized here recruited non-practitioners and yoga practitioners. Study duration ranged from a single session to four months of ANB. As mentioned in the results and Table 1, most studies reported a positive impact of ANB on cardiopulmonary, autonomic and cognitive functioning. Many studies used self-controlled or crossover method to evaluate ANB. Self-controlled and crossover studies can present clinically and statistically significant results even with a smaller sample size. However, for crossover studies, the method by which the subjects are assigned to initial treatment, determination of when to cross-over the treatment and the randomization of treatment sequence order are important to minimize carryover effects from prior treatment.

Two such studies and in which sequence of multiple treatment was kept fixed, considered to have high methodological bias.[4,22] Another study by same author had different baseline levels of high frequency power of HRV between two groups and is also calculated to have high level of bias. Few studies measured reaction time response after practicing ANB but due to questionable validity of testing technique these studies are also put under category of high level of bias.[10,11,22,38,39] Studies which utilized proper randomization and/or utilized objective outcomes were put under the category of low level of methodological bias.

Twenty studies evaluated the effects of single-session ANB on physiological variables. Of these, four studies reported effects on subjects without prior experience of ANB. Yadav et al and Kinabalu reported significant improvement in motor memory retention and simple problem-solving skills plus cardiopulmonary parameters, respectively, after a single session of ANB. Although Kinabalu and Jain et al, found decreased blood pressure, Ghiya et al, reported no changes in blood pressure but increased HRV after a single session of ANB. Kamari et al, reported decreased in both systolic and diastolic blood pressure after a single session in hypertensive subjects though these subject's prior experience of yoga is unknown. Mourya et al, also found significant decrease in blood pressure and improvement in autonomic function tests after three months of ANB practice in stage I hypertensive patients. In contrast, Subramanian et al, noticed increased sympathetic activity during and immediately after ANB at different breathing rates. Differences in results may be explained by varying breathing rates, inspiration to expiration ratio, and the duration of breath retention and subject knowledge of the hypotheses or expectations of possible outcomes. Bhavanani et al, suggested that inhalation phase and duration is important because the nostril being used for inhalation has a greater impact on different divisions of the autonomic nervous system compared to the nostril being used for exhalation.[18] Based on this, a single session may be sufficient to enhance autonomic function and improve motor memory or simple problem-solving skills. However, a single session would not provide enough time to see changes in blood pressure, especially if subjects are normotensive. This occurs partly because the autonomic nervous system directly controls heart rate, but blood pressure is controlled indirectly via decreased systemic vascular resistance - since vasodilation occurs in skeletal muscles under the influence of sympathetic tone.

For those with prior yoga experience, acute exposure of ANB significantly reduced blood pressure increased HR; increase in hand strength and increase in hand dexterity.[14,16,18,22] Joshi A et al, reported no changes in hand grip strength after 20 min of ANB practice, subjects displayed an increased ability to pay attention to and differentiate between auditory stimuli and increase in letter cancellation skills.[15,19]

Potential mechanisms

ANB and lateralization

Normal nasal cycle shows an alternating pattern between right and left nostril dominance due to level of nostril congestion. This is associated with human basic rest activity cycle during which the sympathetic system is dominant during the active phase (in ancient times for hunting and gathering food) while the parasympathetic system prevails during the rest phase (after food consumption to rest).[48] It is proposed that the relation between central and peripheral nervous systems is bidirectional. As a result, breathing through the right nostril can activate the sympathetic nervous system while breathing through the left nostril can stimulate the parasympathetic nervous system.[49] So, regular ANB practice can disrupt fight-flight responses by drawing new balance states between the respiratory, cardiovascular and autonomic nervous systems.

Cellular mechanisms

In peripheral blood circulation, studies have found alternating levels of catecholamines between the right and left sides of the body, which was coupled with the ultradian rhythm of nasal cycle.[50] This suggested possibility of lateralization effects of unilateral nostril breathing.

Another speculated physiological mechanism is the neural reflex mechanism in the superior nasal meatus, by which the brain can receive signals.[51-53] Furthermore, when mechanical receptors in nasal mucosa are stimulated by airflow, they can release signals to the hypothalamus unilaterally which induces nasal vasoconstriction to increase airflow of the same nostril.[54]

ANB is considered slow-paced breathing exercise that can stimulate the vagus nerve to promote neuroplasticity and neurogenesis via release of acetylcholine, epinephrine and brain-derived neurotropic factor (BDNF).[8] Bhavanani et al, suggested that breathing techniques can enhance neuronal information processing to decrease reaction time as the ascending reticular activating system is inhibited.[18]

Breath awareness and cognition

Breath awareness (concentrating airflow through the nostrils and body) is an integral component of ANB and also one of the many techniques to practice mindfulness-based meditation. There is a plethora of research on cognitive functioning and psycho-behavioral positive changes associated with mindfulness-based meditation.[55-59] Focusing on each breath helps reach a meditative stage and improves self-awareness and self- regulation. Gard et al, proposed a conceptual model that explains how yoga can promote cortical and subcortical neural connections as well communication between efferent and afferent pathways to enhance stress coping strategies. According to this model, all the limbs of Ashtanga yoga enhance bidirectional communication between the central nervous system and peripheral tissues to mitigate stress and induce negative responses with minimum efforts.

Low breathing rate and relaxation

The slow breathing rate associated with ANB promotes relaxation and pacing of the heart rate. Slow breathing is the most practical technique of relaxation.[61] According to yoga philosophy, the physical and emotional state of a person is highly interconnected. Emotional stress such as anxiety, worry and anger increases the breathing rate and heart rate involuntarily. As per Seyle stress theory, stress stimulates the sympathetic nervous system in the hypothalamus, which increases systemic vascular resistance and the cardiac workload. Long-term stress is associated with a number of cardiovascular diseases, decreased immunity, worsening of metabolic diseases and other chronic diseases. Voluntary breathing control helps break down vicious stress-mediated cycles of negative physiological effects via generalized relaxation. A reduction in baseline cortisol during breathing exercises indicates decreased sympathetic activity. However, during acute challenge of glucocorticoid increased concentration of cortisol suggests the baseline stress level is reduced while the ability to fight against stressful stimulation is improved significantly.[62]

Pulmonary mechanisms

Respiration-related vagal modulation occurs when the respiratory interval is increased. A low breathing rate can increase high frequency amplitude and decrease the LF:HF ratio of HRV measurements without changing the mean R-R interval or blood pressure.[9,63] Slow breathing is associated with improvements in baroreceptor sensitivity and decreased hypercapnic chemosensitivity.[64] Srivastav et al, suggested lung inflation initiates a reflex response through stretch receptors that enhance vasodilation in skeletal muscles and decrease systemic vascular resistance and blood pressure. Bharadwaj et al, reported increased mucociliary beats of the respiratory tract epithelium in rhinosinusitis patients after practicing ANB, and proposed ANB increases systemic oxygenation and surface availability for oxygen absorption.

Limitations of this review paper did not include studies in which alternate nostril breathing was evaluated as a part of multicomponent comprehensive Yoga therapy. Studies evaluating independent effects of right or left nostril breathing are not included. Including those studies would have provided a broader perspective on the topic. Even the studies included in the review had utilized a wide range of interventions so systemic meta-analysis has not been carried out.

CONCLUSION

Forty-four randomized controlled trials evaluated the effects of alternate nostril breathing on various parameters of cognitive functioning, the autonomic nervous system and the cardiopulmonary system. The lack of homogeneity in the intervention technique (method and dosage of treatment) and different outcomes prevented the author from running a meta-analysis. Most of the studies included healthy subjects aged eight to seventy years. Alternate nostril breathing has few variations and standardization of the technique has yet to be established. As per Cochrane systematic review guidelines, ten studies showed a high level of bias, twenty-nine showed a low level of bias and five had an unknown level of bias.

There is a high level of evidence of the effects of alternate nostril breathing on cardiovascular functioning, as studies have shown that regular practice of alternate nostril breathing is associated with decreased blood pressure and heart rates. There is high level of evidence of regular practice of alternate nostril breathing with improvement on pulmonary function tests. Alternate nostril breathing is associated with improvement in cognitive health - including improved amplitude of P300 at the frontal, vertex and parietal sites, as well as enhanced motor, visual and spatial memory. There is minimal evidence that alternate nostril breathing aids depression/anxiety disorders or increases hand strength. No studies reported adverse effects or intolerance of this breathing technique. Acute effects of alternate nostril breathing are more prominent in subjects with prior yogic experience, implying regular practice of alternate nostril breathing has positive outcomes. More clinical trials are required to evaluate the effects of alternate nostril breathing in clinical populations and to determine effective frequency and duration parameters for maximum benefits.

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