Original Research Article

QUANTIFYING HEART RATE VARIABILITY MODULATION BY TWO SELECTED YOGIC BREATHING TECHNIQUES: A PHOTOPLETHYSMOGRAPHY (PPG) BASED STUDY

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ABSTRACT

Background: This study quantitatively investigated the effects of two distinct yogic breathing techniques, Anulom Vilom pranayama (AVP) and Kapalbhati pranayama (KBP), on heart rate variability (HRV) and cardiovascular parameters using photoplethysmography (PPG) in healthy adults.
Materials and Methods: A total of 100 participants were randomly selected and equally divided into two groups practicing AVP and KBP for three weeks, with sessions guided by certified yoga instructors. Measurement of heart rate variability (HRV) by using a PPG-based heart rate sensor, Polar Verity Sense, and analysis using the Kubios HRV application on iOS.
Results: The results demonstrated that AVP significantly enhanced parasympathetic activity, as reflected by reductions in heart rate and systolic and diastolic blood pressure and increases in Time-domain (SDNN, rMSSD) and Frequency-domain (HF power) and reduction in LF power of HRV indices, indicating autonomic balance towards the parasympathetic domain and cardiovascular relaxation. Conversely, KBP, decreases parasympathetic HRV measures, (HF power) and elicited sympathetic activation, as evidenced by increased heart rate and blood pressure with raised LF power and LF/HF ratio, suggesting an increase in sympathetic activity.
Conclusion: AVP promotes parasympathetic dominance, aiding cardiovascular relaxation and stress reduction, whereas Kapalbhati pranayama stimulates the sympathetic component, enhancing cardiovascular activity. These autonomic differences highlight the importance of selecting pranayama techniques for therapeutic outcomes. The study also reflects PPG-based HRV measurement as a non-invasive tool for monitoring autonomic variation induced by pranayama, highlighting the physiological impacts of pranayama techniques and their potential for personalized therapeutic applications.
Keywords: Anulom Vilom Pranayama (AVP), Kapalbhati Pranayama (KBP), Systolic Blood Pressure (SBP), Diastolic Blood Pressure (DBP), Photoplethysmography (PPG), pulse-to-pulse interval (PPI), Heart Rate Variability (HRV), Autonomic Nervous System (ANS), Time-domain analysis, Frequency-domain analysis, Poincare analysis, healthy adults, yogic breathing techniques, Pranayama, cardiovascular health, parasympathetic activity, sympathetic activity, stress reduction, non-invasive monitoring.

INTRODUCTION

Historically, India, with its vast and youthful population, has focused on controlling and preventing communicable diseases. However, in recent years, public health priorities have shifted toward non-communicable diseases, such as hypertension, coronary artery disease, and stroke, which are increasing at an alarming rate in India. This is due to rapid urbanization and lifestyle changes in the region. Ultra-processed foods and associated lifestyle factors, such as unhealthy diet, physical inactivity, and chronic stress, are associated with higher mortality and chronic diseases (Johnson et al., 2016).[1] Various relaxation and stress reduction techniques, such as yoga, pranayama, and meditation, have been demonstrated to reduce blood pressure through their beneficial effects on the cardiovascular reflex control system (Satyanand et al., 2014).[2]Heart Rate Variability (HRV) serves as a vital physiological indicator of the modulation of autonomic nervous system activity, with implications for cardiovascular health and stress regulation. Yogic breathing techniques, specifically pranayama, have gained prominence in recent years for their potential to influence autonomic balance and promote good health. This study aimed to quantitatively assess the effects of two selected yogic pranayama techniques, Anulom Vilom and Kapalbhati, on HRV parameters using a non-invasive photoplethysmography (PPG) device to elucidate their impact on cardiac autonomic function in healthy adults.

Review of literature: Heart Rate Variability (HRV) is a well-established non-invasive marker reflecting autonomic nervous system (ANS) modulation and cardiovascular health. It quantifies the variation in time intervals between consecutive heartbeats, providing insights into sympathetic and parasympathetic balance(Malik et al., 1996).[3] The measurement of HRV has traditionally relied on electrocardiography (ECG); however, photoplethysmography (PPG) has emerged as a practical alternative because of its ease of use, cost-effectiveness, and suitability for continuous monitoring (Elgendi, Mohamed, 2012).[4] PPG-based HRV analysis captures PPI, which correlates strongly with ECG-derived HRV metrics, enabling a reliable assessment of autonomic function (Gil, Eduardo et. al., 2010).[5] Yogic breathing techniques, rooted in ancient practices, have gained significant attention for their potential to modulate autonomic activity and improve cardiovascular parameters in healthy individuals. Controlled breathing exercises influence HRV by enhancing parasympathetic tone and reducing sympathetic overactivity, thereby promoting relaxation and stress reduction (Jerath et. al.).[6] Among the various yogic breathing methods, slow-paced breathing and alternate nostril breathing have been frequently studied for their distinct physiological effects. Slow-paced breathing typically involves reducing the respiratory rate to around six breaths per minute, which has been shown to increase HRV and baroreflex sensitivity (Vaschillo et. al.).[7] Alternate nostril breathing, a pranayama technique, is purported to balance autonomic function by stimulating both hemispheres of the brain and modulating cardiovascular responses (Sharma, Sachin Telles et. al.).[8] Several studies have investigated the impact of yogic breathing on HRV using ECG; however, few studies have employed PPG technology to quantify these effects. The integration of PPG offers advantages for ambulatory and home-based monitoring, thereby expanding the applicability of HRV analysis in yogic practice. This study aimed to bridge this gap by quantifying HRV modulation induced by two selected yogic breathing techniques using photoplethysmography (PPG)-based measurements. Understanding these effects will contribute to optimizing individual pranayama techniques for cardiovascular and autonomic health benefits and validating PPG as a viable tool for assessment.

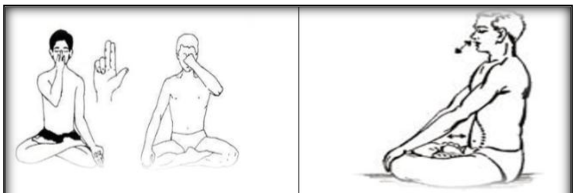
MATERIALS AND METHODS

This study employed a quantitative experimental research design. The study protocol was approved by the Institutional Ethics Committee (IEC) of SMIMER Surat. A cohort of 100 healthy adults, including both males and females, aged between 18 and 58 years, was selected from Surat city based on the criteria that participants had no prior exposure to Anulom Vilom and Kapalbhati pranayama and did not have any cardiovascular disorders.

The participants were assigned to two separate groups, each containing 50 participants practicing the Anulom Vilom and Kapalbhati pranayama. Their age, height, and weight were recorded. Participants who were non-smokers, of the same socioeconomic status, and not under any medication were included in the study. Informed consent was obtained from each participant, and they were provided with training on the methodology prior to commencing regular practice. All participants engaged in Anulom Vilom and Kapalbhati pranayama according to their assigned group for a duration of three weeks. Each session lasted for 20 min and was conducted under the guidance of a certified yoga instructor. Training sessions were scheduled during the early morning hours on an empty stomach.

Pranayama Techniques:

Anulom Vilom: In this pranayama practice, participants sit with their legs crossed (either in Padmasana or Sukhasana) and maintain an upright posture. This technique involves inhaling through one nostril and exhaling through the other nostril, ensuring a consistent breathing rhythm.



Anulom Vilom Pranayama (Source: Yogi, Sarvyoga.com)[9] | *Kapalbhati Pranayama* (Source:Yogi,Sarvyoga.com)[9]

Kapalbhati: For this pranayama, individuals sit cross-legged (either in padmasana or sukhasana) with a straight back and perform forceful exhalations through both nostrils, followed by passive inhalations, facilitated by regular abdominal contractions.

Measurement of Parameters: Blood pressure was measured using a Citizen semi-automatic monitor. To assess HRV, we obtained 5-min PPI recordings using the Polar Verity Sense, a PPG-based armband device. This device is a flexible and high-quality optical heart rate sensor that can track heart rate from the arm, serving as an excellent alternative to traditional chest straps and other arm-based heart rate monitors (Polar.com)[10]. The 5-minute recordings were then processed using the Kubios HRV mobile application on iOS. The variables in the time domain, such as SDNN and rMSSD, along with frequency-domain metrics such as LF, HF, and the LF/HF ratio, and Poincare analysis measures including SD1, SD2, and the SD2/SD1 ratio were used.

Data Analysis: Data were collected and analyzed by comparing the results before and after three week intervention of the assigned pranayama exercises. The data were analyzed using descriptive statistics and a paired sample t-test, where statistical significance was set at $p < 0.05$, and the analyses were conducted using IBM SPSS Statistics version 25.

RESULTS & DISCUSSION

This study evaluated and compared the effects of Anulom Vilom and Kapalbhati pranayama on cardiovascular and HRV parameters within each group. The design ensured balanced age and sex representation across all groups to minimize the confounding variables. The Anulom Vilom group included individuals aged 22–58 years, with 76% men and 24% women. The average age of the participants was 44.50 ± 9.17 years. Heights ranged from 1.50 to 1.85 m, with a mean of 1.69m. Weights varied from 47 kg to 128 kg, averaging 73.40 kg with a standard deviation of 14.12 kg, indicating variability in the data. The BMI values ranged from 19.1 to 37.4, with an average of 25.31 ± 3.75, reflecting moderate diversity in the BMI. The Kapalbhati group had a mean age of 35.22 ± 9.02 years, with 53% males and 47% females. The ages of the subjects ranged from 19 to 55 years. Heights varied from 1.55 m to 1.85 m, with an average height of 1.69 m ± 0.09 m. Weights ranged from 50 to 85 kg, with an average weight of 67.1 ± 11.55 kg. The average BMI was 23.03 ± 1.58, ranging from 20.8–25.7.

Table 1: Pre- and post-intervention changes in mean hemodynamic and HRV parameters in the Anulom Vilom pranayama (AVP).

Parameter	Pre-test mean	Post-test mean	Change	P Value
HR (bpm)	80.61	69.1	- 11.51 bpm	$p < 0.05$
SBP (mm Hg)	126.51	116.92	- 9.59 mmHg	$p < 0.05$
DBP (mm Hg)	80.35	73.84	- 6.51 mmHg	$p < 0.05$
SDNN (ms)	46.8	50.87	+ 8.6%	$p < 0.05$
rMSSD (ms)	28.29	30.41	+ 7.5%	$p < 0.05$
LF (ms²)	493.38	456.84	- 7.4%	$p < 0.05$
HF (ms²)	294.58	317.2	+ 7.7%	$p < 0.05$
LF/HF ratio	1.67	1.43	- 14.4%	$p < 0.05$
SD1 (ms)	21.39	22.66	+ 9.59 %	$p < 0.05$
SD2 (ms)	60.48	56.19	- 4.29 %	$p < 0.05$
SD2/SD1 ratio	2.83	2.48	- 0.35 %	$p < 0.05$

Table 1 presents a comparative analysis of the mean cardiovascular and heart rate variability (HRV) parameters before and after Anulom Vilom pranayama. The results showed a decrease in the mean heart rate (HR) from 80.61 bpm to 69.1 bpm, systolic blood pressure (SBP) from 126.51 mmHg to 116.92 mmHg, and diastolic blood pressure (DBP) from 80.35 mmHg to 73.84 mmHg, indicating reduced sympathetic activity. Time-domain HRV indices improved, with an increase in the standard deviation of NN intervals (SDNN) from 46.8 ms to 50.87 ms and the root mean square of successive RR interval differences (rMSSD) from 28.29 ms to 30.41 ms, suggesting enhanced parasympathetic activity. The frequency-domain parameters also changed, with LF decreasing from 493.38 to 456.84 ms² and HF increasing from 294.58 to 317.2 ms², with a 14.4 % reduction in the LF/HF ratio from 1.67 to 1.43, indicating a shift towards parasympathetic dominance. The nonlinear HRV indices showed an improvement in SD1 from 21.39 ms to 22.66 ms and a decrease in SD2 from 60.48 ms to 56.19 ms, with the SD2/SD1 ratio decreasing from 2.83 to 2.48, reflecting improved HRV.

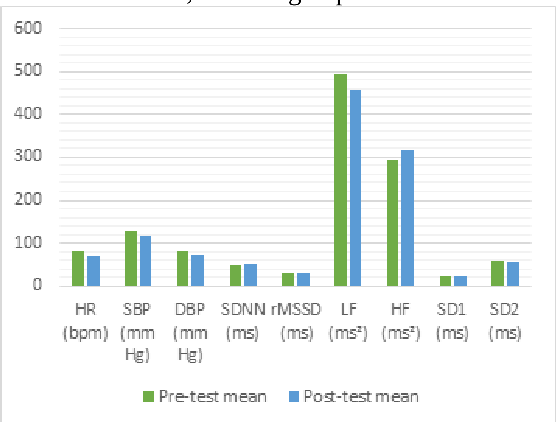


Figure 1. Changes in mean hemodynamic and HRV parameters in Anulom Vilom pranayama

[Figure 1] demonstrates that the practice of Anulom Vilom pranayama resulted in a significant reduction in heart rate (HR), systolic blood pressure (SBP), and diastolic blood pressure (DBP), while enhancing heart rate variability (HRV) metrics such as standard deviation of NN intervals (SDNN), root mean square of successive differences (rMSSD), high frequency (HF), and SD1. Additionally, there was a reduction in low frequency (LF) and SD2, indicating decreased sympathetic and enhanced parasympathetic activities. These findings align with prior research showing that ANB shifts sympatho-vagal balance towards parasympathetic dominance, characterized by a lower heart rate and increased parasympathetic outflow (Ghiya & Lee, 2012).[11] This shift is attributed to slow breathing in ANB, increased baroreflex sensitivity, and decreased sympathetic and chemoreflex activation (Surlya & Jain, 2021).[12]

Table 2: Pre- and post-intervention changes in mean hemodynamic and HRV parameters in Kapalbhati pranayama

Parameter	Pre-test mean	Post-test mean	Change	P Value
HR (bpm)	74.24	78.69	+ 4.45 bpm	< 0.05
SBP (mm Hg)	121.29	125.96	+ 4.76 mmHg	< 0.05
DBP (mm Hg)	78.98	81.49	+ 2.51 mmHg	< 0.05
SDNN (ms)	67.71	65.24	- 3.6%	< 0.05
rMSSD (ms)	29.76	28.2	- 5.2%	< 0.05
LF (ms²)	594	609.2	+ 2.6 %	< 0.05
HF (ms²)	392.75	387.27	- 1.4 %	< 0.05
LF/HF ratio	1.52	1.6	+ 5.3 %	< 0.05
SD1 (ms)	28.57	28.35	- 0.77 %	0.37
SD2 (ms)	66.68	68.47	+ 2.68 %	< 0.05
SD2/SD1 ratio	2.38	2.49	+ 4.62 %	< 0.05

[Table 2] compares the mean Heart Rate Variability (HRV) parameters before and three weeks after Kapalbhati pranayama. Notably, unlike previous pranayama, the heart rate (HR) increased from 74.24 bpm to 78.69 bpm post-practice. Similarly, systolic blood pressure (SBP) increased from 121.29 mmHg to 125.96 mmHg, and diastolic blood pressure (DBP) from 78.98 mmHg to 81.49 mmHg, suggesting increased sympathetic activity in the body.

Time-domain HRV analysis showed a slight decrease in SDNN from 67.71 ms to 65.24 ms and rMSSD from 29.76 ms to 28.2 ms, indicating a reduced parasympathetic activity. Frequency-domain analysis showed increased LF from 594.0 to 609.2 ms² and a small HF reduction from 392.75 to 387.27 ms², with the LF/HF ratio increasing from 1.52 to 1.60, reflecting an enhanced sympathetic dominance. Nonlinear HRV indices showed minor shifts: SD1 decreased from 28.57 ms to 28.35 ms, while SD2 increased from 66.68 ms to 68.47 ms, raising the SD2/SD1 ratio from 2.38 to 2.49, indicating a shift towards sympathetic dominance. In conclusion, [Table 2] shows that Kapalbhati induces a more distinct sympathetic response than other pranayama, altering the autonomic balance towards the sympathetic nervous system (SNS).

[Figure 2] illustrates the changes in HR, SBP, and DBP before and after Kapalbhati, indicating an increase in sympathetic activity. The graph shows reductions in the time-domain HRV parameters (SDNN and rMSSD), indicating decreased parasympathetic influence. Frequency domain data showed elevated LF and a slight decrease in HF, reinforcing the increased sympathetic drive. The nonlinear parameters (SD1, SD2) depicted shifts towards sympathetic dominance, consistent with previous studies showing increased LF and LF/HF ratio during rapid Kapalbhati breathing, reflecting heightened sympathetic tone (Malhotra et al., 2022).[13] These findings contrast with the parasympathetic effects observed after Anulom Vilom, highlighting the distinct physiological impact of Kapalbhati on autonomic regulation.

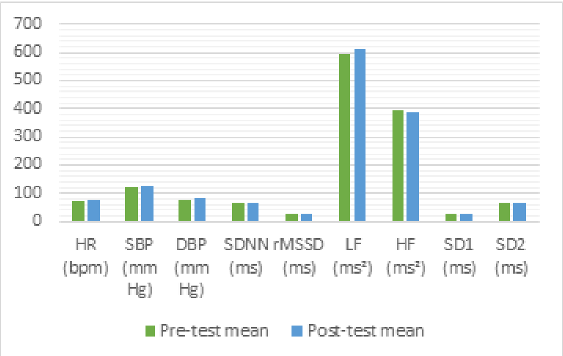


Figure 2: Changes in mean hemodynamic and HRV parameters during Kapalbhati pranayama.

Table 3. Comparative percent change in hemodynamic and HRV parameters after 21 days practice of Anulom Vilom pranayama (AVP) and Kapalbhati pranayama (KBP)

Parameter	% Change in AVP	% Change in KBP
HR	-14.28	+5.99
SBP	-7.58	+3.85
DBP	-8.1	+3.18
SDNN	+8.7	-3.65
rMSSD	+7.49	-5.24
LF	-7.41	2.56
HF	+7.68	-1.4

LF/HF ratio	-14.37	+5.26
SD1	+5.94	-0.77
SD2	-7.09	+2.68
SD2/SD1 ratio	-12.37	+4.62

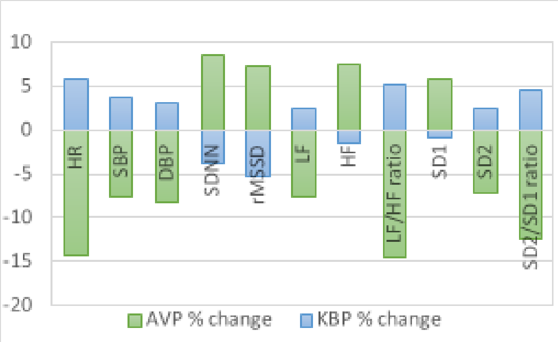


Figure 3: Comparative percent change in hemodynamic and HRV parameters after 21 days practice of Anulom Vilom pranayama (AVP) and Kapalbhati pranayama (KBP)

The data in [Table 3] show distinct autonomic nervous system responses to 21 days of Anulom Vilom pranayama (AVP) versus Kapalbhati pranayama (KBP), reflected in hemodynamic and heart rate variability (HRV) parameters. AVP showed parasympathetic dominance, with reduced heart rate (HR: -14.28%) and blood pressure (SBP: -7.58%, DBP: -8.1%), increased HRV indices such as SDNN (+8.7%), rMSSD (+7.49%), and HF power (+7.68%), and decreased sympathetic markers such as LF power (-7.41%) and LF/HF ratio (-14.37%).These changes align with AVP's slow, alternate nostril breathing, which promotes vagal tone, reduces sympathovagal imbalance (SD2/SD1: -12.37%), and encourages cardiovascular relaxation, consistent with its role in stress reduction and maintaining homeostasis. In contrast, KBP prompted sympathetic activation, with increased HR (+5.99%), SBP (+3.85%), and DBP (+3.18%), reduced parasympathetic HRV measures (rMSSD: -5.24%, SDNN: -3.65%, HF: -1.4%), and increased sympathovagal balance (LF/HF: +5.26%, SD2/SD1: +4.62%). This pattern reflects KBP's rapid exhalations, stimulating the thoracic pump and adrenergic outflow, enhancing alertness and long-term variability (SD2: +2.68%) at the expense of beat-to-beat fluctuations (SD1: -0.77%). These effects highlight AVP's utility for hypotensive and anxiolytic outcomes, while KBP may benefit conditions requiring energetic stimulation, highlighting the tailored therapeutic potential of pranayama in modulating autonomic function.

Summary: This study quantitatively evaluated the effects of two distinct yogic breathing techniques, Anulom Vilom pranayama (AVP) and Kapalbhati pranayama (KBP), on heart rate variability (HRV) and cardiovascular parameters using a non-invasive photoplethysmography (PPG) device. A cohort of 100 healthy adults was divided equally into two groups practicing AVP and KBP for three weeks. The analysis revealed that AVP significantly enhanced parasympathetic activity, as evidenced by reductions in heart rate and systolic and diastolic blood pressure and increases in time-domain (SDNN, rMSSD) and frequency-domain (HF power) HRV parameters. Conversely, KBP elicited sympathetic activation, as demonstrated by increases in heart rate and blood pressure, decreases in parasympathetic HRV indices, and elevated sympathetic markers, such as LF power and the LF/HF ratio. These physiological changes highlight the modality-specific autonomic effects of slow alternate nostril breathing (AVP) versus rapid, forceful exhalations (KBP). The use of PPG with Kubios software provided a reliable HRV assessment, supporting the feasibility of ambulatory monitoring in yogic practice research.

CONCLUSION

The findings show that Anulom Vilom pranayama promotes parasympathetic dominance, which may contribute to cardiovascular relaxation and stress reduction. In contrast, Kapalbhati pranayama activates sympathetic pathways, potentially enhancing alertness and energetic stimulation. These differential autonomic responses underscore the importance of selecting specific pranayama techniques tailored to desired therapeutic outcomes. Furthermore, PPG-based HRV measurement was validated as an effective, non-invasive tool for monitoring autonomic modulation induced by yogic breathing. This study supports the integration of pranayama practices into health and therapeutic programs, emphasizing their distinct physiological effects and potential for personalized autonomic regulation.

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