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Original Article

# Effects of high-intensity interval training on vascular function and maximum oxygen uptake in young sedentary females

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## ABSTRACT

**Objective:** Sedentary behavior is one of the risk factors for cardiometabolic diseases, including cardiovascular diseases, diabetes mellitus, and metabolic syndrome. High-intensity interval training (HIIT) is one effective way to reduce the risk of cardiometabolic diseases. This research studies the effects of cycling-based HIIT on vascular function and cardiorespiratory fitness in sedentary people.

**Methods:** Twenty-two female participants were separated into two groups, including HIIT group who receive intervention and control group who did not receive the intervention. Each of the participants was interviewed to collect and record their medical history, and medical parameters including cardio-ankle vascular index (CAVI), flow-mediated dilation (FMD), and maximal oxygen consumption ($\dot{V}O_{2max}$) were measured as a baseline pre-test. The intervention was a cycling-based HIIT lasting 6 weeks, with three sessions per week. During each session, the participant completed a set protocol consisting of 1 min on a cycle ergometer, cycling at 80–85% maximal heart rate, followed by a 1-min rest period. This sequence was repeated for a total of 5 times.

**Results:** After 6 weeks of intervention, results showed that the HIIT group had significant improvements in CAVI (6.39 ± 0.76 vs. 5.91 ± 0.58), FMD (9.26 ± 6.5 vs. 14.01 ± 4.3%), and $\dot{V}O_{2max}$ (20.10 ± 4.31 vs. 24.34 ± 5.71 ml/kg/min) values compared to the pre-test ($P < 0.05$). In addition, HIIT increased endothelial function as measured by FMD compared to the control group (14.01 ± 4.3 vs. 9.15 ± 4.16 %, $P < 0.05$).

**Conclusion:** Six weeks of HIIT were found to improve vascular function and cardiorespiratory fitness in sedentary people and demonstrated the benefits of HIIT as a time-efficient exercise strategy.

**Keywords:** Cardiometabolic diseases, high-intensity interval training, sedentary behavior

## Introduction

Modern lifestyles have increased sedentary behavior, including among young adults. The United Nations World Health Organization (WHO) defines sedentary behavior as a waking activity involving sitting, reclining, or lying down with an energy expenditure ≤1.5 metabolic equivalents (METs).[1] Previous studies have indicated that sedentary lifestyles increase morbidity and mortality in cardiometabolic diseases, including diabetes, hypertension, stroke, and coronary artery disease.[2-4] In primary prevention, greater physical activity appears to reduce cardiometabolic risk.[5] High-intensity interval training (HIIT) is an appealing exercise for this purpose because it burns many calories in a short time. Busy people can be more inclined to incorporate intermittent bursts of vigorous exercise into their schedule than slower, longer forms of exercise. Several studies have shown that HIIT improves vascular function and reduces the risk of many adverse health conditions.[6-8] Vascular function is assessed by several methods. Measuring the flow-mediated dilation index (FMD) is a non-invasive method that is an independent predictor of endothelium-dependent vascular function.[9,10] The FMD reflects vascular homeostasis and endothelium-derived nitric oxide bioavailability.[11] Two other helpful noninvasive indices for the assessment of arterial function are cardio-ankle vascular index (CAVI) and ankle-brachial index (ABI). CAVI is a predictor of arterial stiffness while ABI is an indicator of arterial occlusion.[12,13]

Past studies on vascular function have mainly focused on people who are at high risk for cardiovascular disease. Few studies have investigated the role of HIIT on vascular function in sedentary subjects who are healthy. High-intensity cycling is known to be an effective form of exercise for improving vascular function and maximum oxygen consumption ($\dot{V}O_{2max}$).[14] This study investigates the effects of high-intensity interval cycle training over a 6-week period on vascular function and cardiorespiratory fitness in sedentary young adults.

## Methods

The ethical study protocol was approved by Naresuan University's Institutional Review Board (permit NU_IRB2368). Before participation in the study, all participants were informed about the purpose of the study, the testing procedure, possible benefits, and risks. The participants provided written informed consent before enrolling in the study.

Twenty-four healthy young adults aged 18–26 years who not involved in the regular physical exercise were included. Participants who had ever previously been diagnosed with cardiovascular disease or other metabolic diseases were excluded from the study. Participants who had medication and dietary supplements were also excluded from the study. The participants were randomly divided into two groups consisting of the no-exercise control (NEC) group ($n = 12$) and the HIIT group ($n = 12$). Two male subjects dropped out before the end of the study. All participants were asked to maintain their regular eating habits without any changes for the duration of the study. Participants allocated to the control group were further asked to maintain their current level of everyday physical activity.

### Data collection

Sedentary behavior was evaluated in terms of activity at work, transportation, and recreational activities using a global physical activity questionnaire (GPAQ). All participants were asked to complete the GPAQ at the start of the study. A GPAQ activity level result of <600 MET/week or <75 min/wk was defined as sedentary behavior.

### HIIT interventions

HIIT group participants were supervised while cycling on an electrically braked ergometer (Monark 828E, Sweden) during three HIIT exercise sessions per week (25 min/session) for a 6-week period. Each of these HIIT sessions consisted of a 5 min light intensity warm-up, followed by five bouts of 1 min HITT cycling performed at a minimum of 80% maximum heart rate (MHR), followed by a 2 min of the recovery period and finally a 5 min cool down. The participant's heart rate (HR) was monitored using a polar chest band throughout the exercise session. MHR was determined using an age-based $HR_{max}$ calculation (220-age). Weight and height were measured twice: At the start of the study and at the end. Body mass index (BMI) was then calculated using the following formula: weight/height$^2$ (kg/m$^2$). Waist circumference was measured with a tailor's tape measure between the last rib margin and the superior iliac crest.

### Maximum oxygen consumption test

The $\dot{V}O_{2max}$ test was performed on a cycle ergometer (Corival cpet, Lode B.V., The Netherlands) using a protocol of Okushima *et al*. (2015), somewhat modified.[15] This test was begun with a 4-min warm-up period, pedaling at 0 watts with a cadence of 60–80 rpm. The exercise was then progressively increased by 20 watts every min until exhaustion. Maximum oxygen consumption ($\dot{V}O_{2max}$) was obtained through a metabolic gas exchange system (Cortex Biophysik, Metalyzer 3B, Germany). The gas analyzer was calibrated using known certified concentrations of $O_2$ and $CO_2$, and the mass flow sensor was calibrated against a 3.0-L calibration syringe at various rates of flow before the tests. Values were obtained on a breath-by-breath basis and averaged over 10-s intervals. $\dot{V}O_{2max}$ was defined as the highest $\dot{V}O_{2max}$ averaged from three consecutive 10-s intervals. HR was continuously monitored (Polar Transmitter, Finland) during the maximum exercise test.

### FMD test

The FMD of the brachial artery was performed in a quiet room. The participants were asked not to consume any caffeine for at least 12 h before the test. Participants were instructed to relax in a supine position with their right arm extended at an angle of ~90° from the torso, and a blood pressure (BP) cuff was placed on the upper arm. A Doppler ultrasound (Sonosite Edge II, FUFIFLM, USA) equipped with a 10MHz multi-frequency linear array probe captured imaging 5–10 cm above the antecubital fossa in the longitudinal plane. The diameter of the brachial artery was defined as the distance (mm) between the intima-lumen interfaces of the anterior and posterior walls. Following a brief rest period, the BP cuff was inflated to approximately 50 mmHg above the baseline systolic BP for 5 min. Digital imaging of the brachial artery was immediately captured following the release of the cuff. The percentage FMD index (%FMD) was calculated as follows:

$$\text{baFMD}(\%) = 100 \times \left[\frac{D_1 - D_0}{D_0}\right]$$

Where,

$D_0$ = diameter of the brachial artery before inflation of the BP cuff

$D_1$ = diameter of the brachial artery after deflation of the BP cuff.

### Measurement of CAVI and ABI

CAVI and ABI were assessed using the VaSera VS-1500N vascular screening system (Fukuda Denshi Co. Ltd, Tokyo, Japan). Explained briefly, the participant was lying supine in the quiet room. A total of four BP cuffs were applied to the bilateral upper and lower extremities, and the phonocardiograph was placed on the sternum. HR and BP measurements were performed simultaneously. The ABI was obtained using VaSera data management software program. The CAVI or vascular stiffness index was calculated using the following equation:

$$\mathrm{CAVI} = \ln\left(\frac{P_s}{P_d}\right) \times \frac{2\rho}{\Delta P \times \mathrm{PWV}^2}$$

PWV is the pulse wave velocity from the aortic origin to the ankle through the femoral artery, $P_s$ is the systolic BP, $P_d$ is the diastolic BP, ρ is the blood viscosity, and ΔP is $P_s$-$P_d$.

### Statistical data analysis

Data were expressed as number (percent) and mean ± standard deviation. The normal distribution was tested using the Shapiro–Wilk test. Paired *t*-tests were used to determine the difference between before and after exercise. Unpaired *t*-tests were used to compare these differences between the two groups. Statistical significance was set as $P < 0.05$. Statistical analysis was performed using SPSS software for Windows version 17.0 (SPSS Inc., Chicago, IL, United States).

## Results

Of the original 12 participants in the HIIT group and 12 participants in the NEC group, 11 women in each of the two groups completed the study. Over the course of the 6 weeks, both groups lost one man each for various personal reasons. The mean age of the remaining participants was 21 ± 0.7 years, and all 20 were lean with no underlying diseases. The physical characteristics of the participants who completed the study are shown in Table 1. At the start of the study, averages of weight, BMI, HR, and BP were similar between the two groups. At the end of the study, averages of weight, BMI, HR, and BP were still similar between the two groups [Table 2]. The HIIT groups before and after measurements were not significantly different. The NEC groups before and after measurements were also not significantly different.

**Table 1:** Physical characteristics of the participants who completed the study

| Parameters | Values |
|---|---|
| Gender | |
| Female | 22 (100) |
| Age, year | 21.27 ± 0.703 |
| Health problem | |
| No | 21 (95.5) |
| Yes (Allergic rhinitis) | 1 (4.5) |
| History of tobacco use | |
| Nonsmokers | 22 (100) |
| Alcohol consumption | |
| Never | 19 (86.4) |
| Yes | 3 (13.6) |
| Family history of cardiometabolic diseases and related complication | |
| Diabetes mellitus | 11 (50) |
| Hypertension | 14 (63.6) |
| Cardiovascular diseases | 2 (9.1) |
| Hyperlipidemia | 2 (9.1) |

Data are presented as number (%) and mean ± standard deviation

Vascular function measurements of the participants who completed the study are shown in Table 3. The data indicate that %FMD was significantly higher in the HIIT group than in the NEC group after completing the training program (14.01 ± 4.3 vs. 9.15 ± 4.16 %, $P < 0.05$). There were no significant differences in $\dot{V}O_{2max}$, CAVI, or ABI between the two groups after training. The HIIT group had a significant increase in %FMD after training, compared to before training (14.01 ± 4.3% after vs. 9.26 ± 6.5% before, $P < 0.05$). Similarly, $\dot{V}O_{2max}$ also rose significantly in the HIIT group (24.34 ± 5.71 ml/kg/min after vs. 20.10 ± 4.31 ml/kg/min before, $P < 0.05$). CAVI was significantly lower in the HIIT group after training than before training (5.91 ± 0.58 after vs. 6.22 ± 0.86 before, $P < 0.05$). All mean CAVI and ABI values remained in the normal range.

A comparison of the percentage changes of FMD, CAVI, and $\dot{V}O_{2max}$ between before and after training in the NEC control and the HIIT groups was performed [Figure 1]. The results showed that in the HIIT group, FMD, and $\dot{V}O_{2max}$ changed positively approximately 130% and 22% after training while CAVI changed negatively about −7% after training.

## Discussion

The findings of this study indicated that HIIT over a 6-week period improved vascular parameters and $\dot{V}O_{2max}$ in sedentary young female adults. Compared to the control group, HIIT increased endothelial function as measured by FMD, reduced arterial stiffness, and improved both $\dot{V}O_{2max}$ and endothelial function, compared to baseline.

This pilot study confirmed the feasibility of using HIIT to induce changes in vascular function in sedentary people. According to the WHO recommendations on aerobic physical activity, adults age 18–64 years should perform at least 150 min of moderate-intensity exercise or 75 min of vigorous-intensity exercise weekly.[1] Previous studies have shown that different types of exercise have different types of effects on vascular function, but typically effects depend on exercise intensity and duration.[7,16] Several studies showed that, compared with moderate exercise, high-intensity exercise significantly improved endothelial function in patients with cardiometabolic diseases, including diabetes and cardiovascular diseases.[14,17-19] Consistent with previous studies, the current study found that high-intensity training is effective at improving cardiopulmonary fitness and vascular parameters in sedentary participants. The result of this study showed that maximum oxygen uptake was a significant improvement in the HIIT group after training than before training. This may be explained that the HIIT protocol provided an optimal stimulus to enhance both maximal cardiovascular

**Table 2:** Clinical parameters of the participants who completed the study

| Parameters | NEC group ($n$=11) | | HIIT group ($n$=11) | |
|---|---|---|---|---|
| | Before | After | Before | After |
| Weight (kg) | 55.18±12.40 | 55.59±12.89 | 55.73±12.11 | 56±12.17 |
| BMI (kg/m$^2$) | 21.25±4.42 | 21.41±4.66 | 21.26±3.93 | 21.38±4.02 |
| HR (bpm) | 71.36±16.42 | 81.55±11.24 | 71.55±11.21 | 74.27±13.57 |
| SBP (mmHg) | 115±13.55 | 114.91±9.36 | 118±11.87 | 119.27±9.45 |
| DBP (mmHg) | 73.82±10.02 | 71.73±5.2 | 79.91±5.50 | 72.64±3.31 |

Data are presented as mean±standard deviation. NEC: No-exercise control, HIIT: High-intensity interval training, BMI: Body mass index, HR: Heart rate, SBP: Systolic blood pressure, DBP: Diastolic blood pressure. Independent $t$-test and paired $t$-test showed no differences between the two groups (all $P$>0.05)

**Table 3:** Maximum oxygen consumption, FMD, cardio-ankle vascular index, and ABI of the participants who completed the study

| Parameters | NEC group ($n$=11) | | HIIT group ($n$=11) | |
|---|---|---|---|---|
| | Before | After | Before | After |
| $\dot{V}O_{2\,max}$ (ml/kg/min) | 21.72±3.42 | 20.51±3.34 | 20.10±4.31 | 24.34±5.71* |
| FMD (%) | 12.74±3.87 | 9.15±4.16 | 9.26±6.5 | 14.01±4.3*† |
| CAVI | 5.95±0.70 | 6.22±0.86 | 6.39±0.76 | 5.91±0.58* |
| ABI | 1.06±0.07 | 1.06±00.7 | 1.04±0.06 | 1.05±0.05 |

Data are presented as mean±standard deviation. NEC: No-exercise control, HIIT: High-intensity interval training, $\dot{V}O_{2\,max}$: Maximum oxygen consumption, FMD: Flow-mediated dilation, CAVI: Cardio-ankle vascular index, ABI: Ankle-brachial index. *Represents a significant difference between pre and post-training values within-group ($P$<0.05). †Represents a significant difference between post-training values of the two groups ($P$<0.05)

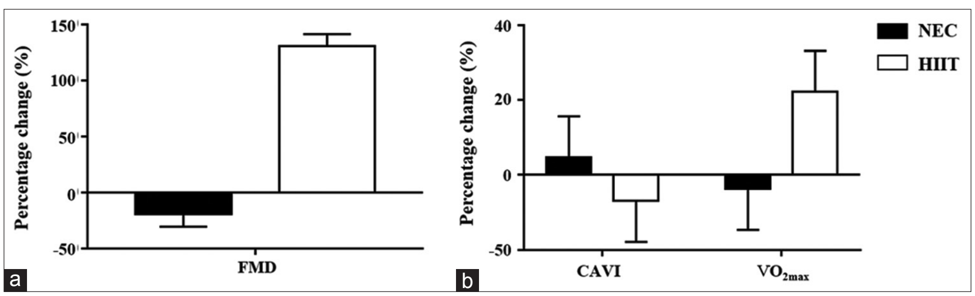


**Figure 1:** Percentage changes of FMD (a), CAVI, and $\dot{V}O_{2max}$ (b) between pre- and post-training values in the NEC control and the HIIT groups. NEC: No-exercise control, HIIT: High-intensity interval training, FMD: Flow-mediated dilation, CAVI: Cardio-ankle vascular index, $\dot{V}O_{2max}$: Maximum oxygen consumption

and peripheral adaptations in HIIT.[20] As mentioned earlier, participants in the current study trained on a bicycle ergometer for 25 min a day, consisting of a 5 min warm-up followed by 1 min of vigorous exercise and then 2 min of recovery. This vigorous exercise and recovery were performed a total of 5 times, followed by a 5 min cool down. This regimen was followed at three sessions per week, over the course of 6 consecutive weeks. Therefore, the 25 min HIIT duration used was effective and time efficient. The 25 min HIIT duration works well for sedentary people who easily get bored or give up with continuous moderate-intensity training. High CAVI and/or low FMD are sensitive markers of early atherosclerosis. Lowering CAVI scores and/or raising FMD blood flow can reduce a patient's risk of developing atherosclerosis. The possible mechanisms of HIIT-improved vascular function have been unclear and remain so. Previous studies have been shown that high-intensity training exerts a significant effect on vascular endothelium.[21,22] Shear stress during repeated exercise augments endothelium-dependent vasodilation through the increased production of nitric oxide.[23,24] In addition, the increased production of nitric oxide also promotes vascular function by decreasing vascular tone, smooth muscle cell proliferation, leukocyte activation, and platelet aggregation.[25,26] However, in contrast to the current results, two other studies showed that HIIT had no effect on vascular function.[16,27] There are many factors that can intersect in different ways to produce different results. Such factors can include characteristics of the subjects, the sample size, and the exercise protocol. The current study assessed participants who were all sedentary young women. A recent study has reported that women participate in physical activity less than men, especially in sport activities.[28] Previous studies have also found that women were more sedentary than men.[29,30] Sedentary women are therefore good candidates for HIIT training. In the current study, even though other parameters improved with HIIT training, surprisingly, body weight and BMI did not change in either the HIIT group or the control group. Even though weight and BMI remained unchanged, HIIT is able to provide health benefits and reduce health risks, even in a 6-week period.

### Strengths and limitations

A strength of this study is that all participants completed all exercise sessions, and no injuries occurred. The percentage adherence of the participants was more than 90%. This study also provided the CAVI parameter, which had not been included in most previous studies.

A limitation of this study is the lack of included male participants. Even though this study recruited both male and female participants, the males dropped out before the completion of the experiment. That is why the study results are all for female participants. In addition, the lack of dietary control could have affected the results. Finally, since physical activity by the participants outside the experiment hours was not reported, such activity or the lack thereof might have affected the findings of the study.

## Conclusion

This study reports that 6 weeks of HIIT significantly improved FMD, CAVI, and maximum oxygen consumption in sedentary young female participants. These results add to a cumulative body of evidence supporting the benefits of HIIT as a time-efficient exercise strategy for improvement of vascular function and cardiorespiratory fitness.

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## Conflicts of Interest

There are no conflicts of interest in this study.

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