

Original Article



Effect of Digital Heart Rate Variability Biofeedback–Guided Resonance Breathing Combined with Moderate-Intensity Aerobic Exercise on Blood Pressure and Autonomic Control in Hypertension Patients

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Summary

Introduction: Hypertension is a leading modifiable risk factor for cardiovascular disease and is commonly associated with autonomic dysfunction, characterized by increased sympathetic activity and reduced parasympathetic modulation. In addition to pharmacological treatment, non-pharmacological interventions such as aerobic exercise and breathing-based therapies have gained increasing attention for their beneficial effects on cardiovascular regulation. Digital heart rate variability (HRV) biofeedback-guided resonance breathing is an emerging intervention that combines paced breathing with real-time physiological feedback to enhance vagal activity and improve autonomic balance.

Methods: A three-arm parallel experimental study was conducted among 48 individuals with hypertension receiving antihypertensive medication. Participants were equally assigned to three groups (n=16 each). Group A received medication alone and served as the control group. Group B performed moderate-intensity aerobic exercise at 60–70% of maximum heart rate for 30 minutes per session. Group C completed the same exercise program followed by HRV biofeedback-guided resonance breathing using a chest-strap heart rate monitor integrated with a mobile biofeedback application. The intervention was delivered three times per week for eight weeks. Systolic and diastolic blood pressure were assessed as primary outcomes, while HRV parameters (RMSSD, SDNN, LF, HF, and LF/HF ratio) were evaluated to assess autonomic function.

Findings: Participants in the combined intervention group demonstrated greater reductions in systolic blood pressure and more favorable changes in HRV parameters than those in the exercise-only and control groups. One-way ANOVA demonstrated a statistically significant between-group difference in the change in systolic blood pressure ($P < 0.001$). In contrast, the between-group difference in diastolic blood pressure was not statistically significant ($P = 0.221$). Significant between-group differences were also observed for the HRV parameters.

Conclusion: The combination of HRV biofeedback-guided resonance breathing and moderate-intensity aerobic exercise may be an effective complementary intervention to improve blood pressure regulation and autonomic function in individuals with hypertension.

Keywords: Hypertension, Heart rate variability, Biofeedback, Resonance breathing, Aerobic exercise, Autonomic regulation

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Introduction

Hypertension is one of the most prevalent chronic non-communicable diseases and continues to be a leading contributor to cardiovascular morbidity and premature mortality worldwide. Persistent elevation of arterial blood pressure increases the workload of the heart and blood vessels, predisposing individuals to complications such as stroke, myocardial infarction, heart

failure, chronic kidney disease, and peripheral vascular disease. Largely because of population ageing, sedentary lifestyles, unhealthy dietary practices, obesity and other metabolic risk factors, effective antihypertensive medications are widely available; achieving optimal blood pressure control remains a major challenge, highlighting the need for complementary therapeutic strategies. The maintenance of arterial blood pressure depends on coordinated interactions among the cardiovascular, nervous, and endocrine systems. A key component of this regulation is the autonomic nervous system, which continuously adjusts heart rate, myocardial contractility, and vascular tone in response to physiological demands. Individuals with hypertension frequently exhibit autonomic

dysfunction, characterized by increased sympathetic activity and reduced parasympathetic modulation. This imbalance contributes not only to sustained elevation of blood pressure but also to progressive cardiovascular dysfunction and an increased risk of adverse clinical outcomes.^{1,2}

Heart rate variability has emerged as a reliable, non-invasive measure for assessing autonomic nervous system activity. Lower HRV values are commonly observed in hypertensive individuals and are associated with impaired autonomic regulation and poor cardiovascular prognosis. Consequently, an intervention capable of improving HRV may also enhance autonomic balance and support better cardiovascular health.³ Current management of hypertension combines pharmacological treatment with lifestyle modification. In addition to antihypertensive medication, regular physical activity, dietary improvement, weight management, stress reduction, and breathing-based therapies are recommended to improve long-term cardiovascular outcomes.⁴ Moderate-intensity aerobic exercise has consistently been shown to lower blood pressure and improve cardiovascular fitness, making it an important component of hypertension rehabilitation. Interest in



breathing-based interventions has also increased because of their potential influence on autonomic regulation. Resonance breathing, usually performed at approximately six breaths per minute, promotes synchronization between respiration, heart rate oscillation, and bar reflex activity. This physiological interaction may enhance parasympathetic modulation and improve cardiovascular regulation. Recent advances in digital health technology have enabled the integration of HRV biofeedback with resonance breathing through wearable sensors and mobile applications, allowing individuals to receive real-time physiological feedback during training. Despite encouraging findings from previous studies, evidence regarding the combined effects of HRV biofeedback-guided resonance breathing and moderate-intensity aerobic exercise remains limited. Therefore, the present study was designed to evaluate whether combining these interventions could produce greater improvement in blood pressure regulation and autonomic function among individuals with hypertension.⁵ Wearable sensors and mobile applications have further improved the accessibility and practicality of this intervention in rehabilitation settings.

Although aerobic exercise and HRV biofeedback have individually demonstrated beneficial effects on cardiovascular health, limited evidence is available regarding their combined impact on blood pressure regulation and autonomic function in patients with hypertension. Therefore, the present study aimed to investigate the effects of digital HRV biofeedback-guided resonance breathing combined with moderate-intensity aerobic exercise on blood pressure and heart rate variability among individuals with hypertension.² It was hypothesized that the combined intervention would produce greater improvements in cardiovascular and autonomic outcomes compared with conventional management alone.⁶

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Therefore, the present study aimed to investigate the effects of digital HRV biofeedback-guided resonance breathing combined with moderate-intensity aerobic exercise on blood pressure and heart rate variability among individuals with hypertension.⁷ It was hypothesized that the combined intervention would produce greater improvements in cardiovascular and autonomic outcomes compared with conventional management alone.⁹

Methods

Study Design

This parallel-arms experimental study aimed to evaluate the impact of digital HRV biofeedback-guided resonance breathing and moderate-intensity aerobic exercise on blood pressure and autonomic function in hypertension patients. Participants were randomly assigned to three groups: Group A (routine antihypertensive therapy); Group B (routine

antihypertensive therapy and moderate intensity aerobic exercise); and Group C (routine antihypertensive therapy, moderate intensity aerobic exercise, and HRV Biofeedback-guided resonance breathing). The intervention period was eight weeks, and the blood pressure and HRV parameters were measured before and after the intervention.

Participants were randomly allocated into three groups using a computer-generated randomization sequence. Allocation was concealed using sequentially numbered, sealed opaque envelopes prepared by an independent investigator who was not involved in participant recruitment or outcome assessment. Outcome assessment was performed by the principal investigator, and blinding was not implemented because of the nature of the intervention. This has been acknowledged as a limitation of the study.

Sample Size Determination

The required sample size for this study was estimated using G-Power; this is commonly used for statistical power analysis in biomedical research. The calculation was performed for a one-way analysis of variance (ANOVA) comparing three independent groups. An effect size of 0.4, significance level (α) of 0.05, and statistical power of 80% were considered for the estimation. Based on these parameters, the minimum total sample size required was calculated to ensure adequate power to detect significant differences between groups. Accordingly, forty-eighty participants were included in the study and equally distributed into three groups, with sixteen participants assigned to each group.¹⁰

Study Participants

Participants included adults diagnosed with hypertension who were receiving antihypertensive medication and were clinically stable at the time of recruitment. Individuals aged 30-60 years with a confirmed diagnosis of hypertension who were receiving antihypertensive medication and were medically fit to participate in moderate-intensity physical activity were considered eligible. Individuals with severe cardiovascular disease, uncontrolled metabolic disorders, recent cardiac surgery, musculoskeletal limitation affecting exercise participation, or any other condition that could interfere with the intervention were excluded.

Before enrolment, all eligible participants received a detailed explanation of the study

objectives, procedures, potential benefits, and possible risks. Written informed consent was

obtained from each participant before participation. Baseline assessments, including blood

pressure and HRV measurements, were completed before group allocation. Participants were then assigned to one of the three study groups and continued their prescribed antihypertensive medication throughout the eight-week intervention period.

Measurement of Blood Pressure

Blood pressure was measured using a calibrated automatic

digital sphygmomanometer (Omron HEM-7120, Omron Healthcare Co., Kyoto, Japan). Participants remained seated comfortably with back support and feet flat on the floor for at least five minutes before measurements were obtained at one-minute intervals. The arm was supported at heart level, and three consecutive measurements were obtained at one-minute intervals. The average of the three readings was used for statistical analysis.¹¹

Measurement of HRV and Calculation

HRV was assessed to evaluate autonomic nervous system function. Beat-to-beat R-R interval data were recorded using a Polar H10 chest strap, a validated wearable device that provides reliable measurements for heart rate variability analysis.¹² The sensor was placed around the participant's chest at the level of the sternum 14 and connected via Bluetooth to the Heart Breath HRV installed on a smartphone. Participants were seated comfortably in a quiet environment during the recording procedure to minimize external influences on heart rate. HRV measurements were recorded for approximately five minutes under resting conditions.¹³

The collected R-R interval data were automatically processed by the application of Heart Breath HRV to obtain standard HRV parameters. Time-domain measures such as the HRV

parameters analysed included SDNN, RMSSD, LF, HF, and the LF/HF ratio, which were calculated to evaluate sympathetic and parasympathetic modulation of cardiac autonomic function.¹²

Training Protocol

Participants underwent an eight-week intervention program depending on their assigned group. The control group received only routine antihypertensive medication. The exercise group performed moderate- intensity aerobic exercise such as brisk walking or treadmill training at 60-70% of maximum heart rate for 30 minutes per session, three of five days per week. The combined intervention group performed the same aerobic exercise followed by heart rate variability biofeedback-guided resonance breathing using the heart breath HRV application connected to the Polar H10 chest strap via Bluetooth.¹⁴ Participants followed slow breathing audio-visual cues at approximately six breaths per minute for 10-20 minutes to improve autonomic regulation.^{15,16}

Statistical Analysis

IBM SPSS Statistics version 25.0 was used for all data analyses. The data are shown as mean $\pm$ SD for continuous variables and as frequencies for categorical ones. Inferential analyses were conducted after verifying for normality of data distributions. Paired t-tests were used to test within-group changes from pre- to post-intervention. One-way analysis of variance (ANOVA) was used to compare change scores (post intervention scores minus pre intervention scores) between groups and Tukey's honestly significant difference (HSD) was used as a post-hoc test when appropriate. A level of

significance of $P < 0.05$ was used.

Results

Participant Characteristics

A total of 48 participants completed the study and were equally distributed among the three groups ($n = 16$ per group). Baseline demographic and clinical characteristics, including age, sex, body mass index, systolic blood pressure, diastolic blood pressure, and heart rate variability parameters, were comparable among the three groups, with no statistically significant differences at baseline ($P > 0.05$). These findings indicate that the study groups were similar before the intervention. (Table 1)

Blood Pressure Outcomes

After the 8 weeks of intervention, the BP of the intervention groups reduced, with the most reduction noted in the combined intervention group. The intermediate reduction pattern was observed in the exercise group, while the control group had the least change. The change in systolic blood pressure was significantly different between the groups ($P < 0.001$) (one-way ANOVA). However, between-group difference in DBP change was not significant ($P = 0.221$). (Table 2)

Heart Rate Variability Outcomes

Several parameters of heart rate variability (HRV) showed beneficial changes after the intervention. The intervention group showed greater improvements in RMSSD, SDNN, and HF power and decreases in LF power and the LF/HF

Table 1. Baseline Demographic, Clinical, and Heart Rate Variability Characteristics of the Study Groups

Variable	Control (Group A) (n=16)	Exercise (Group B) (n=16)	Exercise + HRV-BF (Group C) (n=16)	P value
Age (years)	42.0 $\pm$ 6.0	41.5 $\pm$ 6.5	41.8 $\pm$ 6.2	0.982
Sex (Male/Female)	11 / 5	14 / 2	12 / 4	0.612
BMI (kg/m ²)	29.5 $\pm$ 3.5	29.8 $\pm$ 3.8	29.6 $\pm$ 3.6	0.971
Resting heart rate (bpm)	80 $\pm$ 8	79 $\pm$ 9	78 $\pm$ 8	0.801
Systolic BP (mmHg)	145 $\pm$ 11	145 $\pm$ 11	145 $\pm$ 10	0.998
Diastolic BP (mmHg)	88 $\pm$ 8	85 $\pm$ 7	83 $\pm$ 7	0.213
RMSSD (ms)	22 $\pm$ 8	23 $\pm$ 9	23 $\pm$ 8	0.934
SDNN (ms)	35 $\pm$ 10	36 $\pm$ 11	36 $\pm$ 10	0.956
LF power (ms ²)	700 $\pm$ 250	720 $\pm$ 260	710 $\pm$ 240	0.975
HF power (ms ²)	450 $\pm$ 200	460 $\pm$ 210	460 $\pm$ 200	0.988
LF/HF ratio	1.60 $\pm$ 0.50	1.55 $\pm$ 0.55	1.55 $\pm$ 0.50	0.944

Data are presented as mean $\pm$ standard deviation (SD), except sex, which is presented as the number of participants. BMI, body mass index; BP, blood pressure; HRV, heart rate variability; HRV-BF, heart rate variability biofeedback; RMSSD, root mean square of successive differences; SDNN, standard deviation of normal-to-normal intervals; LF, low-frequency power; HF, high-frequency power. P values represent comparisons among the three groups.

ratio, indicating better cardiac autonomic functioning, as compared to the combined intervention group. Small but beneficial changes were also observed in the aerobic exercise group, with specific improvements generally being less than those seen in the combined intervention group. Table 3 shows Heart Rate Variability Outcomes.

Between-Group Comparison

Between-group analysis using one-way ANOVA demonstrated statistically significant differences in the change scores for systolic blood pressure and the assessed HRV parameters. The between-group difference in diastolic blood pressure change was not statistically significant ($F = 1.56, P = 0.221$). Tukey's post-hoc analysis indicated that

the combined intervention group generally demonstrated greater improvements than the exercise-only and control groups for the outcomes showing significant between-group differences. These findings suggest that adding HRV biofeedback-guided resonance breathing to moderate-intensity aerobic exercise may provide additional benefits for systolic blood pressure regulation and cardiac autonomic function in individuals with hypertension. (Table 4)

Discussion

The findings of the present study indicate that combining moderate-intensity aerobic exercise with HRV biofeedback-guided resonance breathing produced greater improvements in blood pressure and autonomic

Table 2. Pre- and Post-Intervention Blood Pressure Values and Changes Across the Study Groups

Variable	Time	Control (Group A) (n = 16)	Exercise (Group B) (n = 16)	Exercise + HRV-BF (Group C) (n = 16)
Systolic blood pressure (mmHg)	Pre-intervention	146.0 ± 10.0	145.0 ± 11.0	145.0 ± 10.0
	Post-intervention	144.0 ± 10.5	136.0 ± 10.0	130.0 ± 8.0
	Change (post–Pre)	–2.0 ± 4.0	–9.0 ± 5.0	–15.0 ± 5.0
Diastolic blood pressure (mmHg)	Pre-intervention	88.0 ± 8.0	85.0 ± 7.0	83.0 ± 7.0
	Post-intervention	85.0 ± 7.0	82.0 ± 6.0	78.0 ± 5.0
	Change (post–Pre)	–3.0 ± 3.0	–3.0 ± 4.0	–5.0 ± 4.0

Values are presented as mean ± standard deviation (SD). Change was calculated as post-intervention minus pre-intervention values.

Table 3. Changes in Heart Rate Variability Parameters

HRV parameter	Unit	Time	Control (n=16)	Exercise (n=16)	Exercise + HRV-BF (n=16)
RMSSD	ms	Pre	22.0 ± 8.0	23.0 ± 9.0	23.0 ± 8.0
		Post	23.0 ± 8.5	28.0 ± 9.0	35.0 ± 10.0
SDNN	ms	Pre	35.0 ± 10.0	36.0 ± 11.0	36.0 ± 10.0
		Post	36.0 ± 11.0	42.0 ± 12.0	50.0 ± 13.0
LF power	ms ²	Pre	700 ± 250	720 ± 260	710 ± 240
		Post	710 ± 260	680 ± 240	600 ± 220
HF power	ms ²	Pre	450 ± 200	460 ± 210	460 ± 200
		Post	455 ± 205	550 ± 230	750 ± 260
LF/HF ratio	—	Pre	1.60 ± 0.50	1.55 ± 0.55	1.55 ± 0.50
		Post	1.58 ± 0.52	1.30 ± 0.45	0.90 ± 0.35

Data are presented as mean ± standard deviation (SD). HRV, heart rate variability; BF, biofeedback; RMSSD, root mean square of successive differences; SDNN, standard deviation of normal-to-normal intervals; LF, low-frequency; HF, high-frequency. LF/HF ratio represents the ratio of low-frequency to high-frequency power.

Table 4. Between-Group Comparison of Changes in Blood Pressure and Heart Rate Variability Parameters

Outcome	Control (Group A) (n=16)	Exercise (Group B) (n=16)	Exercise + HRV-BF (Group C) (n=16)	F (2,45)	P value	Tukey post-hoc pairwise comparisons
SBP change (mmHg)	–2.0 ± 4.0	–9.0 ± 5.0	–15.0 ± 5.0	30.79	<0.001	A vs B; A vs C; B vs C
DBP change (mmHg)	–3.0 ± 3.0	–3.0 ± 4.0	–5.0 ± 4.0	1.56	0.221	No significant pairwise differences
SDNN change (ms)	+1.0 ± 4.0	+6.0 ± 5.0	+14.0 ± 6.0	26.81	<0.001	A vs B; A vs C; B vs C
RMSSD change (ms)	+1.0 ± 3.0	+5.0 ± 4.0	+12.0 ± 5.0	29.76	<0.001	A vs B; A vs C; B vs C
LF power change (ms ²)	+10.0 ± 20.0	–40.0 ± 25.0	–110.0 ± 35.0	77.51	<0.001	A vs B; A vs C; B vs C
HF power change (ms ²)	+5.0 ± 20.0	+90.0 ± 30.0	+290.0 ± 50.0	270.42	<0.001	A vs B; A vs C; B vs C
LF/HF ratio change	–0.02 ± 0.20	–0.25 ± 0.30	–0.65 ± 0.30	22.17	<0.001	A vs C; B vs C

Values are presented as mean ± standard deviation (SD) of the change from baseline. BP, blood pressure; HRV, heart rate variability; HRV-BF, heart rate variability biofeedback; SBP, systolic blood pressure; DBP, diastolic blood pressure; SDNN, standard deviation of normal-to-normal intervals; RMSSD, root mean square of successive differences; LF, low-frequency power; HF, high-frequency power. One-way analysis of variance (ANOVA) was used to compare changes among the three groups, followed by Tukey's post-hoc test for pairwise comparisons.

function than aerobic exercise alone or routine medical management.¹⁷ Participants who received the combined intervention demonstrated a larger reduction in systolic blood pressure and more favourable changes in HRV parameters than those in the exercise-only and control groups. These findings suggest that aerobic exercise and HRV biofeedback-guided resonance breathing may provide complementary physiological benefits.¹⁶ Several well-established cardiovascular adaptations may explain the reduction in blood pressure observed following aerobic exercise.¹⁸ Regular aerobic training improves endothelial function, increases nitric oxide bioavailability, reduces peripheral vascular resistance, and enhances bar reflex sensitivity.¹⁹ These adaptations improve vascular function while promoting a shift toward greater parasympathetic activity and reduced sympathetic influence, both of which contribute to improved blood pressure regulation.²⁰ The additional improvements observed in the combined intervention group may be attributable to HRV biofeedback-guided resonance breathing. Breathing at an individualized resonance is reflected by higher Root Mean Square of Successive Differences and high frequency values together with a reduction in the LF/HF ratio, indicating improved autonomic balance.²¹ The combination of exercise-induced cardiovascular adaptation and breathing-induced autonomic modulation may therefore explain the greater improvement observed in the study.²²

Our finding is consistent with previous reports demonstrating that aerobic exercise and HRV biofeedback independently improve cardiovascular function in individuals with hypertension.²³ The present study extends this evidence by showing that integrating both interventions may provide greater benefits than either approach alone. Simultaneously targeting cardiovascular fitness and autonomic regulation may enhance the effectiveness of non-pharmacological management of hypertension. From a clinical perspective, the use of wearable heart rate sensors and mobile-based HRV biofeedback applications offers a practical approach for delivering individualized breathing training.²⁴ Real-time physiological feedback may improve patient engagement, treatment adherence, and self-management during long-term rehabilitation.²⁵ Incorporating digital HRV biofeedback into structured aerobic exercise programs may therefore provide physiotherapists with an effective strategy to support blood pressure control and improve autonomic function in individuals with hypertension.²⁶

This study has several limitations that should be considered when interpreting the findings. The relatively small sample size may limit the generalizability of the results to the wider hypertensive population. In addition, the eight-week intervention period may not be sufficient to determine the long-term effects of the combined intervention on blood pressure and autonomic function. Variations in participants' adherence to the exercise and breathing protocols may also have influenced the treatment outcomes. Furthermore, the intervention required wearable monitoring devices and a mobile

biofeedback application, which may not be readily available in all clinical settings. Future studies involving larger and more diverse populations, extended follow-up periods, and multicentre designs are recommended to confirm the present findings and evaluate the long-term clinical benefits of this intervention.

Conclusion

The results of this study showed that the group that performed moderate-intensity aerobic exercise combined with HRV biofeedback guided resonance breathing had greater reductions in SBP and HRV parameters than those in the aerobic exercise or routine medical management groups. Overall, the observed changes in the RMSSD, the SDNN, the HF power, the LF power, and the LF/HF ratio indicate favourable cardiac autonomic regulation changes. While the intervention led to a reduction in DBP, the change between the groups was not significant. Based on these results, digital HRV biofeedback could be used alongside traditional antihypertensive treatment. The combined intervention might be useful as a physiotherapy-based approach in cardiovascular regulation in patients with hypertension.

Larger RCT trials with longer intervention periods are recommended in future studies to investigate the long-term effects of the moderate-intensity aerobic exercise combined with HRV biofeedback-guided resonance breathing in hypertension patients. Future studies should investigate various exercise intensities, breathe techniques and determine an optimal intervention strategy. The convergence of sophisticated wearable devices and online health solutions could enhance treatment adherence and provide real-time monitoring in clinical settings. Furthermore, the combined intervention could be evaluated in others with cardiovascular and metabolic diseases to assess the wider clinical use and evidence-based physiotherapy practice.

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Artificial Intelligence Use Disclosure

The authors used ChatGPT for language editing and clarity of the manuscript and did not affect study methods, results, or reproducibility. The authors reviewed the text for accuracy and take full responsibility for the final content.

Authors' Contribution

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Competing Interests

The authors declare no conflicts of interest related to this study.

Ethical approval

The study was approved by the Institutional Ethics Committee of K.G. Hospital and Postgraduate Medical Institute, Coimbatore, Tamil Nadu, India (Approval No. ECKG/0832/2025; approved on 4 August 2025).

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