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PHYSICAL ACTIVITY, HEALTH AND EXERCISE

The effect of different high-intensity interval training protocols on cardiometabolic and inflammatory markers in sedentary young women: A randomized controlled trial

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ABSTRACT

Few studies have reported the cardiovascular health effects of different high-intensity interval training (HIIT) protocols among sedentary young women. We investigated the impact of a traditional HIIT programme and a high-intensity circuit training (HICT) programme on lipid profiles and inflammatory cytokine levels in sedentary young women. Forty-two women were randomly assigned to HICT (body weight-based training), HIIT (cycling-based training), or control groups (n = 14 each). HICT and HIIT participants completed an 8-week training programme of three sessions per week. Total cholesterol (TC), triglyceride, high- and low-density lipoprotein, leptin, resistin, tumour necrosis factor-alpha (TNF-α), interleukin-8, and interferon-gamma levels were measured before and after the intervention. Post-intervention, TC and leptin were decreased in the HICT group. The HICT group also demonstrated increased lean mass, upper and lower limb strength, and balance, while the HIIT group displayed improved lower limb strength. Additionally, the control group showed significant increases in triglyceride levels, weight, body mass index, and fat mass. In conclusion, although both HICT and HIIT interventions showed improvements in cardiovascular health and physical fitness, participants in the HICT group experienced more health benefits.

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High-intensity circuit training; cardiovascular health; sedentary behaviour; women

Introduction

Sedentary behaviour is defined as any waking behaviour in a sitting, reclining, or lying position that has an energy expenditure of ≤ 1.5 metabolic equivalents (METs) (Tremblay et al., 2017). The estimated prevalence of sedentary behaviour in adults is 6.4 hours per day, and sedentary time has increased in recent years (Bauman et al., 2018). Young female college students spend more time studying and using mobile phones than male students, which increases their sedentary time (Fountaine et al., 2011; Musaiger et al., 2017). Therefore, young women may be more susceptible to a range of adverse health outcomes, including obesity, cardiometabolic risk, poor brain and mental health, diminished cognitive function, reduced sleep duration, reduced work productivity, and fatigue (Saunders et al., 2020).

Cardiovascular health is one of the factors most negatively impacted by sedentary behaviour. Strong associations between sedentary behaviour and cardiovascular disease incidence, mortality, and risk factors have been identified (Same et al., 2016). A surge in unhealthy lifestyles among younger individuals has led to a significant increase in cardiovascular disease risk and incidence (Andersson & Vasan, 2018). Young people, particularly women, are often neglected in research on this topic, which leads to less aggressive treatment strategies being implemented in this population (Gao et al., 2019; Maas & Appelman, 2010). Therefore, in light of the rising prevalence of sedentary behaviour, paying special attention to the cardiovascular health of young women is crucial.

Sedentary behaviour may influence the cardiovascular health of young adults by altering cardiovascular biomarkers such as lipid profiles (Same et al., 2016). Previous research has shown that sedentary behaviour increased triglyceride (TG), total cholesterol (TC), and low-density lipoprotein (LDL) levels, and decreased high-density lipoprotein (HDL) levels (Brocklebank et al., 2015). Additionally, sedentary behaviour impacts cardiovascular health via chronic low-grade systemic inflammation (De Rooij et al., 2009), particularly by affecting the levels of circulating inflammatory cytokines and adipokines (Shibata et al., 2017; Williams et al., 2019). For example, pro-inflammatory cytokines such as tumour necrosis factor-alpha (TNF-α), C-reactive protein, interleukin-6, interleukin-8 (IL-8), and interferon-gamma (IFN-γ) were increased after prolonged sitting (Arouca et al., 2019; Dogra et al., 2019; Rodas et al., 2020). Adipokines such as adiponectin have anti-inflammatory and insulin-sensitizing effects, whereas others such as leptin and resistin have proinflammatory effects. While a sedentary lifestyle can reduce adiponectin levels, leptin and resistin levels are elevated (Kinoshita et al., 2023; Rava et al., 2020; Zheng et al., 2021). Unfortunately, current

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experimental research on sedentary behaviour and its impact on major pathways in cardiovascular health is limited to the acute effects of prolonged sitting and is often confined to male participants (Dunstan et al., 2021). Therefore, investigating effective ways to overcome even short-term negative health outcomes, especially among women, is necessary.

Replacing sedentary behaviour with physical activity (PA) is associated with many favourable health indicators (Rollo et al., 2020). Compared with traditional aerobic exercise, high-intensity interval training (HIIT) has recently been suggested as an effective and feasible approach to overcome the negative impacts of sedentary behaviour (Wewege et al., 2017). Further, an updated form of HIIT called high-intensity circuit training (HICT) is emerging, which emphasizes multi-joint and functional movements. HICT comprises both aerobic and resistance training elements, resulting in greater recruitment of major muscle groups than that typically achieved through traditional running- or cycling-based HIIT. Consequently, HICT enhances cardiovascular endurance, muscular fitness, and body composition in young men and women (Lu et al., 2021; Murawska-Cialowicz et al., 2015). The extant research indicates that exercise as a medical strategy is important to cardiorespiratory fitness, which could be a routine health measure of cardiovascular disease. Similarly, muscular strength has a similar role, i.e., it also relates to the risk of developing cardiovascular disease and its risk factors. Considering the strong relationship between physical fitness and cardiovascular health, HICT may potentially improve cardiovascular health through improving physical fitness (Carbone et al., 2020; Kaminsky et al., 2019). Moreover, traditional exercise routines may be perceived as monotonous, which may lead to low adherence rates in adults (Bartlett et al., 2011). However, a previous study showed that young women preferred a structured exercise programme (Othman et al., 2022). HICT is a carefully designed protocol that incorporates a variety of exercises such as jumping jacks, stepping, squatting, and burpees, and has shown strong exercise adherence and increased enjoyment among women (Abbasi et al., 2022). Although traditional HIIT may have favourable effects on lipid and specific cardiovascular biomarker levels (da Silva et al., 2020; Ghodsi et al., 2016), HICT may have a greater impact on cardiovascular health given its distinct advantages. Also, considering that HICT requires less space and no equipment compared to running or cycling-based HIIT, it has better feasibility. Few studies have compared the effects of HICT and traditional HIIT on body composition and physical fitness. However, certain limitations were observed in these studies. For example, their samples were relatively small (Blackwell et al., 2017; Evangelista et al., 2019; Lu et al., 2021) and/or they entailed relatively short-term interventions (Blackwell et al., 2017; Evangelista et al., 2019; Islam et al., 2019). Some studies did not include a blank control group (Blackwell et al., 2017; Evangelista et al., 2019; Lu et al., 2021). Additionally, very few studies have compared the effects of HICT and traditional HIIT on lipid profiles or inflammatory cytokines in a sedentary, young, female population. It is necessary to conduct a well-designed study with a larger sample, longer intervention durations, and a control group to investigate and compare the effects of HICT and traditional HIIT on different health indicators.

Therefore, the purpose of the current study was to investigate the effects of traditional HIIT and HICT on lipid profiles and selected adipokines and cytokines in sedentary young women. We hypothesized that both HIIT and HICT would improve lipid profiles, inflammatory cytokine levels, body composition, and physical fitness, and HICT would be more effective than HIIT.

Materials and methods

Participants

The required sample size was estimated using G*Power software (Version 3.1.9.7) with the assumption of an F-test, ANOVA: repeated measures within-between interaction. To achieve 80% statistical power, a type I error of 0.05, and an effect size $f = 0.28$ on decreasing TG, one of the primary outcomes (Ouerghi et al., 2022), a total of 36 participants with 12 participants per group was necessary. Considering a 20% potential dropout rate based on our previous experience, 45 participants in total were needed. Finally, 45 young women were recruited from local university and 42 participants completed the intervention. The inclusion criteria were as follows: individuals were Chinese, female, and 18–25 years old; were sedentary for ≥8 hours per day, as defined by objective measurement; had no exercise contraindications; had no history of chronic diseases or other health problems that might have affected participation; and were not involved in any dietary approaches or other experiments during the past six months. Ethical approval was obtained from the Human Research Ethics Committee of the University (reference number 2020–2021–0382) and the study was also registered at the Chinese Clinical Trial Registry (number ChiCTR2200061665). All participants provided written informed consent prior to enrolment.

Study design and procedures

The current study was an 8-week three-arm randomized controlled trial (RCT). Participants were randomly assigned to three groups of equal numbers: the HICT group, in which participants performed body-weight training; the HIIT group, in which cycling-based training was performed; and the control (CON) group, in which participants continued their normal daily PA. Randomization was conducted using random numbers generated by a computer. Participants were not blinded to the interventions. During the first visit, the participants received more information about the study, and an ActiGraph wGT3X-BT (Pensacola, FL, USA) was provided to evaluate their sedentary time by wearing it on their nondominant wrist for 24 hours for seven consecutive days. Participants were instructed to remove the device only when performing any activities involving water, such as showering or swimming. When participants returned the ActiGraph at the second visit, their body composition was evaluated by a bioelectrical impedance analysis method, and physical fitness was measured by handgrip, standing long jump, 1-minute sit-up, and single-leg standing tests. Blood samples were collected during the third visit at least 1 day after the second visit. To minimize data contamination and its impact on intervention implementation, participants were instructed not to discuss the intervention with individuals from other groups. During the 8-week intervention period, participants in the HICT and HIIT groups attended exercise training three times per week in a similar environment at the university. The same tests were conducted after the intervention.

Intervention

The 8-week intervention period was divided into three stages. The sets and intensities of the exercises were gradually increased at each stage to accommodate the improved abilities of the participants. Standard warm-up, including some jogging followed by dynamic stretching and cool-down protocols, including free walking followed by static stretching of different muscle groups, were conducted before and after each training session, respectively. Aside from the training programmes, the participants were advised to maintain their regular PA and nutritional habits during the entire intervention period. The details of each group are described as follows (or in the supplementary materials).

HICT

The design of the HICT protocol was based on a previous study (Klika & Jordan, 2013). The training began at 2 sets in stage 1 and gradually increased to 3 sets in stage 3 comprising 12–15 30-second all-out whole-body exercises per set, a 10-second rest between each exercise, and a 5-minute rest between each set. The exercise order was designed to maintain an adequate intensity and alternate arrangement on the trunk and upper and lower limbs. The workout included, but was not limited to, jumping jacks, squats, and push-ups (knee push-ups for most of the beginners). Participants were encouraged to complete as many of the repetitions as possible.

HIIT

Participants completed a specifically designed cycling-based HIIT programme using a bicycle ergometer (Monark LC7, Vansbro, Sweden). The cycling protocol matched that of the HICT group (2–3 sets of 12–15 30-second cycling sessions and 10-second rests, 5-minute rests between sets). Training intensity was all-out, starting at a resistance of 5% of each participant's body weight and gradually increasing to 7.5%. During training, encouragement was provided by the researcher to keep the participants at a high cycling cadence. The participants were allowed to walk around during the set rest period.

CON

Participants in the CON group did not receive any exercise training and continued their regular PA habits. However, due to ethical considerations, they were provided with similar training to the other groups after the intervention period.

Outcomes

The outcome measures were assessed before and after the intervention. The primary outcomes were lipid profiles and levels of several inflammatory cytokines related to cardiovascular health. The secondary outcomes were weight, height, body mass index (BMI), body composition, and the results of five physical fitness tests targeting multiple capacities. Handgrip, standing long jump, 1-minute sit-up, and single-leg standing tests were used to assess upper limb strength, lower limb strength, flexibility of the lower back and hamstring muscles, abdominal endurance, and balance, respectively.

Blood sampling and analysis

Fasting blood samples were collected from the antecubital vein by a nurse. The samples were centrifuged at 3000 rpm for 15 minutes at 4°C. The separated plasma samples were frozen and stored at −80°C until later analysis. TG, TC, and HDL were analysed using a colorimetric kit (Stanbio, EKF Diagnostics, Penarth, Wales, UK), and LDL was calculated according to the Friedewald formula: LDL = TC − HDL - (TG/5) (Friedewald et al., 1972). Leptin, resistin, TNF-α, IL-8, and IFN-γ were measured using a multiplex bead assay (Human Magnetic Luminex Customized Assay, R&D Systems Inc., Minneapolis, MA, USA) following the manufacturer's instructions. Samples were analysed using a Bio-Plex analyser and Bio-Plex Data Pro software (Bio-Rad, Hercules, CA, USA)

Anthropometry

Height and weight were measured using a digital stadiometer and weight scale to the nearest 0.1 cm and 0.1 kg, respectively. Bioelectrical impedance analysis was performed to measure body composition using a Tanita MC-780 MA analyser (Tanita Corp., Tokyo, Japan). BMI was calculated using the following formula: BMI = weight (kg)/height $(m)^2$.

Handgrip strength

Three handgrip strength measurements were taken alternately for each hand. The participants were asked to maintain a standing position and relax their arms and hands at their sides. A dynamometer (TKK 5401; Takei Scientific Instruments Co. Ltd., Tokyo, Japan) was grasped without bending the elbow or wrist for up to 3 seconds each time. The highest value (kg) for each hand was recorded.

Standing long jump

Each participant was given three opportunities to perform this test, and the longest distance was recorded. Standing at the starting line, the participants were asked to jump forward as far as possible. The distance between the starting line and the heel of the hindfoot was measured.

One-minute sit-up

Participants lay on a mat with their arms across their chest and knees bent, and then elevated their upper body to their knees. They were asked to repeat this as many times as possible in 1 minute. The numbers of repetitions were recorded.

Single-leg standing

Participants were instructed to perform single-leg standing with their eyes closed. The research assistant stood next to them to ensure their safety and recorded the time. The time was stopped when the participants lost their balance or

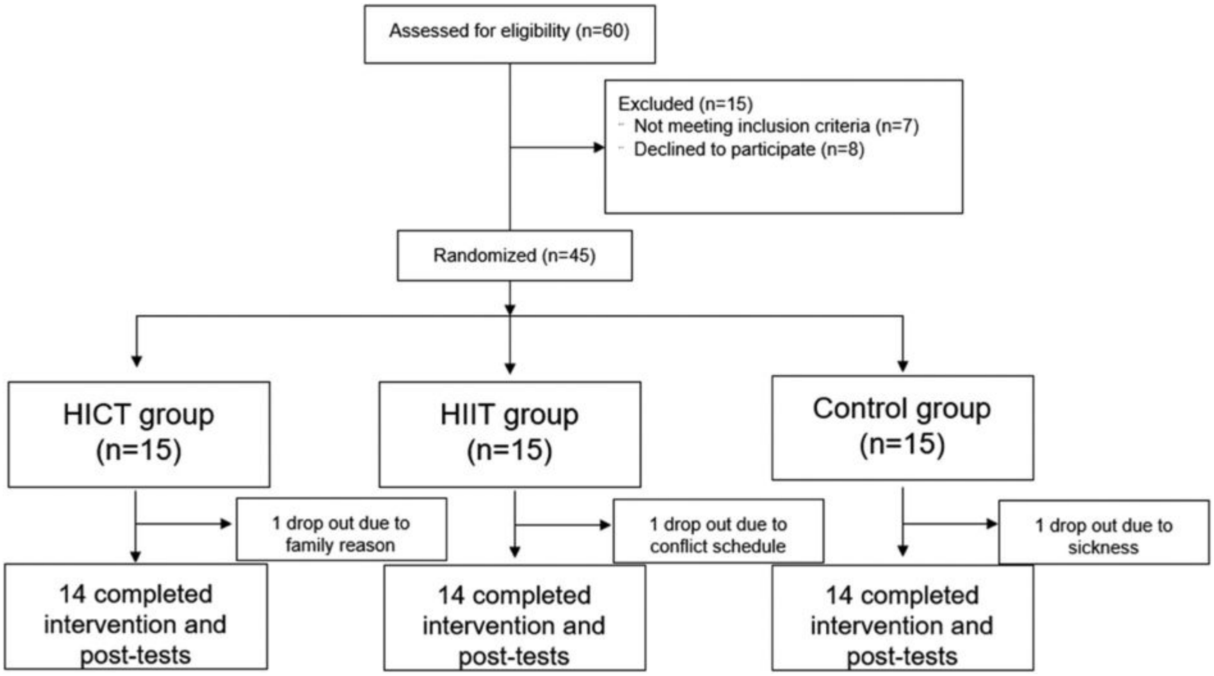

Figure 1. Flowchart of study participants. HICT: high-intensity circuit training; HIIT: high-intensity interval training.

opened their eyes. Each participant was allowed to try the test three times, and the longest time was recorded.

Data analysis

The results are expressed as mean ± standard deviation. Normality of all variables was checked using the Shapiro-Wilk test and non-normally distributed data were log-transformed for further analysis. Baseline (pre-intervention) values among the three groups were compared using a one-way analysis of variance (ANOVA). A two-way ANOVA with repeated measures (HICT vs. HIIT vs. CON × pre- vs. post-intervention) was used to test the differences between the groups and to assess pre- and post-intervention differences. Post hoc Bonferroni tests were conducted to correct for multiple testing, when appropriate. Additionally, analysis of covariance controlling for baseline values as covariates was used to compare group differences. The statistical significance level was set at $p < 0.05$ for all tests. All data were analysed using SPSS Statistics (version 28; IBM Corp., Armonk, NY, USA).

Results

Figure 1 shows a flowchart of the study participants. Initially, 60 participants were included. After assessing eligibility, 15 participants who were not sedentary were excluded and 45 participants were enrolled in the study. Each group lost one participant during follow-up due to discontinuation, for reasons not associated with the design of the study. Finally, 14 participants in each group completed the intervention and post-testing. Overall, the mean age of participants was 22.33 (±2.18) years. All participants had healthy BMIs (20.7 ± 2.06 kg/m^2). No differences were observed in the baseline variables between the groups. The baseline characteristics, exercise intensity, and overall compliance of all participants and each group are shown in Table 1.

Primary outcomes

Lipid profiles

Significant time × group interactive effects on TG (F [2, 39] = 3.349, $p = 0.045$, $\eta^2 = 0.147$), TC (F [2, 39] = 4.822, $p = 0.013$, $\eta^2 = 0.198$), and LDL (F [2, 39] = 3.902, $p = 0.029$, $\eta^2 = 0.167$) were identified, while no significant difference in HDL was observed. Further simple effects analyses revealed that TG levels increased in the CON group ($p = 0.046$, Figure 2(a)) and TC levels decreased in the HICT group ($p = 0.014$, Figure 2(b)). However, no significant difference was found in the HICT group ($p = 0.074$) and the CON group ($p = 0.070$) in LDL. No difference in lipid profiles between groups was observed.

Inflammatory cytokines

A significant main effect of time was found for TNF-α (F [1, 39] = 9.281, $p = 0.004$, $\eta^2 = 0.192$). Additionally, a marginally significant interaction effect on leptin (F [2, 39] = 3.103, $p =$ 0.056, $\eta^2 = 0.137$) and a significant main time effect on resistin (F [1, 39] = 12.899, $p < 0.001$, $\eta^2 = 0.249$) were identified. Further pair-wise comparisons revealed that leptin levels significantly decreased in only the HICT group at post-test ($p = 0.023$, Figure 3(d)). However, no effect was observed for IL-8 or IFN-γ levels (Figure 3(b,c)). We observed a significant post-intervention group difference in leptin levels between only the HICT and CON groups ($p = 0.043$, Figure 3(d)), with no difference identified between the two intervention groups.

Table 1. Baseline characteristics, intensity and overall compliance.

	HICT ($n = 14$)	HIIT ($n = 14$)	Control ($n = 14$)
Individual variables			
Age, years	22.1 ± 1.6	22.5 ± 2.4	22.4 ± 2.6
Height, cm	163.4 ± 4.8	166.4 ± 4.8	163.6 ± 6.2
Weight, kg	54.6 ± 7.2	58.1 ± 6.7	55.6 ± 7.8
BMI, kg/m^2	20.4 ± 2.3	20.9 ± 1.9	20.7 ± 2.1
Fat mass, kg	15.7 ± 4.0	16.9 ± 5.1	16.0 ± 4.3
Lean mass, kg	36.6 ± 3.3	38.8 ± 2.4	37.3 ± 3.6
HR (S1)	158.9 ± 9.5	159.4 ± 7.3	
RPE (S1)	14.5 ± 0.7	14.6 ± 0.5	
HR (S2)	161.3 ± 6.7	161.0 ± 8.6	
RPE (S2)	15.1 ± 0.7	14.8 ± 0.9	
HR (S3)	163.4 ± 5.2	162.3 ± 7.3	
RPE (S3)	15.4 ± 0.7	15.4 ± 0.9	
Compliance	93.8%	93.5%	

Values are expressed as mean ± SD.
HICT: high-intensity circuit training; HIIT: high-intensity interval training; BMI: body mass index; HR: heart rate; RPE: rate of perceived of exertion; S1: stage 1; S2: stage 2; S3: stage 3.

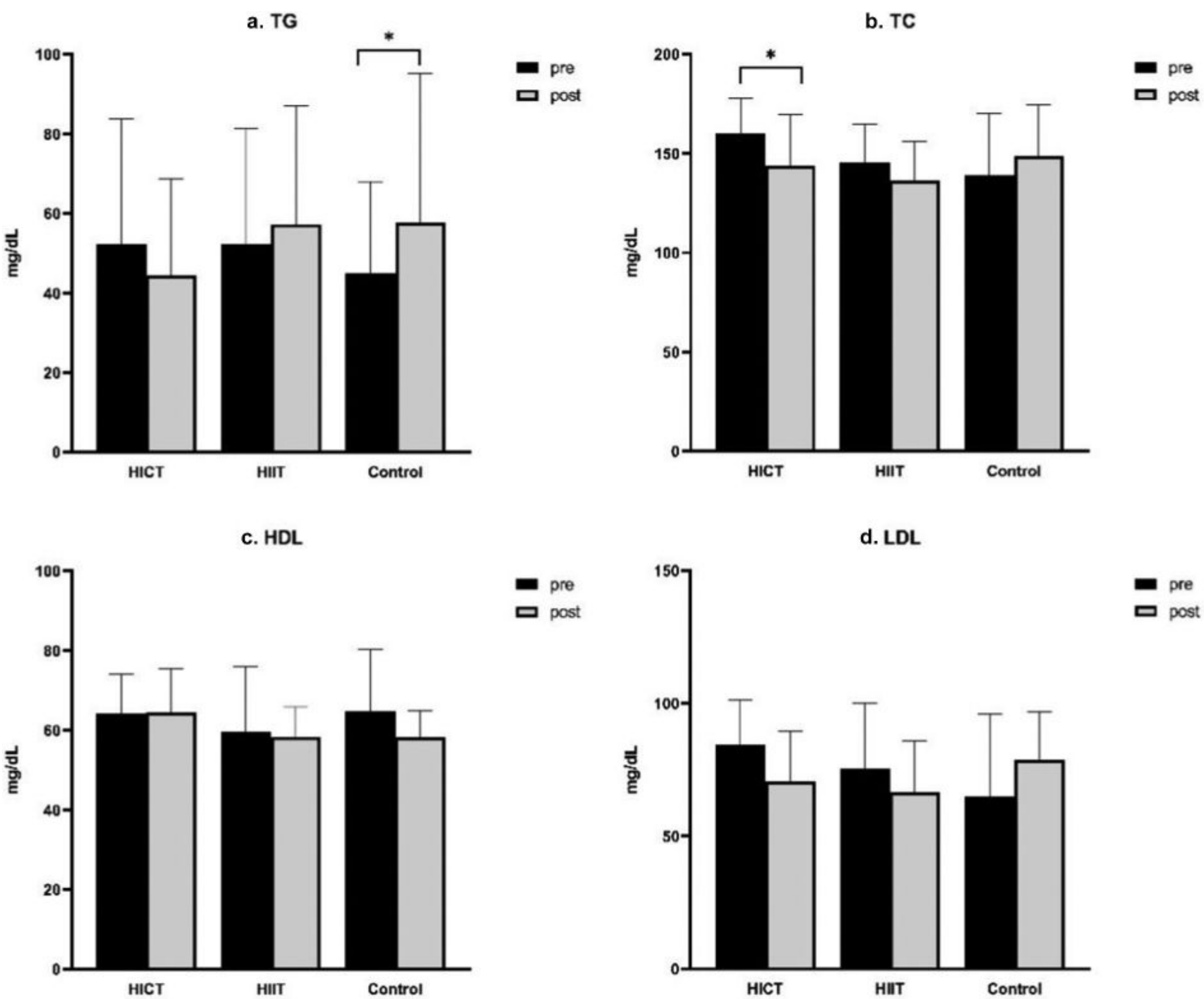

Figure 2. Differences in effects of 8-week intervention on lipid profiles. HICT: high-intensity circuit training; HIIT: high-intensity interval training; TG: Triglycerides; TC: total cholesterol; HDL: high-density lipoprotein; LDL: low-density lipoprotein. *$p < 0.05$, pre-post differences.

Secondary outcomes

Body composition

There were significant interactive effects on weight (F [2, 39] = 3.832, $p = 0.03$, $\eta^2 = 0.164$), BMI (F [2, 39] = 4.209, $p = 0.022$, $\eta^2 = 0.178$) and fat mass (F [2, 39] = 6.392, $p = 0.004$, $\eta^2 = 0.247$). A significant main effect of time was also observed for lean mass (F [1, 39] = 14.972, $p < 0.001$, $\eta^2 = 0.277$). Further analysis revealed significantly increased body weight in the HIIT ($p = 0.006$, Figure 4(a)) and CON groups ($p < 0.001$, Figure 4(a)). Similarly, post-intervention BMI was significantly higher in the HIIT ($p = 0.008$, Figure 4(b)) and CON groups ($p < 0.001$, Figure 4(b)), whereas fat mass significantly

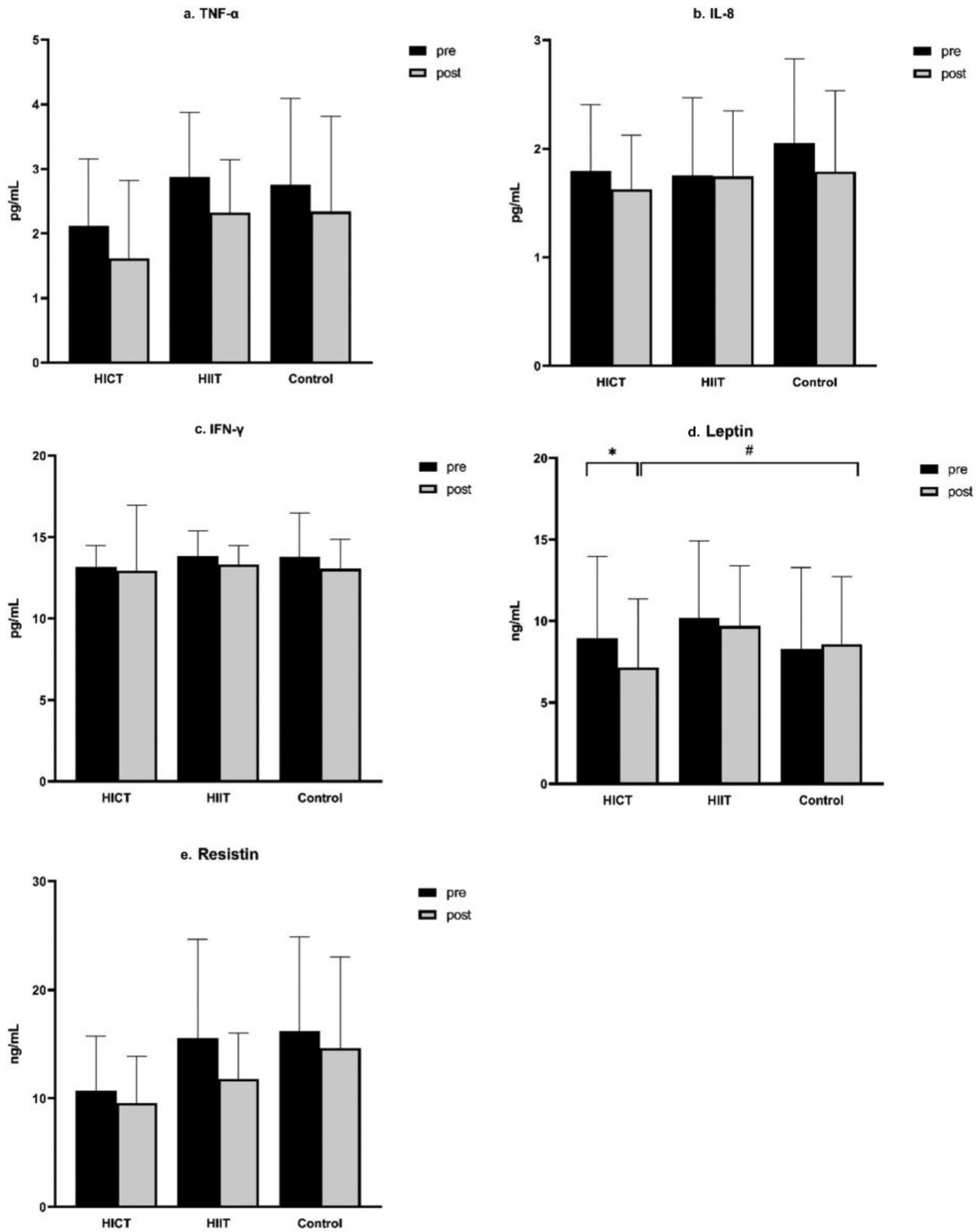

Figure 3. Differences in effects of 8-week intervention on inflammatory cytokines. HICT: high-intensity circuit training; HIIT: high-intensity interval training; TNF-α: tumour necrosis factor-alpha; IL-8: Interleukin-8; IFN-γ: Interferon-gamma. $*p < 0.05$, $**p < 0.01$, pre-post differences; # $p < 0.05$, group differences.

increased in the controls ($p = 0.004$, Figure 4(c)). Group comparisons showed a significant difference between the HICT and CON groups in body weight ($p = 0.015$, Figure 4(a)), BMI ($p = 0.006$, Figure 4(b)), and fat mass ($p = 0.002$, Figure 4(c)) at post-test. In contrast, only fat mass differed among the HICT and HIIT groups ($p = 0.045$, Figure 4(c)) at post-test.

Physical fitness

Significant interactive effects were observed on handgrip strength (F [2, 39] = 4.043, $p = 0.025$, $\eta^2 = 0.172$), standing long jump distance (F [2, 39] = 3.566, $p = 0.038$, $\eta^2 = 0.155$), and balance (F [2, 39] = 4.230, $p = 0.022$, $\eta^2 = 0.178$); However, only main effects for time on 1-minute sit-up performance were

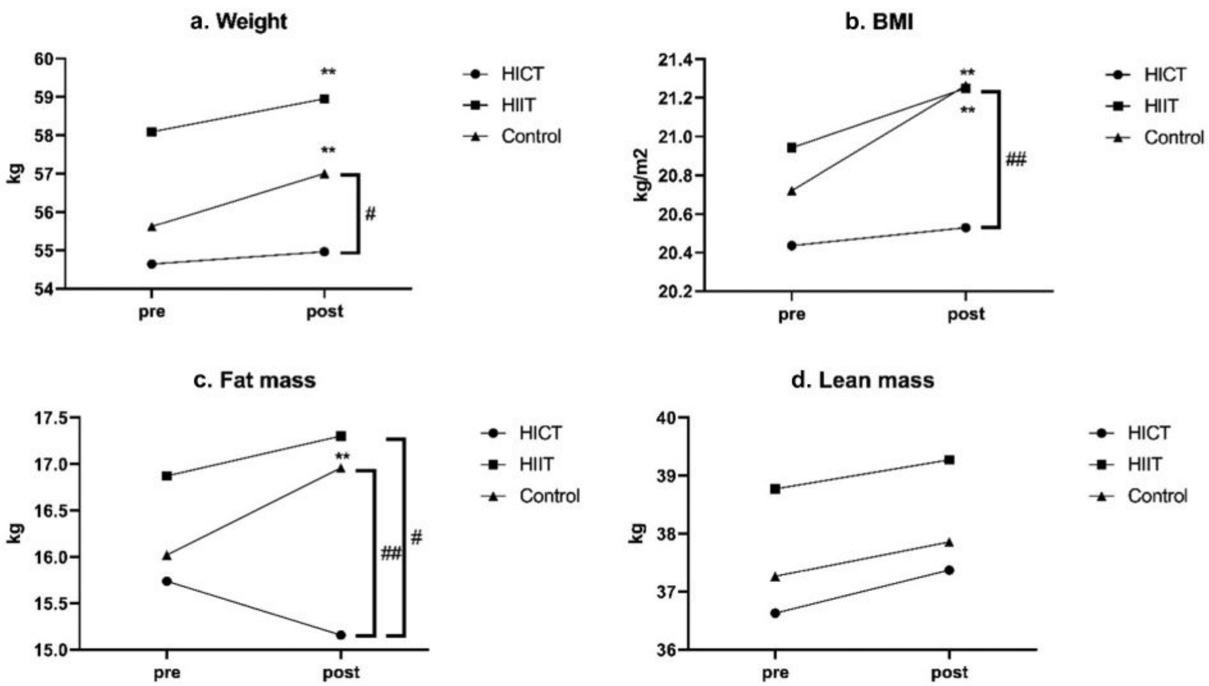

Figure 4. Differences in effects of 8-week intervention on body composition. HICT: high-intensity circuit training; HIIT: high-intensity interval training; BMI = body mass index. *$p < 0.05$, **$p < 0.01$, pre-post differences; # $p < 0.05$, ## $p < 0.01$, group differences.

identified (F [1, 39] = 20.608, $p < 0.001$, $\eta^2 = 0.346$). Total handgrip strength significantly increased in the HICT group ($p =$ 0.046, Figure 5(a)). Additionally, standing long jump distance increased in the HICT ($p < 0.001$, Figure 5(b)), HIIT ($p < 0.001$, Figure 5(b)), and CON ($p = 0.046$, Figure 5(b)) groups. Balance increased in only the HICT group ($p = 0.001$, Figure 5(c)). We observed significant between-group differences for the HICT and CON groups in handgrip strength ($p = 0.041$, Figure 5(a)), and standing long jump distance ($p = 0.028$, Figure 5(b)). Finally, balance differed significantly between the HICT and HIIT groups ($p = 0.029$, Figure 5(c)).

Discussion

To the best of our knowledge, this is the first study to compare the effects of an 8-week HICT and traditional cycling-based HIIT on lipid profiles, inflammatory cytokines, body composition, and physical fitness in sedentary young women. HICT may be more efficient than HIIT in reducing fat mass and improving balance. When compared to CON, HICT showed significant improvement whereas HIIT did not. In addition, the CON group showed negative outcomes after 8 weeks. Given the higher prevalence of sedentary behaviour and its strong association with cardiovascular health among young women, the findings of the present study may have practical implications.

A significant decrease in TC was shown after HICT, whereas no changes in lipid profiles were observed in the HIIT group. This result is consistent with that of a recent meta-analysis concluding that long-term HIIT has no effect on the lipid profiles of overweight or obese populations (Batacan et al., 2017). The favourable changes in lipid profiles after HICT may be associated with increased lipoprotein lipase activity, increased blood lipid uptake, and decreased lipid levels. In addition, the activation of peroxisome proliferator-activated receptors and gamma receptors could also be an underlying mechanism leading to improved lipid profiles (Hemmatinafar et al., 2020; Wang & Xu, 2017). Given that the participants in this study were young and healthy with lipid profiles within the normal range, the potential for improvement might have been limited. Additionally, the lack of control over energy intake during the study could have contributed to the absence of significant changes in lipid profiles.

Our findings revealed a significant main effect of time on TNF-α, suggesting that TNF-α may have been reduced in all groups. The reduction in TNF-α may be associated with the observed decrease in body weight and fat mass, particularly the decrease in fat mass unique to the HICT group, potentially leading to the speculation of greater contribution of HICT on the overall TNF-α reduction. One recent study suggested that 24 weeks of functional training reduced TNF-α among postmenopausal women (Rocha et al., 2023). Two additional studies showed no significant within- or between-group changes in inflammatory marker levels after a 9-week cycling-based HIIT programme among sedentary people or after 8 weeks of HIIT among overweight and obese individuals (Allen et al., 2017; Vella et al., 2017). Comparatively, our study revealed a main effect of time for TNF-α, which is in contrast with the previous observations possibly due to differences in study protocols or populations. In addition to changes in body composition, another inflammation-related mechanism involves the exercise-induced stimulation of an anti-inflammatory environment, including the increased production of other muscular anti-inflammatory myokines and the reduction of human monocyte toll-like receptor 2 levels (Durrer et al., 2017; Gleeson et al., 2011). Our finding also suggested that no favourable changes

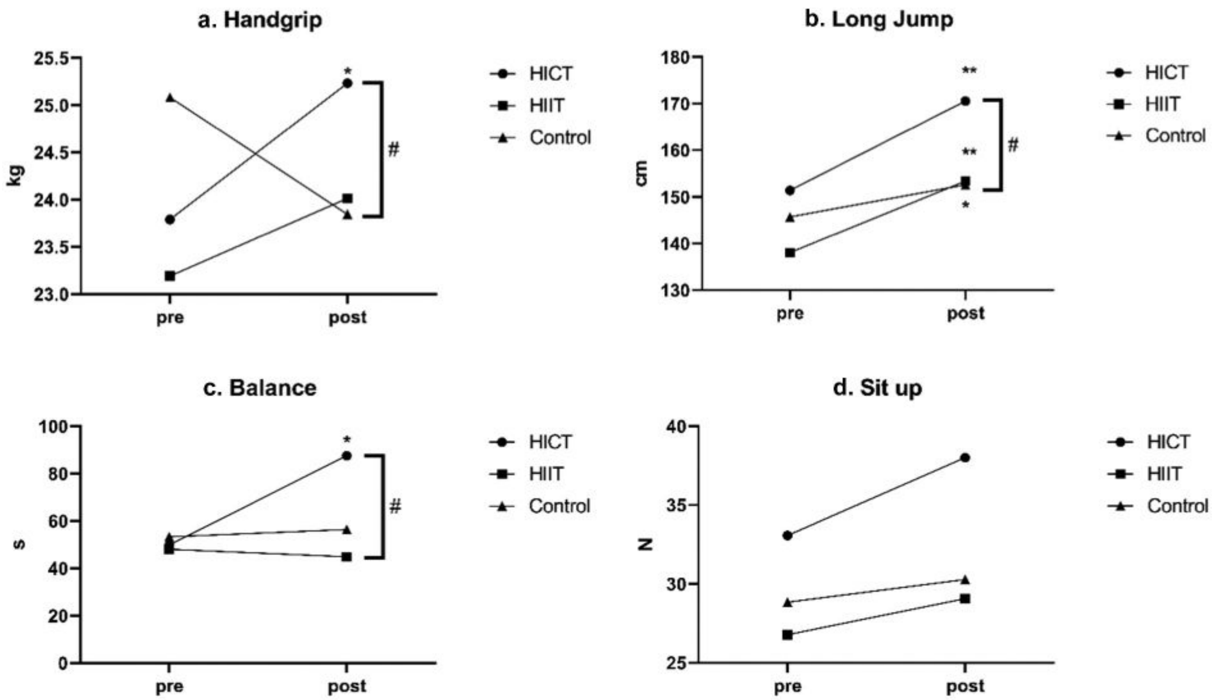

Figure 5. Differences in effects of 8-week intervention on physical fitness. HICT: high-intensity circuit training; HIIT: high-intensity interval training. *$p < 0.05$, **$p < 0.01$, pre-post differences; # $p < 0.05$, group differences.

in IL-8 or IFN-γ were identified in either the HICT or HIIT group. Although IL-8 and IFN-γ are affected by acute exercise (Dogra et al., 2019; Vijayaraghava & Radhika, 2014), the long-term effects remain unclear. A 6-week study found no reduction in salivary IL-8 levels after HIIT in healthy young adults (O'Neill et al., 2022). Moreover, another study reported that 2 weeks of HIIT did not significantly change IFN-γ in young women with obesity (Soltani et al., 2023). Similarly, the absence of significant changes in IL-8 and IFN-γ levels in our study may be attributed to the fact that the participants were young and healthy with no significant chronic inflammation at baseline, despite their sedentary lifestyle.

Leptin and resistin are two inflammatory adipokines produced by the adipose tissue that play critical roles in regulating metabolism and inflammation. Our results showed that, compared with pre-test, HICT may be a useful approach to decrease leptin levels, whereas a significant main effect of time on resistin suggested that resistin was reduced in all groups. The effects of exercise on leptin and resistin levels have been studied extensively (Fedewa et al., 2018). A meta-analysis suggested that HIIT decreased circulating leptin levels in individuals with metabolic disorders (Khalafi & Symonds, 2020). Another previous study reported that several months of HIIT reduced serum resistin levels in participants with diabetes and obesity (Balducci et al., 2010). Similar findings were reported in obese women after 8 weeks of HIIT (Aghajani et al., 2022). The reduction in fat mass may be the main reason for the observed changes in adipokine levels since they are primarily produced by adipose tissue (García-Hermoso et al., 2017). Similar to the speculation on TNF-α, when considering the impact of HICT on fat mass reduction, HICT may potentially contribute significantly to the overall reduction of resistin levels. However, other potential mechanisms contributing to these changes have not yet been fully elucidated. Some studies have suggested that these changes may be due to increased energy expenditure, improved insulin sensitivity, or reduced inflammation associated with this type of training (Babaei & Hoseini, 2022). Although the potential mechanisms remain unclear, our study illustrated the beneficial effects of HIIT and HICT on inflammatory adipokine levels in healthy young women after 8-week training compared with pre-test.

Several studies have shown that HICT may be an effective strategy for improving body composition and physical fitness. A recent review concluded that HICT improves fat-free mass, fat mass, and physical fitness indicators (Scoubeau et al., 2022). The mechanism behind these beneficial changes may be related to negative energy balance, increased post-exercise oxygen consumption, appetite suppression, improved hormonal responses, and more muscle recruitment (Jakobsen et al., 2012; Sultana et al., 2019). Compared to moderate-intensity continuous training (MICT), HIIT showed a greater excess of post-exercise oxygen consumption (Panissa et al., 2021). Likewise, acute HIIT could suppress hunger compared to MICT (Hu et al., 2023). Although energy expenditure, oxygen consumption, and appetite after HICT and cycling-based HIIT were not evaluated in the current study, it would be informative to compare the effects of the two different forms of HIIT on those factors. However, the performance of strength tests could support that HICT may preferentially recruit type 2 muscle fibres, leading to muscle hypertrophy and increased energy expenditure. Notably, the participants in our study were of average, healthy weight, and some were underweight. Thus, an increase in body weight and BMI might have actually improved their overall health rather than creating negative outcomes. Also, traditional HIIT is usually unimodal, while HICT is multimodal and includes specific motor skills and core stability. Such unique benefits of HICT may make it a better training protocol to improve physical fitness. In the present study, an 8-week HICT training resulted in significantly greater improvement in balance performance than HIIT, partially supporting our hypotheses. Many studies have revealed the effects of core muscle training on balance and stability (Granacher et al., 2013). HICT engages a greater number of muscle groups than HIIT, including the core muscles, which may more effectively improve balance and stability. Physical fitness aspects, such as cardiorespiratory fitness and muscular strength, have a strong relationship with cardiovascular diseases and their risk factors (Carbone et al., 2020; Kaminsky et al., 2019). In the present study, HICT was identified as a potential approach that can lead to improvements in physical fitness. Therefore, it is evident that HICT has the potential to enhance cardiovascular health by positively influencing different physical fitness components.

Several studies have compared differences in body composition and physical fitness results between HICT and traditional HIIT. Unfortunately, these studies did not investigate the potential differences in cardiovascular health between the two modalities. Although the effect of exercise on biochemical parameters may be related to weight changes (Isanejad et al., 2023), a potential additional factor contributing to the observed differences between HICT and HIIT is the use of resistance training in HICT, which may promote the production of specific cytokines. Previous studies have suggested that selected cytokines are stimulated to a greater extent by resistance training than by endurance training. Furthermore, the production of these cytokines may be linked to the activation of specific pathways, such as the mammalian target of rapamycin or adenosine monophosphate-activated protein kinase (AMPK) pathways. Activation of the AMPK pathway has been associated with improvements in metabolic diseases such as type 2 diabetes, obesity, and cardiovascular disease. However, further studies are required to investigate the role of these pathways (Zunner et al., 2022).

The present study has several strengths. Our RCT investigated the effects of two different HIIT protocols on lipid profiles and inflammatory cytokine levels, which have seldom been reported by previous studies. Additionally, our participants were sedentary young women; this population has been examined less frequently in previous research. However, our study also has limitations. First, the daily PA and energy intake of the participants during the intervention period were not well controlled, which may have influenced outcomes. Second, considering that the participants were generally healthy, the scope of HIIT and HICT for further improvement might have been limited. Additionally, this study was conducted during the COVID-19 pandemic, which may have influenced the results (Narici et al., 2021). For example, the CON group experienced several negative changes. It is possible that both intervention groups may been influenced by the COVID-19 pandemic restrictions and the resulting prolonged, sedentary behaviour. Third, only heart rate and RPE data were collected during the training, other data, such as power for HIIT or the repetition of each exercise for HICT, were not collected, whereas these data may help to better monitor exercise intensity and workload. Future studies should attempt to investigate the effects of different HIIT modalities in other populations, such as those with chronic diseases, and should adopt a longer intervention period with various exercise contents. Based on the results of this study, several practical recommendations can be made. Considering the advantages of HICT, such as combining strength and aerobic training, and minimal requirements for space and equipment, it is a valuable form of exercise that can easily be incorporated into daily PA in any setting. Furthermore, compared with running and cycling in the lab, HICT does not require a treadmill or power bicycle. With only a small space, it can be performed by using only body weight. Additionally, HIIT has been suggested to elicit more enjoyment than other types of exercise (Li et al., 2022), which may help with programme adherence (Poon et al., 2022). Although our results did not reveal a significant difference in overall compliance in cycling-based between HIIT and HICT, in the long term, considering that participants could replace or add different exercises in HICT freely, it may lead to higher enjoyment and may be easier to adhere to than traditional HIIT. Furthermore, this study suggests that HICT and HIIT can be successfully implemented during a COVID-19 pandemic, which enhances our confidence in effectively managing future crises or potential lockdown situations.

In conclusion, an 8-week HICT intervention was not only effective in improving cardiovascular health by decreasing total cholesterol and leptin levels, but also in increasing muscle strength and balance among sedentary, young women. Although cycling-based HIIT also improved muscle strength, more favourable changes from pre- to post-intervention were observed in the HICT group, suggesting that HICT may be superior for improving cardiovascular health, body composition, and physical fitness.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

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