

ACUTE EFFECTS OF CIRCUIT-BASED COMBINED EXERCISE ON BLOOD PRESSURE AND GLYCEMIA IN ADULTS WITH METABOLIC DISORDERS: A RANDOMIZED CROSSOVER TRIAL

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ABSTRACT

Objectives: To evaluate the effects of a single session of circuit-based combined exercise on blood pressure and glycemia in adults with metabolic disorders.

Methods: In this crossover trial, adults with at least two components of metabolic disorders (hypertension, abdominal obesity, insulin resistance, or dyslipidemia) were randomized into two experimental sessions: circuit-based combined exercise and control sessions. The circuit-based combined exercise was structured in five blocks, consisting of four exercises performed for 40 seconds each, with 20 seconds of rest between them, alternating between resistance and aerobic modalities. Each block was performed twice. During the control, the participants remained seated at rest without any exercise. Each protocol lasted 50 min. Office blood pressure and glycemia were assessed before and after the experimental sessions for 1-h. Enjoyment was also evaluated after the circuit-based combined exercise. Generalized estimating equation analysis was used to compare the main effects of intervention on outcomes. A $p < 0.05$ was considered statistically significant.

Results: Twenty-two adults (7 men and 15 women aged 40-65) participated in the study. Comparing circuit-based combined exercise with control, systolic blood pressure showed a significant reduction at total average at post 60' (-5 mmHg; $p=0.048$), while diastolic blood pressure shows a trend observed at total average at post 60' (-3 mmHg; $p=0.053$). No significant difference in glycemia between circuit-based combined exercise and control sessions was found. The enjoyment score after circuit-based combined exercise was 124 AU or 98%.

Conclusion: The circuit-based combined exercise effectively reduced blood pressure, maintained glycemic stability, and demonstrated high levels of participant enjoyment. These findings highlight its potential as a non-pharmacological intervention for improving metabolic health in adults with metabolic disorders.

Keywords: *Cardiovascular disease; Aerobic exercise; Resistance exercise; Metabolic syndrome; Hypertension; Diabetes mellitus*

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INTRODUCTION

Metabolic disorders are conditions that include abdominal obesity, insulin resistance, dyslipidemia, and hypertension, and the set of three or more of these factors is called metabolic syndrome¹. The increasing prevalence of metabolic disorders, fueled by sedentary lifestyles, unhealthy diets, and population aging², results in a cardiovascular disease mortality rate three times higher than adults without metabolic disorders³. The main factors are chronic elevation of blood pressure and glucose levels that contribute to vascular damage, insulin resistance, and systemic inflammation, which collectively increase the risk of myocardial infarction, stroke, and kidney disease⁴.

Exercise has been recognized as a critical non-pharmacological strategy for managing these metabolic abnormalities⁵⁻⁷. Aerobic exercise improves cardiovascular fitness and glucose utilization⁸, while resistance training enhances muscular strength and insulin sensitivity^{9,10}. Combined training, which integrates aerobic and resistance components, has emerged as a promising approach for individuals with metabolic disorders¹¹. A single session of combined exercise can acutely reduce blood pressure, a phenomenon known as post-exercise hypotension (PEH)¹²⁻¹⁴, contributing to the chronic blood pressure-lowering effects of regular exercise¹⁵. In addition to blood pressure control, acute session of combined exercise, can lead to significant reductions in blood glucose levels¹⁶.

Circuit-based combined exercise, a time-efficient modality, involves performing aerobic and resistance exercises in succession with minimal rest between sets¹⁷. This format maximizes energy expenditure and elicits simultaneous cardiovascular and metabolic responses¹⁸. Although the blood pressure-lowering effects of combined exercise have been extensively documented in various studies^{12,14,17}, the acute effects of the aforementioned exercise modes combined in a circuit method on PEH, are scarce¹⁹. This knowledge gap is particularly evident among individuals with metabolic disorders, a population at heightened risk of cardiovascular complications.

Based on these premises, this study aimed to evaluate the acute effects of a single session of circuit-based combined exercise on blood pressure in adults with metabolic disorders. As a secondary outcome, we also assessed glycemia throughout the study. We hypothesize that this training protocol induces significant reductions in blood pressure and glucose levels in the immediate post-exercise period.

METHODS

Study Design and Participants

This randomized crossover trial was conducted to assess the effect of circuit-based combined exercise versus a non-exercise control session on the blood pressure and glycemia of adults with metabolic disorders. The study protocol was conducted according to the principles of the Declaration of Helsinki and in compliance with the Brazilian legal and regulatory framework for research involving human beings (NR 466/12). The study protocol was approved by the Institutional Review Board of *Universidade do Extremo Sul Catarinense* (nº 7.199.130). The protocol followed the CONSORT guidelines for nonpharmacological treatment²⁰.

Twenty-two participants were randomly allocated to undergo a circuit-based combined exercise or a non-exercise control session. The randomization

sequence was generated by an independent researcher who was not involved in the recruitment, intervention, or outcome assessments. This researcher used a computer-generated randomization list created using Excel 365 (Microsoft, USA) with a 1:1 allocation using random block. The randomization list was kept hidden from the research team and participants until the time of allocation (allocation concealment). Participants between 40 and 65 years, who have not engaged in structured exercise programs in the past 3 months were recruited through telephone calls, newspaper releases, word of mouth, and personal references. Participants were eligible for inclusion if they met at least two risk factors for metabolic syndrome based on the International Diabetes Federation (IDF)² criteria in two consecutive visits or were in treatment for hypertension, diabetes, or dyslipidemia.:

- Elevated triglyceride levels: $\geq 150 \text{ mg/dL}$ (1.7 mmol/L).
- Reduced HDL cholesterol levels: $< 40 \text{ mg/dL}$ (1.03 mmol/L) for men and $< 50 \text{ mg/dL}$ (1.29 mmol/L) for women.
- Elevated blood pressure: Systolic blood pressure $\geq 130 \text{ mmHg}$ or diastolic blood pressure $\geq 85 \text{ mmHg}$.
- Elevated fasting glucose levels: $\geq 100 \text{ mg/dL}$ (5.6 mmol/L).
- Abdominal obesity by waist circumference (males $> 100 \text{ cm}$ and females $> 88 \text{ cm}$) reflects increased visceral adiposity.

This approach ensured a standardized selection of participants with clinically relevant metabolic risks for the study, aligning with widely accepted diagnostic criteria. Exclusion criteria encompassed a prior diagnosis of cardiovascular disease within the past 24 months, including ischemic heart disease, stroke, or heart failure. Additional exclusions included current smoking and musculoskeletal conditions that impeded the ability to perform exercise. Before enrollment, all participants were informed about the study procedures and objectives, provided written informed consent, and were assured that their participation was entirely voluntary. The study adhered to ethical standards, including strict confidentiality and data protection protocols, in compliance with applicable guidelines.

Preliminary Sessions

Each participant underwent a comprehensive clinical screening conducted in a laboratory setting. Body composition was assessed through anthropometric measurements and bioelectrical impedance analysis (BIA). Body mass and height were measured following standardized procedures according to the International Society for the Advancement of

Kinanthropometry (ISAK) guidelines²¹. Body mass was evaluated using the InBody 270 BIA device, while height was measured with a Sanny® stadiometer with a resolution of 0.1 centimeters. Participants were instructed to remain in an upright position, barefoot with feet together, and with their heads aligned to the Frankfort plane. The stadiometer cursor, positioned at a 90° angle relative to the scale, touched the highest point of the head at the end of maximum inspiration. Following these measurements, the Body Mass Index (BMI) was calculated using the equation: $BMI = \text{body mass} / \text{height}^2$. Additionally, circumferences of the waist and hip were measured using an anthropometric tape, adhering to ISAK standardization²¹. The BIA octopolar model, a multi-frequency device with eight electrodes that measures resistance, was used to evaluate fat mass. During the BIA assessment, participants stood upright, holding two hand grips, with their feet positioned on a platform. The evaluation took approximately two minutes. All participants followed pre-test recommendations, which included: Fasting for at least four hours, wearing light clothing (bikinis, swim trunks, swimsuits, sports bras, or Lycra shorts), being barefoot and free of jewelry, rings, or any metallic items, avoiding intense physical activity on the previous day, abstaining from caffeinated beverages for 12-h prior to the assessment. Women who were menstruating on the evaluation day were rescheduled for another time.

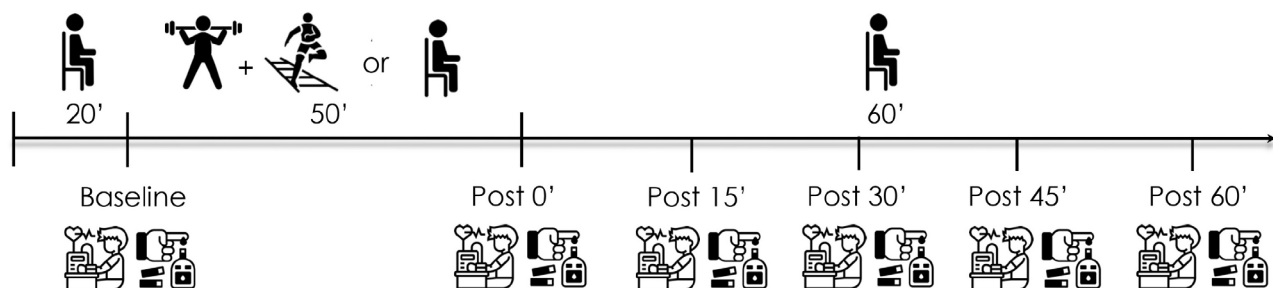
During a subsequent visit, within 24–48h following the initial visit, all participants completed 3 familiarization sessions using the exercises that composed the experimental protocol. These sessions aimed to standardize the execution technique and to determine the intensity of each exercise. A rating of perceived exertion scale

was used for setting exercise intensities²² and a training zone of 5–6 (hard) was adopted for all exercises. When necessary, adjustments in the range of motion and body position were made to find these target intensities.

Experimental session

Participants randomly performed two experimental sessions: circuit-based combined exercise and control sessions. Participants were instructed to avoid any physical exercise for 24h before the experimental sessions, maintain their usual dietary intake, and avoid alcohol, coffee, and other stimulant substances on the same day of the experimental session. The participants maintained their current antihypertensive medication use. The participants were instructed to control mealtimes, maintaining the same composition on the days of both experimental sessions. The meal should be light and consumed no more than two hours before each session. No specific instructions were given, nor was there any control regarding caloric intake or macro- and micronutrient content. The sessions started between 9:00 and 10:30 AM (at the same time of day to account for diurnal variations in blood pressure) with the ambient temperature ranging between 27°C and 28°C, with relative humidity 67% and 69%, and lasted approximately 2 hours. The experimental session started with 10 minutes of rest before the protocols, 50 minutes of exercise or non-exercising control, and 60 minutes of passive recovery after that (figure 1). To minimize potential residual effects between sessions, a minimum interval of 48 hours was maintained. Sixteen participants (80%) completed the 2-day interval between sessions, while four (20%) completed the 5-day interval, resulting in an average interval of 2.6 days.

Figure 1: Illustration of the experimental session procedures



The circuit-based combined exercise was structured into two sets of five blocks, each consisting of 40 seconds of exercise alternating between resistance and aerobic modalities. Exercise intensity was primarily regulated using the Borg CR10 scale²², with participants instructed to maintain a perceived exertion between 5 and 6 A.U. ("hard"). To ensure sufficient engagement during each 40-second exercise interval, participants were encouraged to perform the maximum number of repetitions possible using volitional velocity. They were also instructed to avoid performing the Valsalva maneuver during exercise execution. A 20-second rest interval was observed between exercises, and a 2-minute rest period was provided between blocks. The exercises performed in each block were as follows:

Block 1: Squat, agility ladder, pec deck, and stationary jogging; Block 2: Hip abductor, step, upright row, and stationary jogging; Block 3: Hip adductor, agility ladder, seated row, and stationary jogging; Block 4: Knee extension, agility ladder, bicep curl, and stationary jogging, and Block 5: Knee flexion, agility ladder, triceps pushdown, and stationary jogging.

The training sessions were supervised by three researchers, consistent across all experimental sessions, who were experienced in the exercise protocols performed. These researchers did not participate in subsequent assessments or data analysis to ensure objectivity.

We assessed enjoyment levels during the mixed circuit training session using the Physical Activity Enjoyment Scale (PACES)²³. Each participant received a questionnaire and was asked to rate the level of enjoyment based on the following question: "How do you feel at the moment about the physical activity you have been doing?" The questionnaire consisted of 18 items rated on a 7-point bipolar rating scale. A total of 11 items were reverse-scored. Summing the individual item scores generated an overall PACES score. This yielded a possible range of 18 to 126, and higher PACES scores reflect greater enjoyment.

Non-exercising control session was performed in a seated position at rest without engaging in any physical activity or using any electronic devices such as smartphones or notebooks throughout the session.

Assessment

The primary outcome of the study was the difference in systolic blood pressure after each session. Firstly, standardized blood pressure was obtained after 10 minutes of seated rest according to the Brazilian National Guidelines in Cardiology²⁴ using an automated oscillometric device (Omron HEM-7346T, Illinois, USA). Participants were instructed to remain silent and use no electronic devices (i.e., smartphones or notebooks) during the measurement. A properly sized cuff was positioned approximately 2 cm above

the antecubital fossa on the arm. Blood pressure measurements were performed in both arms with a 1-minute interval between measurements, and after twice in the arm with the highest blood pressure values. The mean of these blood pressure values was used to represent baseline blood pressure.

The arm with the highest systolic blood pressure value was utilized for all evaluations conducted during the study. Following the session protocol, assessments were carried out during the recovery period at 15-minute intervals over a total duration of 60 minutes, in accordance with the Brazilian National Cardiology Guidelines²⁴.

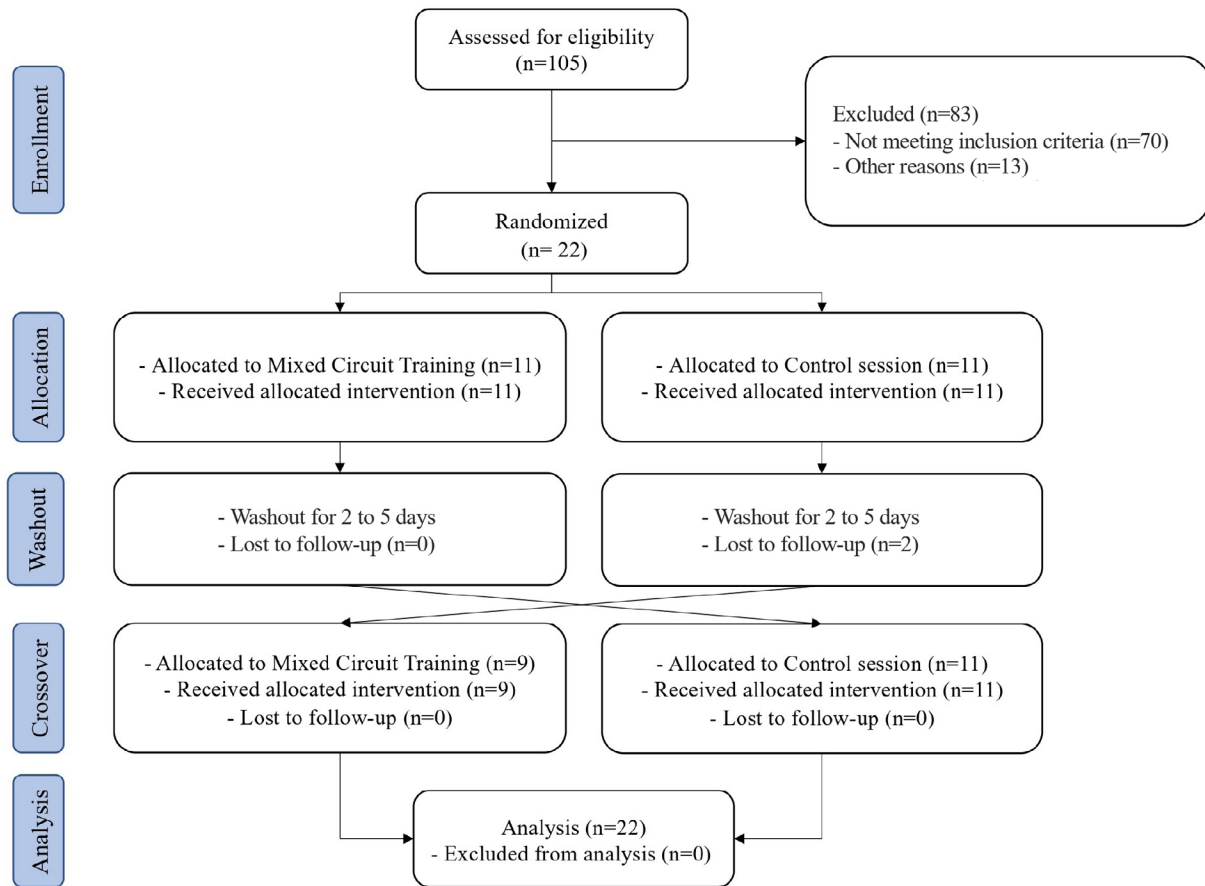
Blood glucose levels were measured immediately after blood pressure. The collections were performed using a digital puncture with disposable lancets (Accu-Chek Safe-T-Pro Uno, Roche, Portugal). A drop of capillary blood was obtained to fill a test strip, which was analyzed with a clinical glucometer (Accu-Chek Performa, Roche, Portugal). The glucometer provided real-time blood glucose concentration results within approximately 5 seconds. Both the automatic oscillometric blood pressure monitor and the clinical glucometer were selected to ensure standardized and objective measurements, thereby eliminating potential investigator bias. All devices were calibrated and used according to the manufacturer's instructions to maintain the accuracy and reliability of the data collected.

Statistical analyses

The sample size for this study was determined based on the study by Ferrari et al.²⁵, who conducted a similar crossover design study. Considering the methodological similarities and aiming for comparable statistical power, we initially planned to recruit 23 participants as the study highlighted above. However, due to practical constraints during the recruitment period, we were able to enroll 22 participants. The normality assumption was assessed using the Shapiro-Wilk test, visual inspection of histograms, and Q-Q plots. The results are expressed as the means, standard errors, and 95% confidence intervals (95% CIs). Generalized estimating equation analysis was used to compare the main effects between the interventions (mixed circuit training and control session) by time (time points). Post hoc comparisons were performed using the Bonferroni correction. Statistical significance was set at $p < 0.05$. All the statistical analyses were performed using SPSS Statistics for Windows version 22.0 (IBM, Armonk, NY, United States).

RESULTS

A flowchart of the trial is shown in Figure 2. Twenty-two participants started the study, but two dropped out of the study due to lack of time. Participants' characteristics are shown in Table 1. Overall, the majority were obese and hypertensive.

Figure 2: Flow diagram of participants**Table 1:** Participant characteristics

Variables	(n = 22)
Age, years	56.5 ± 1.2
Sex, n (%)	
Women	15 (68)
Men	7 (32)
Body weight, kg	91.3 ± 3.8
Height, cm (range)	160 (157 – 163)
BMI, kg/m ²	34.8 ± 4.6
Fat mass, kg	38.5 ± 9.2
Waist circumference, cm	102.7 ± 14.9
Hip circumference, cm	113.3 ± 7.6
Comorbidities, n (%)	
Hypertension	17 (77)
Diabetes mellitus	8 (36)
Obesity	21 (95)
Dyslipidemia	7 (32)

Values are mean ± standard deviation (SD) for parametric data, and medians ± interquartile interval (range) for nonparametric data; body mass index (BMI).

At the beginning of the two experimental sessions, participants exhibited similar values for systolic blood

pressure ($p=0.134$), diastolic blood pressure ($p=0.420$), and glycemia ($p=0.634$). During the circuit-based combined exercise, participants reported an average enjoyment level of 124 ± 5 A.U., as measured by the PACES Scale. No adverse events were observed throughout the study.

A significant time vs. intervention interaction was observed for systolic and diastolic blood pressure ($p<0.001$), but not for glycemia. Blood pressure and glycemia data are summarized in Table 2. Following the circuit-based combined exercise, systolic blood pressure showed a significant reduction at post 0', 30', and 45', and the total average at post 60', while diastolic blood pressure decreased significantly at post 45' ($p<0.005$), with a trend observed at post 0' ($p=0.059$) and the total average at post 60' ($p=0.053$) when compared to the corresponding control session. Compared to baseline, systolic blood pressure was reduced at post 0', 15', 30', 45', and the total average at post 60' ($p<0.005$) in the circuit-based combined exercise. Glycemia also decreased significantly at post 0', 15', 30', 45', 60', and the total average at post 60' ($p<0.005$) in both sessions.

Table 2: Blood pressure and glycemia responses after mixed circuit training and control sessions in adults with syndrome metabolic risk factor

Variables	Intervention			
	Mixed circuit training	Control	Δ	P-value
Systolic blood pressure				
Pre	133 $\pm$ 4	129 $\pm$ 3	4 (-1 to 11)	0.134
Post 0'	120 $\pm$ 3*	128 $\pm$ 3	-8 (-13 to -2)	0.005
Post 15'	122 $\pm$ 3*	126 $\pm$ 3	-4 (-11 to 2)	0.265
Post 30'	120 $\pm$ 3*	127 $\pm$ 3	-7 (-14 to -2)	0.023
Post 45'	120 $\pm$ 3*	128 $\pm$ 3	-8 (-14 to -2)	0.014
Post 60'	125 $\pm$ 3	130 $\pm$ 3	-5 (-12 to 3)	0.286
Average post 60'	122 $\pm$ 3*	127 $\pm$ 3	-5 (-11 to -1)	0.048
Diastolic blood pressure				
Pre	90 $\pm$ 2	89 $\pm$ 2	1 (-2 to 5)	0.420
Post 0'	85 $\pm$ 2	89 $\pm$ 2	-4 (-7 to 0)	0.059
Post 15'	89 $\pm$ 2	90 $\pm$ 2	-1 (-6 to 4)	0.658
Post 30'	88 $\pm$ 2	91 $\pm$ 3	-3 (-8 to 1)	0.107
Post 45'	86 $\pm$ 2	92 $\pm$ 3	-6 (-11 to -1)	0.015
Post 60'	90 $\pm$ 2	93 $\pm$ 2	-3 (-6 to 1)	0.246
Average post 60'	88 $\pm$ 2	91 $\pm$ 2	-3 (-6 to 0)	0.053
Glycemia				
Pre	145 $\pm$ 13	141 $\pm$ 15	4 (-1 to 11)	0.634
Post 0'	117 $\pm$ 13*	130 $\pm$ 14	-8 (-13 to -2)	0.220
Post 15'	116 $\pm$ 11*	127 $\pm$ 16*	-4 (-11 to 2)	0.336
Post 30'	116 $\pm$ 11*	116 $\pm$ 14*	-7 (-14 to -2)	0.998
Post 45'	109 $\pm$ 9*	114 $\pm$ 14*	-8 (-14 to -2)	0.607
Post 60'	105 $\pm$ 8*	109 $\pm$ 11*	-5 (-12 to 3)	0.576
Average post 60'	111 $\pm$ 10*	116 $\pm$ 14*	-5 (-11 to -1)	0.583

Values: mean $\pm$ SE or (95% confidence interval); Blood pressure (mmHg). P-value in the intervention compares the interventions (mixed circuit training vs control); Bold p-values indicate significant results (P < 0.05); *indicates significant results at pre-values each session separately (P < 0.05).

DISCUSSION

The key findings of this study include significant reductions in blood pressure observed throughout the first-hour post-exercise compared to both pre-intervention levels and the control session. Additionally, glycemic responses exhibited a similar pattern after both the exercise and control sessions, indicating consistent behavior across conditions. These findings indicate that a single session of circuit-based combined exercise induces PEH without causing adverse glycemic responses, supporting its potential as a safe strategy in individuals with metabolic disorders.

To the best of our knowledge, this is the first study to evaluate blood pressure and glycemic responses following a circuit-based combined exercise protocol in adults with metabolic disorders. A previous study in healthy adults demonstrated that after 60 minutes of circuit-based combined exercise led to greater PEH compared to a control session (systolic:

Δ -6 mmHg)¹⁹. Our findings align with these results, showing significant reductions in systolic blood pressure at the same time point compared to the control session (Δ -5 mmHg). While the current study did not aim to investigate the mechanisms underlying PEH responses, it is plausible that the observed changes result from a combination of autonomic and metabolic events following exercise²⁶. These likely include a reduction in sympathetic activity and the activation of local vasodilatory mechanisms, influenced by the integration of aerobic and resistance exercise²⁷. Given that PEH is associated with sustained blood pressure reductions¹⁵ and that a 5 mmHg decrease in systolic blood pressure can lower the risk of cardiovascular events by up to 10%²⁸, these results emphasize the potential of circuit-based combined exercise as an effective strategy to reduce cardiovascular risk.

The American Diabetes Association emphasizes the inclusion of both aerobic and resistance exercises in physical activity programs²⁹, a previous research

has indicated that aerobic exercise tends to reduce blood glucose levels more rapidly than resistance exercise³⁰, but performing resistance exercise before aerobic exercise improves glycemic stability throughout the exercise and reduces the duration and severity of postexercise hypoglycemia³¹. In our study, we used resistance exercise interspersed with aerobic exercise, and no significant differences were observed between the exercise protocol and control sessions regarding post-exercise glycemic levels. One possible explanation is the volume and/or moderate intensity of the exercise session, which may not have been sufficient to elicit significant changes in glycemia among individuals with well-controlled metabolic conditions. Moreover, the timing of the intervention—performed in the morning, approximately two hours after breakfast—and the elevated pre-exercise glycemic levels observed in participants may have influenced the glycemic response, including in the control session. This finding is particularly relevant for individuals with metabolic dysfunction, as it suggests that this type of combined exercise protocol may help maintain post-exercise glycemic levels without requiring additional interventions or dietary modifications during the recovery period.

Combined exercise offers numerous health benefits, including improved cardiovascular fitness, enhanced muscle strength, and better metabolic regulation³². These adaptations make it a highly effective strategy for managing and preventing chronic diseases, such as metabolic disorders^{33,34}. However, traditional exercise methods often face challenges related to low adherence, as they can be perceived as monotonous or overly demanding for many individuals³⁵. In contrast, the protocol used in our study demonstrated a high level of enjoyment (124 AU or 98%), a similar result to that found in studies with recreational sports^{36,37}. Enjoyment is recognized as a key predictor of intention to maintain regular physical activity, the formation of exercise habits, and long-term adherence, all of which are crucial for sustaining healthy behavior over time³⁸. Therefore, this dynamic and enjoyable format, defined by alternating exercise modalities in a circuit-based approach, has significant potential to increase adherence.

This study has some limitations that should be acknowledged. First, the sample size was insufficient to perform subgroup analyses based on specific comorbidities, such as diabetes or hypertension, and the absence of an assessment of the mechanisms associated with acute blood pressure reduction after exercise which could provide a deeper understanding of the effects of circuit-based combined exercise in distinct clinical populations. Second, blood pressure measurements were limited to the laboratory setting and conducted during the acute recovery period, without

the use of ambulatory blood pressure monitoring, which might have captured longer-lasting effects, however, minutes after exercise correlates with chronic reduction in blood pressure¹⁵. Furthermore, there was a lack of detailed information on the specific classes of antihypertensive and antidiabetic medications used by the participants. Although all included individuals had stable clinical conditions and were on regular pharmacological treatment, complete records on medication types and dosages were not consistently available. This limitation may have introduced some degree of variability in physiological responses. Lastly, while participants were advised to consume breakfast two hours prior to the training session and to replicate the same meal for consistency, there was no strict control over the type or composition of the meal, which could have influenced glycemic and cardiovascular responses. Future studies should address these limitations to enhance the generalizability and precision of the findings. Despite these limitations, the study presents several strengths that reinforce the reliability and validity of its findings. Notably, the use of a randomized design with allocation concealment minimized bias and ensured an objective assessment of the results. Furthermore, standardized protocols and validated measurement instruments were employed, contributing to the consistency and accuracy of the data collected.

In summary, the circuit-based combined exercise protocol emerged as an effective non-pharmacological intervention, eliciting significant acute reductions in blood pressure among adults with metabolic disorders compared to the control session. These findings underscore its potential utility in mitigating cardiovascular risk within this population. Interestingly, while glycemic levels decreased in both the exercise and control sessions, no significant between-group differences were observed, suggesting that factors beyond the exercise protocol itself—such as circadian rhythms and high pre-session blood glucose levels—may have contributed to this effect. Considering the acute benefits observed, the integration of this exercise protocol into daily activities within primary healthcare units shows potential as a cost-effective, supportive strategy. While the current findings are limited to short-term effects, they are aligned with public health policies that emphasize preventive care and the promotion of non-pharmacological approaches. However, longitudinal studies are needed to confirm whether this intervention can lead to sustained health improvements and reductions in medication dependence among individuals with metabolic disorders.

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