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Improved heart rate variability in postmenopausal women following short-term combined exercise training

Mejora de la variabilidad de la frecuencia cardiaca en mujeres posmenopáusicas tras un entrenamiento combinado de ejercicio de corta duración

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Abstract. Imbalances in cardiac autonomic nervous systems are associated with cardiovascular risk factors and poor cardiac outcomes. Heart rate variability (HRV) is a practical and reproducible measure of cardiac autonomic nervous system function. Exercise training promotes positive adjustments in HRV. However, previous studies have reported mixed results. Therefore, this study aimed to investigate the effects of short-term combined exercise training on heart rate variability in post-menopausal women. Thirty-four women aged 50-80 years, at least 12 months post-menopause, were divided into a control (CON) group and an exercise (EX) training group. The participants in the exercise group underwent a 2-week of combined exercise program consisting of aerobic, strength, flexibility, and balance exercises. HRV was recorded using an Actiheart device, before and after the final exercise intervention in a sitting position. The significant main effects of time and group were found in the parameter of SDNN (p time = 0.039; p group = 0.026). Post-hoc analysis showed a borderline increase in SDNN in the EX group (POST: 48.79 ± 17.88 VS 44.54 ± 17.39, p = 0.055). No significant change was observed in the CON group (POST: 35.55 ± 13.51 VS 33.17 ± 8.74, p = 0.288). Statistical analysis of other HRV components revealed no significant results (all P > 0.05). In conclusion, a 2-week of combined exercise training program, including aerobic, resistance, balance, and flexibility exercises improves global cardiac autonomic function in post-menopausal women.
Keywords: combined exercise training, heart rate variability, blood pressure, menopause, and women

Resumen. El desequilibrio del sistema nervioso autónomo cardiaco se asocia con factores de riesgo cardiovascular y malos resultados cardiacos. La variabilidad de la frecuencia cardiaca (VFC) es una medida práctica y reproducible de la función del sistema nervioso autónomo cardiaco. El entrenamiento con ejercicio promueve ajustes positivos en la VFC. Sin embargo, los resultados de anteriores intervenciones de ejercicio sobre la VFC siguen siendo equívocos. Por lo tanto, este estudio tuvo como objetivo investigar los efectos del entrenamiento combinado de ejercicio a corto plazo sobre la variabilidad de la frecuencia cardíaca en mujeres posmenopáusicas. Se dividió a 34 mujeres de entre 50 y 80 años, con al menos 12 meses de posmenopausia, en un grupo de control (CON) y un grupo de entrenamiento con ejercicio (EX). Las participantes en el grupo de ejercicio se sometieron a un programa combinado de 2 semanas de ejercicios aeróbicos, de fuerza, flexibilidad y equilibrio. La VFC se registró utilizando el dispositivo Actiheart, antes y después de la última intervención de ejercicio en posición sentada. Se observó que los efectos principales de tiempo y grupo eran significativos en el parámetro de SDNN (p tiempo = 0.039; p grupo = 0.026). El análisis post-hoc mostró que había un aumento de SDNN sólo en el grupo EX (POST: 48.79 ± 17.88 VS 44.54 ± 16.39, p = 0.055), pero no en el grupo CON (POST: 35.55 ± 13.51 VS 33.17 ± 8.74, p = 0.288). El análisis estadístico de otros componentes de la VFC no mostró resultados significativos (todos P > 0.05). En conclusión, 2 semanas de programa de entrenamiento combinado, que incluye ejercicios aeróbicos, de resistencia, equilibrio y flexibilidad, mejora la función autonómica cardiaca global en mujeres posmenopáusicas.
Palabras clave: entrenamiento combinado, variabilidad de la frecuencia cardiaca, presión arterial, menopausia y mujeres

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Introduction

Cardiovascular diseases, such as coronary heart disease, hypertension, and heart failure, are commonly identified in post-menopausal women and are the leading cause of sudden death and all-cause mortality in women (Hayashi et al., 2015). Heart rate variability (HRV) is a non-invasive, practical, and reliable measure of cardiac autonomic nervous system function. Abnormality or reduced HRV reflects sympathovagal imbalance (increased sympathetic or reduced vagal activity) and is clinically useful as it is associated with an increased risk of cardiovascular diseases and risk factors such as hypertension and type II diabetes (Kubota et al., 2017; Liao et al., 2002; Soares-Miranda et al., 2015; Tsuji et al., 1996). HRV is lower in post-menopausal women compared to pre-menopause (Brockbank et al., 2000; Ramesh et al., 2022). Furthermore, the main menopausal symptoms such as hot flushes have been associated with an imbalance in the sympathetic and parasympathetic systems (de Zambotti et al., 2013). HRV can also distinguish the intensity of menopausal symptoms, indicating reduced vagal control in women with more severe symptoms (Martinelli et al., 2020). Therefore, the assessment of HRV in postmenopausal women is important.

Physical exercise has been proposed as a preventive intervention to limit or reverse the decline in cardiovascular function and lower the risk of age-related diseases (Suryadi et al., 2024). The protective and therapeutic effects of exercise training on the cardiovascular system are associated with promoting positive adjustments in cardiac autonomic modulation (Joyner & Green, 2009). A large, prospective population-based study demonstrated that higher levels of physical activity are associated with more favorable HRV measures (Soares-Miranda et al., 2015). Increased walking pace or distance had a more favorable effect on certain indices of HRV, specifically resulting in higher 24-hour SDNN and higher Ultra Low Frequency (ULF) parameters. These parameters likely reflect circadian variations, the combined activity of sympathetic-parasympathetic modulation, and vagal control of heart rate (Soares-Miranda et al., 2015). Although the biological pathways through which regular physical exercise provides cardioprotective benefits are complex and involve multiple factors, long-term adjustment of sympathetic and parasympathetic nervous systems are considered the most important pathway. These adjustments result from dynamic interactions between feed-forward signals from the central command (brain) and the feedback circuits from the exercise pressor reflex during physical exercise (Fu & Levine, 2013; Soares-Miranda et al., 2015). This interaction leads to several adaptations in exercise, including decreased sympathetic activity, increased vagal tone, increased baroreflex sensitivity, decreased heart rate, and increased HRV.

Combining different types of exercises within the same session is a recommended strategy for exercise intervention in post-menopausal women that provides benefits in overall health-related outcomes (Pereira et al., 2023). However, the effect of exercise training on HRV in post-menopausal women remains inconclusive (Sánchez-Delgado et al., 2023). While endurance training has been reported to increase the HRV in older women, strength training did not show the same effect. Additionally, a study in middle-aged women found that neither endurance, strength, nor combination exercise induced changes in HRV at rest (Karavirta et al., 2013; Kingsley & Figueroa, 2016; Madden et al., 2006). Several moderating factors within exercise training regimens contribute to discrepancies observed in the previous studies. Among these factors, training frequency appears to be the key factor in influencing HRV. It is recommended that older adults engage in at least four exercise sessions per week to enhance cardiac health through the enhancement of vagal activity (Raffin et al., 2019). Therefore, this study aimed to investigate the effect of short-term combined exercise training on HRV in post-menopausal women, while also assessing functional mobility and exercise capacity.

Materials & Methods

Study design

Participants were recruited from women's organizations participating in the Family Welfare Empowerment Program in Surabaya, East Java, Indonesia. They were eligible for this study if they met the inclusion criteria: women aged 50-80 years old who are at least 12 months postmenopausal and had a minimum level of education of junior high school. Women with the history of stroke or any neurological problems, having recent surgery, severe hearing or visual impairment, recent cardiovascular diseases (ischemic heart diseases, heart failure), hypertension (blood pressure higher than or equal to 140/90 mmHg based on the study of Unger et. al., (2020), dementia, and a medical history of hypertension/diabetes were excluded from this study. Participants who met the inclusion criteria were allocated to the exercise training group (EX, n=15). Age-matched participants were recruited from the neighborhood for the control group (CON, n=14). Informed consent was obtained from all participants prior to their enrollment in this study. During the first meeting, participants were asked to complete a form to collect baseline information, including age, educational level, marital status, medical history, and medication use. They were also screened to ensure that they do not have any history of stroke or any neurological problems, recent surgery, severe hearing or visual impairment, recent cardiovascular diseases (ischemic heart disease, heart failure), or dementia. This study was approved by the Ethics Committee of the Faculty of Medicine, Airlangga University, with reference number: 43/EC/KEPK/FKUA/2023.

After enrollment, we assessed the outcomes of this study three days before the first exercise session (pre-test) and three days after the final exercise session (post-test). All measurements were conducted in a controlled-temperature room (25℃) at the same time (06:00 – 08:00 AM). Before the outcome measurements, all participants were asked to fast for 10 hours (last meal at 08.00 PM on the previous day), refrain from smoking, alcohol consumption, carbonated drinks, and vigorous exercise. Body height was measured using a stadiometer (SECA 213 Portable Stadiometer, Germany) and body weight was measured using a body scale (Omron HN-289, Japan). Body mass index (BMI) was calculated by dividing body weight (in kgs) by height in squares (in kg/m^2). Resting heart rate and blood pressure were measured twice using an automatic sphygmomanometer (OMRON Model HEM-7156, Omron Healthcare Co., Ltd, Japan) after 20 minutes of quiet rest in a sitting position. Participants in the EX group performed 2 weeks of combined exercise (aerobic, strength, balance, and flexibility), while those in the CON group were asked to maintain their usual activities.

Sample Size

The sample size was estimated using G*Power software (G*power, version 3.1.9.7) based on the published data of Rizvi et al. (2023) which reported the beneficial effects of a 6-week knee strengthening exercise on HRV in women with an effect size of 0.39 for LF-HRV. Assuming α=0.05 and β=0.95, the minimum total number of subjects required to establish significance is 24 (12 in each group).

Exercise training

Participants in the exercise (EX) group attended exercise training sessions 5 times per week for 2 weeks (every weekday) in a community-based hall. A minimum of 8 exercise sessions over two weeks has been shown to improve heart rate variability in physically inactive adults (Alansare et al., 2018; Lee, 2001). Each session was conducted in a group setting and included a combination of aerobic exercise (brisk walking), strength exercise (loop band exercise), flexibility exercise, and balance exercise. The balance exercise consisted of standing with feet side by side, tandem walking, and one-leg standing with two hands support in the first week and without hand support in the second week. Initially, each session lasted for 40 minutes and progressively increased to 60 minutes at a moderate intensity (RPE 5-6 out of 10). The exercises were led by one instructor with 2 assistants, who monitored and guided participants' movement. Attendance was recorded in the logbook, and the adherence rate was calculated based on the number of sessions completed. Only participants who attended at least 80% of the exercise sessions were included in the post-test.

Heart rate variability

Heart rate variability (HRV) was recorded using Actiheart (Cambridge Neurotechnology, Cambridge, UK), three days before and after the final exercise intervention. Actiheart is technically reliable and valid compared to standard ECG recordings. The device is user-friendly, with minimal discomfort to participants, and its software enables data extraction for further analysis. It has a sensitivity of 250 μV and a sampling frequency of 128 Hz (~8ms). The measurable range of HR is 35–250 bpm. At the end of each epoch, the R-R interval durations for the last 16 valid heart beats were analyzed to get a representative value and exclude noisy or missed beats. The 16 values are initially averaged. Any values outside of +/-25% of this average were removed (CamNtech, 2012). The device was attached using a disposable electrode (One Dot ECG Electrode Onemed, Jakarta, Indonesia) to the participants' chest at the level of the fourth-fifth intercostal space. After 20 minutes of quiet rest at sitting position, the Actiheart device was attached and tested for signal quality. This signal test ensured that the level of the R wave signal detected by the device was adequate, avoiding artifacts caused by a high noise level or a low R wave signal. The test involves making a short recording and analyzing the signal using a built-in utility which provides a Pass/Fail indication of signal. After recording, the data was downloaded to a laptop and assessed for the signal quality. Once an acceptable signal was obtained, a short-term recording with 15-second epoch length was programmed. The Actiheart monitor device was then re-attached in the same position to record HRV for at least 15 minutes. In short-term mode, the analog signal from Actiheart was filtered (10 Hz-35Hz) and sampled at a frequency of 128 Hz. The analysis software interpolates each interbeat interval (IBI) to 1 ms resolution (Actiheart software version 4.0.116). Once processing was completed, the data was exported from the Actiheart device for post-processing analysis using the built-in software provided by the Actiheart manufacturer. The software provides measures of beats per minute (BPM), IBI with maximum, minimum, and average values, as well as time- and frequency -domain HRV indices.

The HRV was analyzed using both time-domain and frequency-domain methods based on inter-beat-interval (IBI) data. All HRV indices were analyzed using 15-minute sampling period derived from the accelerometer. Time-domain indices included the Standard Deviation of Normal-to-Normal IBI (SDNN) and Root Mean Square of Successive Differences (RMSSD). Power spectral analysis was performed to measure HRV, identifying low-, mid-, and high-frequency oscillations using the Fast Fourier Transform. Thus, in this frequency-domain analysis of interbeat intervals, the absolute value of the power spectral density includes variation in the range of very-low-frequency (VLF, 0.0033–0.04 Hz), low-frequency (LF, 0.04–0.15 Hz), high-frequency (HF, 0.15–0.40 Hz)) as well as the ratio of low- to high-frequency (LF/HF ratio) (CamNtech, 2012). SDNN reflects the global index of HRV, while RMSSD and HF are indicators of parasympathetic activity. The LF/HF ratio represents the balance between parasympathetic and sympathetic activity (Task Force of ESCNASPE, 1996).

Functional exercise capacity

Functional exercise capacity was assessed using a six-minute walking test, following the guideline of the American Thoracic Society (American Thoracic Society, 2002). Participants were instructed to walk as fast as they could for 6 minutes along the 30-meter corridor in the hall. Turnaround points and the length of the corridor were marked every 3 meters with cones, while the start and finish lines were marked using colored tape. If the participants felt uncomfortable or tired, they were allowed to take a rest and continue whenever they were ready (American Thoracic Society, 2002).

Muscle Strength

Grip strength was measured on the dominant arm using a grip dynamometer (Takei A5401 Grip-D Digital handgrip dynamometer, Takei Scientific Instruments Co., Ltd, Tokyo, Japan). Participants stood with arms by their sides and elbows fully extended, and were instructed to squeeze the dynamometer for 3 seconds. This was repeated 3 times with 5 seconds of rest between each attempt. The best of three attempts was reported (Luna-Heredia et al., 2005).

Upper body strength was measured using a push-and-pull dynamometer (Dynamometer, TTM, Tokyo, Japan). Participants held the dynamometer with both hands parallel to the ground in front of their chest while standing. They were instructed to push and pull with maximum effort for 3 seconds, repeating this 3 times with 5 seconds of rest between repetitions. The best of three attempts was reported (Fraser et al., 2018).

Leg and back strength were measured using a leg and back dynamometer (Takei 5002 BACK-D, Type 3 Takei Japan), following the guidelines from a previous study (Fraser et al., 2018). Participants stood barefoot on the leg-back dynamometer base and held the bar with an overhand grip. Leg muscle strength was assessed in the standing position with 115° knee flexion at which point a chain was attached from the dynamometer to the bar. Participants were then instructed to pull the bar upwards as far as possible. Back muscle strength was determined by evaluating the maximal isometric strength of the trunk muscles in a standing position with a 30° lumbar flexion. The best value of three attempts was used for further analyses.

Statistical analysis

Statistical analysis was performed using PRISM 9.5.1 (Graph Pad PRISM 9.5.1, La Jolla, CA, USA). All data are presented as Mean (SD) unless stated otherwise. The Shapiro-Wilk test confirmed that the data were normally distributed. An independent t-test was used to compare baseline characteristics data, while primary outcomes were assessed using 2-way repeated measures (RM) ANOVA to analyze interaction (time*group) and main effects (time (pre*post) and group (CON*EX). Post-hoc analysis was conducted using Bonferroni's multiple comparison test, with a significance level of 95%.

Result

All 15 participants in the EX group attended at least 90% of the total exercise sessions. Baseline characteristics of the participants are presented in Table 1. There were no significant differences in participants' baseline characteristics, including age, BMI, resting heart rate, and blood pressure (all p > 0.05) as detailed in Table 1.

Table 1.
Participants Characteristics

Variable	EX group (n= 15)	CON group (n= 14)	p-value (Independent T-test)
Age (year-old)	60.63 ± 4.42	57.39 ± 4.27	0.055
BMI (kg/m^2)	25.57 ± 4.36	25.21 ± 2.52	0.787
Blood pressure (mmHg)			
Systolic blood pressure	129.7 ± 16.43	124.3 ± 15.75	0.376
Diastolic blood pressure	80.30 ± 6.24	77.21 ± 8.52	0.273
Mean arterial blood pressure	96.80 ± 9.25	92.88 ± 10.09	0.284
Resting heart rate (bpm)	80.27 ± 8.40	78.18 ± 6.87	0.472

Note: EX group: group that performed exercise; CON: Control group; BMI: Body Mass Index; bpm: beat per minutes

Table 2 presents the results of the exercise training effect on functional capacity and muscle strength. Statistical analysis using 2-way RM ANOVA showed no significant interaction or main effects on the 6-minute walking test (all p > 0.05).

In handgrip strength, we observed a significant time*group interaction (p = 0.021), but none of the main effects were significant (all p > 0.05). Handgrip strength increased in the EX group (POST: 18.29 ± 4.29 kg VS PRE: 16.74 ± 3.13 kg, p = 0.009) but did not change in the CON group (POST: 17.91 ± 3.63 kg VS PRE: 18.29 ± 3.45 kg, p = 0.505). There was no significant interaction for upper body strength either in push or pull performance. No significant results were found in the other strength performances, as detailed in Table 2.

Table 3 shows the results of resting blood pressure measurement before and after the exercise intervention. Statistical analysis results using 2-ways RM ANOVA revealed no significant time*group interaction and main effect of mean arterial blood pressure (MAP) and diastolic blood pressure (DBP) (all p > 0.05). However, the main effect of time systolic blood pressure (SBP) was significant (p time = 0.014) as shown in Table 3.

We found no significant interaction in resting heart rate (RHR) or any parameters of heart rate variability (HRV) using the 2-way RM ANOVA test, as shown in Table 4 (all p > 0. 05). However, the main effect of time and group were significant for the SDNN parameter (p time = 0.039; p group = 0.026).

Table 2.
Mean and standard deviation (SD) of fitness level pre- and post- intervention

	EX Group		CON Group		p-value[2]		
	Mean ± SD	p-value[1]	Mean ± SD	p-value[1]	Interaction	time	group
Six-minute walking test (m)							
Pre	299.4 ± 46.44	0.014	339.1 ± 75.87	0.958	0.074	0.086	0.208
Post	326.7 ± 42.66		338.6 ± 61.12				
Muscle strength fitness test (kg)							
Handgrip							
Pre	16.74 ± 3.13	0.009*	18.29 ± 3.45	0.505	0.021*	0.153	0.657
Post	18.29 ± 4.29		17.91 ± 3.63				
Push							
Pre	10.91 ± 4.74	0.133	11.14 ± 2.38	0.353	0.696	0.091	0.998
Post	12.13 ± 4.28		11.91 ± 3.91				
Pull							
Pre	8.73 ± 4.30	0.286	9.93 ± 1.88	0.137	0.731	0.074	0.248
Post	9.41 ± 3.62		10.93 ± 2.89				
Leg							
Pre	45.70 ± 14.62	0.608	52.25 ± 15.11	0.719	0.921	0.539	0.243
Post	44.47 ± 16.68		51.36 ± 16.91				
Back							
Pre	45.70 ± 14.62	0.651	55.14 ± 13.85	0.101	0.373	0.135	0.159
Post	44.47 ± 16.68		50.39 ± 15.48				

Note: [1] Bonferroni's multiple comparisons (Post hoc) test; [2] 2-way repeated measures ANOVA

Table 3.
Blood pressure pre- and post- intervention

Variable	EX Group		CON Group		p-value[2]		
	Mean ± SD	p-value[1]	Mean ± SD	p-value[1]	interaction	time	group
			MAP (mmHg)				
Pre	96.80 ± 9.25	0.015	92.88 ± 10.09	0.810	0.059	0.117	0.694
Post	92.11 ± 7.47		93.33 ± 12.01				
			SBP (mmHg)				
Pre	129.7 ± 16.43	0.004*	124.3 ± 15.75	0.537	0.096	0.014*	0.679
Post	121.9 ± 11.00		122.7 ± 18.42				
			DBP (mmHg)				
Pre	80.30 ± 6.24	0.088	77.21 ± 8.52	0.438	0.084	0.513	0.765
Post	77.20 ± 6.40		78.64 ± 10.63				

Note: BMI (Body mass index); MAP (Mean arterial pressure); SBP (Systolic blood pressure); DBP (Diastolic blood pressure); [1] Bonferroni's multiple comparisons (Post hoc) test; [2] 2-way repeated measures ANOVA

Table 4.
Heart rate and Heart rate variability pre- and post- intervention

Variable	EX Group		Control Group		p-value[2]		
	Mean ± SD	p-value[1]	Mean ± SD	p-value[1]	interaction	time	group
			RHR (bpm)				
Pre	80.27 ± 8.40	0.359	78.18 ± 6.87	0.121	0.083	0.618	0.973
Post	78.70 ± 7.83		80.96 ± 8.07				
			SDNN (ms)				
Pre	44.54 ± 16.39	0.055	33.17 ± 8.74	0.288	0.546	0.039*	0.026*
Post	48.79 ± 17.88		35.55 ± 13.51				
			RMSSD (ms)				
Pre	37.56 ± 26.21	0.423	22.55 ± 11.67	0.209	0.722	0.148	0.066
Post	39.49 ± 26.25		25.71 ± 13.15				
LnVLF							
Pre	5.75 ± 0.86	0.315	5.34 ± 0.57	0.579	0.760	0.274	0.133
Post	5.89 ± 0.86		5.43 ± 0.84				
LnLF							
Pre	5.19 ± 1.06	0.548	5.11 ± 0.64	0.987	0.668	0.684	0.719
Post	5.29 ± 1.10		5.11 ± 1.11				
LnHF							
Pre	4.67 ± 1.48	0.646	4.17 ± 0.93	0.178	0.507	0.199	0.379
Post	4.77 ± 1.51		4.47 ± 0.98				
			LnLF/HF				
Pre	1.61 ± 0.21	0.996	0.94 ± 0.99	0.243	0.396	0.399	0.472
Post	1.16 ± 0.21		1.15 ± 0.16				

Note: RHR (Resting heart rate); bpm: beats per minute; Ln (natural logarithm); SDNN (Standard deviation of all N-N intervals); RMSSD (Root mean square of successive difference); VLF (Very low-frequency spectral power); LF (Low-frequency spectral power); HF (High-frequency spectral power); [1] Bonferroni's multiple comparisons (Post hoc) test; [2] 2-way repeated measures ANOVA; *significantly different at $p < 0.05$

Discussion

The primary finding of our study demonstrates that a short-term (2 weeks) of combined exercise training in postmenopausal women improves one of the important indicators of cardiovascular health and autonomic nervous system activity, as evidenced by changes in SDNN parameters of heart rate variability and systolic blood pressure. Additionally, it is also found that combined exercise training enhances strength, including dominant-hand grip and upper-body strength.

Aging is associated with imbalanced autonomic cardiac modulation, leading to increased blood pressure while heart rate and heart rate variability decrease (Joyner & Green, 2009). Female reproductive hormones drive ß2-mediated vasodilation and counteract the vasoconstrictor effects of noradrenaline. In older women, this mechanism is lost, allowing full expression of the vasoconstriction effects of high sympathetic activity, regardless of menopausal status (Narkiewicz et al., 2005). Additionally, aging also progressively reduces endothelial function and decrease nitric oxide bioavailability, leading to increased arterial stiffness (Joyner & Green, 2009). Together, imbalanced autonomic cardiac modulation and endothelial dysfunction have a synergistic and detrimental effect on cardiovascular risks (Joyner & Green, 2009).

In women during the menopause transition, changes in sympathetic and vagal regulation of heart rhythm are associated with aging and estrogen level (Akiyoshi et al., 2011; de Zambotti et al., 2013). This condition continues afterward, with vasomotor symptoms such as hot flush linked to sympathetic predominance in postmenopausal women (Freedman et al., 2011; Neufeld et al., 2015).

Exercise training improves HRV through mechanisms such as increased blood vessel distensibility, decreased sympathetic activity, enhanced vagal tone, and increased baroreflex sensitivity (Earnest et al., 2012; Earnest et al., 2008; Fu & Levine, 2013; Joyner & Green, 2009; Roveda et al., 2003). Animal studies have demonstrated that exercise has significant central nervous system effects on the autonomic nervous systems, promoting sympato-inhibition in the brainstem cardiovascular centers and enhancing vagal outflow (Joyner & Green, 2009; Mueller, 2007). In this study, it is found that 2 weeks of combined exercise training in postmenopausal women increased the global index of cardiac autonomic function, as indicated by the improvement of SDNN. Although the biological interpretations of SDNN are complex involving multiple factors, it likely reflects the modulation of both the sympathetic and parasympathetic systems. Generally, higher SDNN values are associated with better health (Kubota et al., 2017), conversely, lower values of this index are associated with an increased risk of mortality in patient populations (Kubota et al., 2017). Our study aligns with previous longitudinal study showing that physical activity is associated with specific indices of HRV measures, including higher SDNN and ULF (Soares-Miranda et al., 2015). These findings support the notion that exercise training enhances ANS activities. However, specific effects on sympathetic or parasympathetic activity could not be determined, as the corresponding time-domain (RMSDD) and frequency-domain indices did not reach statistical significance.

Previous studies on the impact of exercise training on HRV in postmenopausal women have shown mixed results. While some studies observed positive effects of exercise training on HRV, other studies did not find significant changes (Davy et al., 1997). Despite the inconsistent finding, HRV adaptations appear to follow a dose-response relationship, with higher training volumes potentially leading to greater parasympathetic adaptations (Earnest et al., 2012; Raffin et al., 2019). Higher training volume may lead to greater parasympathetic adaptations to exercise training (Earnest et al., 2012; Earnest et al., 2008). However, achieving high training volume can be challenging for older adults, due to reduced exercise capacity. Therefore, increasing the exercise frequency rather than increasing the duration or intensity are recommended, as the gain magnitude in SDNN (short term) appears to be positively associated with the frequency of training sessions. Additionally, long-term interventions typically yield a greater effect size (Raffin et al., 2019; Soares-Miranda et al., 2015). In this study, short-term exercise with high frequency (5 times per week) was sufficient to induce the adjustment in HRV.

In this study, we observed no significant improvement in resting mean arterial blood pressure (MABP), diastolic blood pressure (DBP), and heart rate following the exercise intervention, despite a trend towards reduction compared to baseline. Reviews indicated that not all types of exercise effectively reduced blood pressure and resting heart rate. Contributing factors include the type and total volume of exercise, which are among the most significant moderators of exercise intervention effects. Aerobic exercise and longer duration of exercise intervention (longer than 8 weeks) typically show more substantial benefits for blood pressure and heart rate (Pal et al., 2013; Reimers et al., 2018). Therefore, the lack of significant changes in these parameters in this study may be due to exercise dose in this study was below the physiological stimulus threshold required to induce the changes in MABP, DBP, and heart rate at rest. Furthermore, exercise intervention tends to have more pronounced effects in hypertensive individuals (Reimers et al., 2018). Our study found an increase in strength measurements in the EX group (18.29 ± 4.29 kg vs. PRE: 16.74 ± 3.13 kg, $p = 0.009$). Each exercise intervention in this study included resistance training, which is known to be effective in increasing muscle mass and strength. It is recommended for ageing postmenopausal women (Agostini et al., 2018). Additionally, such exercise induces mechanical tension in the muscles. This leads to molecular changes such as increased intracellular calcium concentration and activation of various signaling pathways that enhance muscle mass. These pathways include the extracellular signal-regulated kinase (ERK)/c-Jun N-terminal kinase (JNK) pathway, Ca^{2+}/calmodulin-dependent protein kinase II (CaMKII), and phosphatidylinositol 3-kinase (PI3K)/protein kinase B (AKT) (Attwaters & Hughes, 2022). According to ACSM recommendations, effective muscle strength exercises should be performed 2 to 3 times a week with 2 to 4 sets of 8 to 12 repetitions and adjusted according to individual conditions (ACSM, 2017). In women, the decline of skeletal muscle mass and strength accelerates with the onset of menopause, significantly impacting autonomy and quality of life. Therefore, it is essential to design exercise programs for post-menopausal women that incorporate resistance or weight-bearing exercises.

Although we did not evaluate the biological mechanisms underlying our findings, the observed benefits may be attributed to the positive interaction between a balanced autonomic nervous system, improved endothelial function, and increased compliance of blood vessels, which collectively contribute to reduce blood pressure and enhanced heart rate variability with exercise. However, this study has some limitations. The not-randomized selection of participants into groups may have contributed to increased heterogeneity in the baseline values. To address this, we recruited age-matched controls. Future studies could benefit from evaluating serum indicators (hormones, cytokines, etc.) to provide further support for these findings.

Conclusion

In conclusion, a 2-week regimen of combined aerobic, resistance, balance, and flexibility training in postmenopausal women enhanced muscle strength, particularly hand muscle strength. The intervention also led to a reduction in systolic blood pressure and an increase in HRV parameters, notably SDNN, which provides valuable insights into autonomic nervous system function and cardiovascular risk. These findings suggest that short-term combined exercise offers protective effect against cardiovascular risk factors and improve general fitness in postmenopausal women.

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