Effects of High-Intensity Interval Training, Resistance Training, or Combined Training on the Ideal Cardiovascular Health Metrics in Adults with Metabolic Syndrome Criteria: A Secondary Analysis of the Cardiometabolic HIIT-RT Study

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Objective: We aimed to investigate whether 12 weeks of high-intensity interval training (HIIT), resistance training (RT), combined training (CT=HIIT+RT), or nutritional guidance (NG) induced improvements in metabolic syndrome (MetS) risk factors and ideal cardiovascular health (CVH) in sedentary and overweight adults, and to compare the training adaptations between intervention groups.

Methods: This secondary analysis derives from the Cardiometabolic HIIT-RT study (ClinicalTrials.gov ID: NCT02715063). The study included a total of 51 sedentary subjects (no participation in exercise more than once a week for the previous six months) aged 30–50 years. Subjects with abdominal obesity (waist circumference [WC] ≥90 cm [men] ≥80 cm [women]) or excess weight, a body mass index ≥ 25 and ≤ 30 kg/m², and who identified as being willing and almost immediately available were enrolled. Parameters linked to CVH such as anthropometric and body composition, cardiovascular indices, and cardiorespiratory fitness (CRF) were assessed.

Results: After the intervention, HIIT, RT and CT improved maximal oxygen uptake (VO₂max) and muscular strength, but HIIT elicited the largest improvements for VO₂max (effect size=0.579) and RT for muscular strength (effect size=0.625). Only the NG group had an increase in the percentage of the pre-value in the healthy diet metric, whereas the HIIT and CT groups had an improvement in VO₂max. The HIIT and RT groups had a 33.4% (P = 0.032) and 41.6% (P = 0.020) increase in >5 metrics, respectively.

Conclusion: A 12-week HIIT training program resulted in greater CRF than NG alone. Both the HIIT and RT programs increased the ideal CVH metrics, supporting the positive effect of both exercise training programs on CVH in sedentary and overweight adults.

Keywords: High-intensity interval training, resistance training, concurrent training, cardiovascular health, vascular function, metabolic syndrome

INTRODUCTION

Obesity has increased dramatically worldwide in recent decades (1). This raises a public health concern, as it is a major risk factor for non-communicable diseases (NCDs), such as cardiovascular diseases, diabetes, and some cancers, which are an economic burden to health (2, 3). Even though physical activity is associated with energy balance and weight control, globally, it is estimated that 60% of adults do not achieve the recommended amount of physical activity needed to maintain health (4, 5). Given the association of physical activity with cardiometabolic health and body weight, identifying the most effective ways of exercising is important to attenuate the incidence of obesity and NCDs.

Cardiovascular health (CVH) is a concept that was proposed in 2010 by the American Heart Association to address not only cardiovascular diseases, which are the main cause of death by NCDs (6), but also their well-documented health behaviors and risk factors. An ideal CVH score is defined by the presence of four health behaviors (physical activity, diet, body weight, and non-smoking) and three risk factors (blood pressure, blood glucose, and cholesterol) in their respective ideal levels (7). Altogether, the score provides patients, institutions, and health personnel with a monitoring and screening tool in the decision-making of everyday life, clinical practice, or the design and implementation of public health interventions (8).

Observational studies have found a low prevalence of ideal CVH in different populations worldwide (9, 10), with higher scores being associated with better CVH, lower risk for subclinical atherosclerosis (11), less arterial stiffness, lower risk for cardiovascular disease (12), and lower future health costs (13). The metrics with the highest improvement potential are diet, physical activity, and body weight (14); however, there is only one intervention study using this score, which showed that a lack of nutritional guidance (NG) represents 1.35 times the odds of having a low CVH score (15).

Studies carried out with the adult sedentary population have found that regular continuous exercise and high-intensity interval training (HIIT) have comparable effects on CVH by improving insulin sensitivity, blood pressure, blood lipids, and body composition (16, 17). Furthermore, HIIT has been suggested to have a better effect on blood lipids (18), maximal
oxygen uptake (VO₂max), insulin resistance, and body fat percentage compared to continuous training (19), especially in individuals with cardiovascular risk (17, 20). On the other hand, studies comparing HIIT with resistance training (RT) have found similar effects on insulin and insulin resistance (21) and no effect of RT on any of the metabolic syndrome (MetS) risk factors (22, 23). This suggests that HIIT might be a time-effective alternative to obtain the benefits of exercise, and it is the training modality that has shown to exert the most benefits on CVH.

Concurrent training is the combination of endurance and RT in a single training session or program. Although this training modality has been less studied than single-mode endurance training or RT, evidence suggests the existence of an interference effect that attenuates muscle hypertrophy and strength, with no compromise of training-induced gains in aerobic capacity (24, 25). This raises the question of whether this interference also affects the metabolic response to exercise.

All the above-mentioned studies compare the effects of different training modalities on isolated cardiometabolic and performance variables. However, no intervention studies have compared the effects of these training modalities on cardiometabolic health, measured according to the American Heart Association (AHA) proposal of the CVH index. Therefore, this article aims to assess the effects on CVH metrics of 12 weeks of HIIT, RT, or both in a group of adults with one or more criteria for MetS. We hypothesized that 12 weeks of HIIT would elicit greater improvements in the CVH index than RT only or concurrent training modalities.

**METHODS**

*Study design and participants*

The Cardiometabolic HIIT-RT study is a single-blind, randomized-controlled 2 × 2 factorial trial (ClinicalTrials.gov ID: NCT02715063) conducted from March 2016 to June 2017 in Bogotá, Colombia. The study was approved by the Research Ethics Committee of the University of Manuela Beltran (ID 06-1006-2014) and complied with the revised ethical guidelines of the Declaration of Helsinki (2013 revision).
The study included a total of 51 sedentary subjects (no participation in exercise more than once a week for the previous six months) and women from 30 to 50 years old with one or more criteria for MetS according to the definition given by the International Diabetes Federation, which includes central obesity, high systolic and diastolic blood pressure and blood glucose, hypertriglyceridemia, and low HDL cholesterol. Exclusion criteria were systemic infection; cancer; weight loss greater than 10% within the last six months; consumption of appetite-stimulating or -suppressing drugs, steroids, or antidepressants; uncontrolled hyperthyroidism or hypertension; diabetes; fasting blood glucose > 110 ml/dl; use of medication for diabetes; medical restriction on exercise; or any condition that, in the researcher’s opinion, might adversely affect the study. Written informed consent was obtained from the participants at the beginning of the study.

After individual interviews and application of eligibility criteria, the Study Center for the Measurement of Physical Activity (by its Spanish initials, CEMA) carried out a computerized randomization into the four study arms by using a block randomization with a block size of 4. After baseline, participants were randomly assigned to a training group or usual clinical care group. The main researcher and study personnel were blinded to treatment allocation during the study. A statistician, external to the study, had access to the random allocation code, and he was not involved in the final data analysis.

**Sample**

Using estimates obtained from the literature and a previously performed study (26, 27), a sample size of 12 subjects in each group would be needed to reach a power of 80% to detect a difference in means in the FMD of 2% in the FMD after 12 weeks of training, assuming a standard deviation (SD) of 2.7 using a two-sample t test with a 0.05 two-sided significance level. Assuming a drop-out rate of 15%, the total minimal sample size increased to 15 subjects for each group.

**Intervention**

1. **Nutritional guidance (NG):** Without exercise training. Participants received counselling about goals for CVH, as well as monitoring of CVH over time in the Colombian population, key signs and symptoms, diet, and screening for cardiometabolic risk factors. All
participants received NG four times during the program: twice in individual sessions (baseline and after 12 weeks) and twice in groups (fourth and eighth weeks). Diets were monitored by means of two-day dietary recall. The prescribed NG was based on an exchange list, by reducing 250 kilocalories (kcal) from the calorie total in the diet, to promote a 250-g reduction per week in body mass (0.5 to 1.0 kg per month). Total energy intake in kilocalories and the amounts of each nutrient (carbohydrates, fat, and protein in grams) were assessed at baseline (0, 4, and 12 weeks) using a 24-hour weighed dietary record method. The assessment was carried out by a trained registered clinical dietitian (AH), and the scoring was controlled by one researcher (RRV).

2. **Resistance training (RT):** Participants attended the training center three times a week, where they completed a resistance circuit encompassing eight exercises that involved upper and lower muscle groups with an average duration of 30 to 40 minutes per session. The preparatory phase lasted four weeks, during which participants spent 300 kcal per session at 20–50% of 1RM, with 2 x 20–30 repetitions and one-minute rest intervals. As of week 5 to 12, participants achieved 500-kcal energy expenditure at 40–80% of 1RM, with 4 x 20–30 repetitions and one-minute rest intervals.

3. **High-intensity interval training (HIIT):** Participants trained three times a week spending 300 kcal per session during the preparatory phase. To accomplish the prescribed energy expenditure, participants warmed up for five minutes at 60% maximum heart rate (HRmax) and then performed four-minute intervals at 60–80% HRmax with four minutes of recovery at 55% HRmax. As of week 5 to 12, participants performed intervals at 85–95% HRmax with four minutes of recovery at 65% HRmax, reaching 500 kcal expenditure per session. During the supervised intervention, we recorded heart rate (HR) using an HR monitor (Polar Pacer, USA) to ensure compliance with the exercise stimulus at the predetermined target HR zone. In addition to HR, Borg ratings were measured in each exercise session.

4. **Combined training (CT):** Participants performed the RT and HIIT protocols in every session, with a frequency of three times a week, with each protocol reaching 50% of the prescribed energy expenditure according to the week (300 kcal the first four weeks and 500 kcal as of week 5 until completion of 12 weeks).
Overall, each subject's HR was monitored (FS1, Polar Electro Öy, Kempele, Finland) during the exercise sessions. Energy expenditure during the exercise sessions was estimated by calibrating the energy expenditure to the HR during the VO$_2$max tests performed at the baseline and post-intervention time points. The regression of the energy expenditure was calculated for each participant according to HR and minutes spent exercising during the training sessions. Trainers were physical therapists and physical educators with experience developing and monitoring exercise programs among clinical populations. All protocol training was performed under observation and supervision in an exercise laboratory with complete and strict monitoring of the amount of exercise completed in each session. Adherence to the exercise program was encouraged by the exercise professional who supervised each of the group sessions.

**Outcome measures**

The primary outcome measure is the ideal CVH index, measured by a score of 0 for no compliance or 1 for compliance with each health behavior and risk factor (Table 1). Data on smoking were collected via self-reported questionnaires (number of cigarettes smoked per day). Ideal smoking status was determined as non-smoker or quit smoking ≥12 months. Although the AHA relies on physical activity to determine active habits, we used estimated cardiorespiratory fitness (CRF), due to its robust association with cardiovascular risk factors and ideal CVH in this population (28, 29). Exercise capacity was dichotomized to high (ideal CVH) versus low (non-ideal CVH) based on estimated CRF (cut-off point of VO$_2$max > 35 mL/kg/min in women or >40 mL/kg/min in men).

Body mass index (BMI) was classified using WHO criteria (normal: 18.5 to 24.9 kg/m$^2$; overweight: 25.0 to 29.9 kg/m$^2$; and obese: ≥30 kg/m$^2$) (30). A seven-day recall was the dietary assessment tool used to assess the Mediterranean diet (MetDiet) quality. As suggested by Thanapoulou et al., the total score was divided into two categories of MetDiet diet quality: (1) ≤8 points = poor diet quality; and ≥9 points = good diet quality (optimal MetDiet style) (31). Participants who had at least ≥9 points were categorized as having an ideal healthy diet,
whereas adults with 8 points were classified as having a non-ideal healthy diet. Fasting glucose, total cholesterol, and blood pressure were included as CVH risk factors.

**Table 1.** Definition of the ideal cardiovascular health metrics (>20 years of age) as defined by the American Heart Association and the criteria used in this study

<table>
<thead>
<tr>
<th>Health behaviors</th>
<th>AHA definition</th>
<th>Ideal metric, definition in this study</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Smoking</strong></td>
<td>Never tried; never smoked whole cigarette</td>
<td>Never smoked a cigarette</td>
</tr>
<tr>
<td><strong>Body mass index</strong></td>
<td>&lt; 25 kg/m²</td>
<td>&lt; 25 kg/m²</td>
</tr>
<tr>
<td><strong>Physical activity</strong></td>
<td>≥60 min of moderate- or vigorous-intensity activity every day</td>
<td>Exercise capacity was dichotomized to high vs. low based on estimated aerobic consumption (cut-off point of VO₂max &gt; 35 mL/kg/min in women or &gt; 40 mL/kg/min in men)</td>
</tr>
<tr>
<td><strong>Diet</strong></td>
<td>4–5 components:</td>
<td>Mediterranean diet quality</td>
</tr>
<tr>
<td></td>
<td>Fruit and vegetables: ≥4.5 cups/d</td>
<td>Participants who had at least ≥8 points were categorized as having an ideal healthy diet</td>
</tr>
<tr>
<td></td>
<td>Fish: 2 or more 3.5-oz servings/wk</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fiber-rich whole grains: 3 or more 1-oz-equivalent servings/d</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sodium: &lt;1500 mg/d</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sugar-sweetened beverages: ≤450 kcal (36 oz)/wk</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Health factors</th>
<th>AHA definition</th>
<th>Ideal metric, definition in this study</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total cholesterol</strong></td>
<td>&lt;170 mg/dL (&lt;4.40 mmol/L)</td>
<td>&lt;170 mg/dL</td>
</tr>
<tr>
<td><strong>Blood pressure</strong></td>
<td>&lt;120/&lt;80 mmHg</td>
<td>&lt;120/&lt;80 mmHg</td>
</tr>
<tr>
<td><strong>Plasma glucose</strong></td>
<td>&lt;100 mg/dL (&lt;5.6 mmol/L)</td>
<td>&lt;100 mg/dL or HbA1c &lt; 5.7%</td>
</tr>
</tbody>
</table>
**AHA criteria (health behaviors)**

*Smoking:* Data regarding current smoking were obtained from the self-reporting FANTASTICO questionnaire. This tool has been previously adapted and validated for the Colombian population and was found to have internal consistency for items and domains (Cronbach’s α > 0.5) (32).

*Body mass index:* Body weight was measured with minimal clothing. An electronic scale was used (mBCA SECA ®515) and registered to the closest 0.1 kg. Height was measured using a stadiometer (Seca® 274, Hamburg, Germany), with the subject standing in anthropometric position and at the end of a deep inward breath, registering to the closest centimeter. The weight and height of each participant were used to calculate the BMI.

*Physical activity as cardiorespiratory fitness:* At 48 hours after the start of the training period, the VO$_2$max of inactive subjects was determined 24 hours before the acute intervention using a maximum treadmill exercise test (Precor TRM 885, Italy). Exercise capacity was evaluated according to the treadmill exercise test duration, which was used to estimate aerobic consumption expressed in metabolic equivalents (METs), based on well-characterized regression equations recommended by the American College of Sports Medicine. In addition, previous studies have demonstrated that treadmill test time correlates well (r=0.92) with VO$_2$max (33, 34). Blood pressure was recorded at rest, at each stage change, at peak exercise, and during recovery using a standardized cuff sphygmomanometer.

*Dietary assessment:* A seven-day recall was the dietary assessment tool used to assess the MetDiet quality. As suggested by Thanapoulou et al., the total score was divided into two categories of MetDiet quality: (1) ≤8 points = poor diet quality; and ≥9 points = good diet quality (optimal MetDiet style) (31). Participants who had at least ≥9 points were categorized as having an ideal healthy diet, whereas adults with 8 points or fewer were classified as having a non-ideal healthy diet. Glucose fasting, total cholesterol, and blood pressure were included as CVH risk factors. Additionally, we determined the average habitual energy and macronutrient intake. A detailed 24-hour diet record was obtained from all subjects on one weekday and one weekend day during the one-week baseline period. The Food Intake Analysis Software (FAO/INFOODS, Report of the Technical workshop on standards for food composition data
interchange, Rome 2004) and national food composition tables (for specific foods) were used to analyze total energy and macronutrient intake of each subject's 24-hour diet.

**AHA criteria (health factors)**

**Total cholesterol and plasma glucose:** Participants were asked to maintain a 12-hour fast, after which a finger-prick blood sample was taken. Blood samples were analyzed with the CardioCheck® system to measure plasma markers. The variation coefficient was 1.8%. The HA1Now+® system (variation coefficient of 2%) was used to measure glycated hemoglobin (HbA1c).

**Blood pressure:** Systolic and diastolic blood pressure was measured on the dominant arm with the subject facing up and using the TensioMed Arteriograph®. This equipment has its own quality control with a maximal error range of 1SD. The equipment was calibrated prior to pilot testing, after inclusion of the first 30 participants, and at the end of baseline.

**AHA criteria**

The AHA guidelines (7) were used to construct an ideal CVH index based on seven metrics and using the cut-off points for adults, with participants receiving one point for the presence of each ideal metric. The ideal behaviors defined by the AHA were as follows: BMI <25 kg/m², CRF (VO₂max >35 mL/kg/min in women or >40 mL/kg/min in men), non-smoking status (or never having smoked), and consumption of a dietary pattern that promotes ideal CVH. The factors were classified as an untreated systolic blood pressure <120 mmHg and diastolic blood pressure <80 mmHg, untreated total cholesterol ≤200 mg/dL, and untreated fasting blood glucose <100 mg/dL or HbA1c <5.7%.

Finally, the participants were categorized into one of three health levels based on the number of CVH metrics in the ideal range that they exhibited. The healthiest level (favorable ideal CVH score) was defined as having between five and seven metrics in the ideal range; the intermediate level, three to four metrics; and the unfavorable level, zero to two metrics. These cut-off points have been used in previous international studies (35, 36).
**Statistical analysis**

Baseline demographics were summarized as means and SDs, and between-group differences were examined using ANOVA for continuous data. Categorical data were summarized as frequencies and percentages, and group differences at baseline were examined using lineal χ² tests. The mean change in each group was reported as the estimated margin of the mean, as assessed by 95% confidence intervals (CI) with adjustment for kcal for diet, sex, and baseline values as covariates using an unstructured covariance matrix for the repeated measures. Within-group differences were considered significant when the 95% CI did not include zero. In the pre-protocol mixed-model analyses, we used 95% CI and p values (<0.05) for the intergroup comparisons for each outcome measure across group × time interaction factors. Cohen's d for effect size was also calculated to determine the magnitude of the group differences. The effect size was classified as small, medium, and medium-to-large effects (<0.20, 0.2–0.6, and 0.6–1.2, respectively); partial η² was considered small if η²<0.04 and large if η²>0.36 in interaction effect analysis (37).

To examine the cumulative effects of the seven CVH metrics, we created a dichotomized variable for each component of the health metrics: “ideal” was coded as 1, and “poor” was coded as 0. The total ideal CVH metrics score of each individual ranged from 0 to 7. Changes in CVH metrics were calculated by subtracting the total score for the metrics obtained in pre-intervention from the total score obtained in post-intervention. Participants were divided into three categories based on the changes in the seven CVH metrics. Categorical CVH metrics were described as percentages and were compared using χ² tests. The significance level adopted to reject the null hypothesis was P < 0.05. All analyses were performed using the SPSS software package (Version 24, IBM, New York, USA).

**RESULTS**

**Characteristics of the subjects**

Figure 1 shows the CONSORT flow diagram of study progression. A total of 80 participants were eligible after assessment. Reasons for eligible subjects declining to
participate included “lack of time” (n=5) and “personal reasons” (n=3). Of the remaining 72 participants, 18 were randomized into each of the following intervention groups: i) NG, ii) HIIT, iii) RT, and iv) CT (HIIT and RT protocol).

Figure 1. Consolidated Standards of Reporting Trials (CONSORT) flow diagram

The details of biochemical parameters in cases are shown in Table 1. Overall, nine patients had abnormalities in total cholesterol levels, whereas 39.7% had high HbA1c (> 5.6%). Approximately 72.4% of participants were not currently smoking, 5.2% had normal weight, 46.6% had healthy VO₂max, and 32.8% had a healthy diet by MetDiet score. Most study participants reached ideal health status for the following cardiovascular factor metrics: total cholesterol (84.5%), fasting glucose (87.9%), and blood pressure (89.7%). Other details of parameters are shown in Table 1.
Table 1. Characteristics of the subjects (n=58)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Sex, men n (%)</th>
<th>Morphological parameters, mean (SD)</th>
<th>Cardiometabolic risk factor parameters, mean (SD)</th>
<th>AHA’s ideal CV health criteria, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Age, years</td>
<td>40.78 (7.06)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Weight, kg</td>
<td>79.55 (12.30)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Height, cm</td>
<td>162.51 (7.94)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>BMI, kg/m²</td>
<td>30.04 (3.49)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Waist circumference, cm</td>
<td>92.68 (9.49)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total cholesterol, mg/dl</td>
<td>167.29 (34.51)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>High total cholesterol, n (%)</td>
<td>9 (14.5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Glucose, mg/dL</td>
<td>89.68 (7.92)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>High glucose, n (%)</td>
<td>7 (12.1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>HbA1c, %</td>
<td>5.45 (0.47)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>High HbA1c, n (%)</td>
<td>23 (39.7)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Systolic blood pressure, mmHg</td>
<td>116.12 (10.30)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Diastolic blood pressure, mmHg</td>
<td>73.01 (9.87)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean arterial pressure, mmHg</td>
<td>87.37 (9.66)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total cholesterol &lt;200 mg/dL</td>
<td>49 (84.5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Glucose &lt;100 mg/dL or HbA1c &lt; 5.7%</td>
<td>51 (87.9)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Blood pressure &lt;100 mmHg MAP</td>
<td>52 (89.7)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Baseline daily caloric intake, mean (SD)</td>
<td>1666 (460.0)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Protein, %</td>
<td>18 (4.6)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Fat, %</td>
<td>36.7 (6.0)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Saturated fat, %</td>
<td>10.1 (2.9)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Carbohydrate, %</td>
<td>45.3 (7.8)</td>
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</table>

Change in CVH score (behaviors and factors) metrics according to AHA criteria

We compared the baseline characteristics of the seven categories of cardiovascular behaviors and factor metrics in Figure 2. Only the NG group had an increase in the percentage of the pre-value in the healthy diet metric, whereas the HIIT and CT groups had an improvement in VO₂max (P < 0.05).
Figure 2. Changes after the 12-week follow-up in categorical ideal cardiovascular health metrics criteria according to AHA by intervention groups. NG, nutritional guidance; HIIT, high-intensity interval training; RT, resistance training; concurrent training (HIIT+RT) group. Data shown are unadjusted prevalence (%).
The estimated changes of the three health categories based on the number of CVH metrics are shown as a percentage of the pre-value in Figure 3. The HIIT and RT groups had a 33.4% (P = 0.032) and 41.6% (P = 0.020) increase in >5 metrics, respectively.

**Figure 3.** Changes after the 12-week follow-up in ideal cardiovascular health metrics criteria according to AHA by intervention groups. NG, nutritional guidance; HIIT, high-intensity interval training; RT, resistance training; concurrent training (HIIT+RT) group. Data shown are unadjusted prevalence (%).

**DISCUSSION**

To our knowledge, this is the first randomized-controlled trial comparing the effects of prolonged aerobic interval training, RT, and the combination of both on the ideal CVH metrics in a sample of sedentary adults with criteria for MetS. The primary findings were that both isolated training regimes, HIIT and RT, produced a significant shift towards the ideal CVH. These results are important to the clinical practice setting in patients with non-ideal CVH, given that they suggest a superiority of isolated training modalities over concurrent training to improve CVH.
Despite the potential benefits of combining HIIT with RT, the CT group failed to improve the CVH index or any of the individual metrics except for CRF. Similarly, Bateman et al. examined the effect of concurrent training on MetS risk factors compared to either training modalities alone and found no improvements in systolic blood pressure (22). A limitation to this study was that exercise was not matched, so that the CT group exercised almost twice as much as the other training modalities, even though there were no metabolic improvements. On the other hand, our results are not consistent with those of Libardi et al., who found a significant reduction of total cholesterol (-14.0%, P = 0.0001) after 16 weeks of concurrent resistance and aerobic training (38). Given that this study had a longer duration, the insufficient intervention time to cause improvements in lipid profile might explain our lack of results in this metric.

An interference effect has been previously described when aerobic and RT are combined in a single training session or program in studies evaluating training-induced strength and muscle lean mass gains (39). It has to be noted that interference was proposed for studies including aerobic or endurance training and not HIIT prescribed alongside RT. A recent meta-analysis examined the effect of concurrent training with HIIT and found no negative impact on muscle mass gains compared to RT alone; given that there was an attenuation of lower but not upper muscular strength, the authors suggested it was due to fatigue of the predominant muscle groups utilized during HIIT (40).

Considering the association between lean mass and muscular strength on health outcomes and cardiovascular risk (41), our results are not consistent with those of Sabag et al. (40). Nevertheless, this is not a linear relationship, and there is insufficient evidence to assume that our results are related to lean mass or strength gains; thus, the research remains insufficient to affirm or deny interference in concurrent training that might explain the lack of effect on cardiovascular risk factor outcomes.

Physical activity guidelines fall into the definition of concurrent exercise, given that they recommend 150 weekly minutes of moderate-intensity aerobic training and twice-weekly strength training as a measure to maintain health in the adult population. Given the lack of cardiometabolic effect of concurrent training found in this article, it raises the question as to the possible effects of physical activity recommendations on ideal CVH. Knowing that
improvements in CRF and its adjunct health benefits will be maintained in concurrent training, for now, it would be safe to promote a 24-hour rest period between each exercise modality, as studies have suggested that this might attenuate the possible interference effect for strength gains (25). Further research is needed to evaluate the effect on ideal CVH following the guidelines.

Similarly, studies comparing continuous and interval aerobic training with concurrent training have found greater increases in peak uptake in HIIT-only groups (42). Despite the interreference effect, concurrent strength and endurance training does not compromise training-induced gains in aerobic capacity (25). Although both training regimes improved only in this metric, the overall result for the primary outcome differed. This suggests that the power of the CVH index to detect changes is not given by the significant change of the individual behavior or health factors but by the cumulative effect of the changes of each.

HIIT failed to improve any metric aside from CRF. The lack of change in BMI can be explained by the BMI not being designed to discriminate changes in body composition, given that our results show HIIT-group subjects reduced body fat percentage. A meta-analysis on obese adults showed fat mass reduction following HIIT intervention with no changes in BMI (19). It is also noteworthy that the fat reduction might be statistically significant but not necessarily of clinical meaningfulness, and thus it might not be enough to affect the BMI (16). Furthermore, studies that associate HIIT with blood pressure reduction were carried out in the hypertensive population (43). Given that our sample had a low prevalence of hypertensive adults, it could have limited the data needed to detect a significant change for this variable.

We hypothesized that HIIT would elicit greater effects than any other training modality; nevertheless, our results showed a greater increase of ideal CVH in the RT group than in the HIIT group. Interestingly, RT failed to improve any of the CVH metrics. This result is consistent with studies on adults with MetS without T2D that found no significant effects on metabolic or cardiovascular risk factors following resistance exercise interventions (22, 23). Indeed, a previous meta-analysis by Wewege et al. (23) examined aerobic, resistance, combined exercise for cardiovascular risk factors, CRF, and MetS criteria. They found no significant effects on MetS risk factors compared to the control. Only one of four resistance
trials reported an 11% (p< 0.05) increase in CRF following eight weeks of vigorous-intensity RT, and no body composition analysis was performed due to limited data.

On the other hand, inconsistent with our results is blood pressure reduction found after RT in a meta-analysis by Cornelisse and Fagard (44). The small sample size in our study could account for the lack of statistical significance of blood pressure improvement. Furthermore, the present study did not include diabetic patients. Even though 23% of the sample had high HbA1c, there was no response to RT. Improvements in HbA1c following RT have been reported, but in adults with T2D (41). Despite some evidence of possible cardiorespiratory improvement when RT is performed vigorously, our results and the evidence suggest that 12 weeks of RT may not have the potential to significantly improve any isolated metric of the ideal CVH index in non-diabetic adults. Unexpectedly, RT significantly increased the incidence of ideal CVH, despite having no significant effect on any of the isolated CVH metrics. This might be due to a compound effect of the different slight improvements in each of the metrics, which together may impact overall CVH. Our results also highlight the need for more research in the matter and the importance of measuring CVH as a robust index instead of measuring the isolated behavior or health factors.

Although NG was administered equally to all intervention groups, only the control group improved in this metric. This could be explained by the control group having had greater motivation to lose weight with diet as the only source of benefit compared to those who could also obtain the weight-losing benefits of exercise. Another possible explanation might be low adherence to diet, as previous studies have hinted that the level of caloric restriction is inversely related to diet adherence measured by accomplishing the established daily caloric deficit (45, 46). In contrast, a meta-analysis assessing the effect of chronic HIIT found no compensatory increase of energy intake compared to moderate-intensity continuous training or no exercise (47). Also, this suggests that, at least in the HIIT group, post-exercise hunger or compensatory intake may not explain the lack of diet change. Because these studies defined adherence to diet as expected versus actual daily calorie intake but the definition of the ideal diet in the CVH index is given in terms of food
servings, they are not enough to explain our findings. Nevertheless, the present study matched energy expenditure from all exercise interventions to 1500 calories a week. This additional negative energy balance marked greater caloric restriction compared to the control group, even though the overall caloric restriction in all groups was lower than 20%. As such, our results support the hypothesis that greater caloric restriction results in lower adherence to diet.

This study has several limitations that should be considered before interpreting the findings. Firstly, the number of participants in our study was relatively small; therefore, larger, multicenter studies are needed to reinforce our findings. Secondly, compliance to diet was measured by a seven-day recall self-administered questionnaire, not with the information obtained from the 24-hour recall, due to a lack of timely response needed to collect data of 24-hour recall at follow-up. This limited the exact quantification of diet intake and required modification of the definition of the ideal diet metric. Moreover, there could have been misinterpretation of the questions, leading to overreporting or underreporting of the actual food intake. Another limitation is the effect of NG that may modify metabolic outcomes. However, we continually reminded subjects of their commitment to maintain their current nutritional advice to minimize the influence of diet. Further research is needed to better describe the effect of different exercise interventions on isolated and cumulative cardiometabolic health metrics. Finally, it should be noted that the ideal CVH metrics are formed by binary variables, which assumes that all health behaviors and factors contribute the same to the final score (48).

The main strength of our study is that it is the first randomized-controlled trial, to our knowledge, on the effect of 12 weeks of HIIT, RT, CT, or NG on ideal CVH metrics in adults from the Latin-American population. Secondly, there was high exercise compliance, and we used state-of-the-art measures of cardiovascular fitness and metabolic parameters. Moreover, body composition markers were assessed by dual-energy X-ray absorptiometry, considered the current “gold standard” for body composition measurement.
CONCLUSION

The present study showed that 12 weeks of HIIT or RT improve the ideal CVH in adults with MetS criteria. CT improved CRF with no effect on the overall index. Interestingly, a lack of change in isolated metrics following RT did not affect improvement of the ideal CVH index. This suggests that the CVH index as proposed by the AHA might be more sensible to change than the isolated metabolic and cardiovascular risk factors, and its use should be encouraged as a screening and follow-up tool in the clinical and public settings.

PRACTICAL APPLICATIONS

A 12-week training program of HIIT resulted in greater CRF than NG, whereas an RT program improved the ideal CVH index in adults with MetS criteria. However, both the HIIT and RT programs increased the ideal CVH metrics, supporting the positive effect of both training programs on CVH in sedentary and overweight males.

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DISCLOSURE

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POTENTIAL CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.
AUTHOR CONTRIBUTIONS

Conception and design of the research: Robinson Ramírez-Vélez; analysis and interpretation of the data: Robinson Ramírez-Vélez and Alejandra Hernandez; acquisition of data: Katherine Gonzalez-Ruiz, Alejandra Tordecilla-Sander, Robinson Ramírez-Vélez, and Jorge E. Correa-Bautista; statistical analysis: Robinson Ramírez-Vélez and Alejandra Hernandez; critical revision of the manuscript for intellectual content: Robinson Ramírez-Vélez and Alejandra Hernandez; obtaining financing: Robinson Ramírez-Vélez and Karem Castro; writing of the manuscript: Robinson Ramírez-Vélez and Alejandra Hernandez.

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