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# Comparative Effects of Different Exercise Types on Cardiovascular Health and Executive Function in Sedentary Young Individuals

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## ABSTRACT

HUANG, J., L. LENG, M. HU, X. CUI, X. YAN, Z. LIU, K. WANG, J. WU, S. HE, W. DENG, P. LI, Y. CHEN, D. GAO, Y. WEI, and J. HUANG. Comparative Effects of Different Exercise Types on Cardiovascular Health and Executive Function in Sedentary Young Individuals. *Med. Sci. Sports Exerc.*, Vol. 57, No. 6, pp. 1110–1122, 2025. **Purpose:** The present study aimed to compare the impacts of different exercise types on cardiovascular health and executive function (EF) in sedentary young individuals, and to determine the associations between cardiovascular function and EF after exercise. **Methods:** Sixty-three sedentary participants were randomly divided into high-intensity interval training (HIIT), moderate-intensity continuous training (MICT), resistance exercise (RE), and control groups. Macro- and microvascular endothelial functions were assessed using brachial artery flow-mediated dilation and fingertip reactive hyperemia index, respectively. Arterial stiffness was evaluated through carotid–femoral pulse wave velocity, ankle–brachial index, and augmentation index. EF performance was evaluated using the Stroop and *N*-back tasks. Functional near-infrared spectroscopy was employed to measure cortical activation and real-time oxyhemoglobin concentration (Oxy-Hb) changes in different cerebral regions. Key circulating biomarkers for vascular and cognitive function, including brain-derived neurotrophic factor (BDNF), irisin, vascular endothelial growth factor, insulin-like growth factor 1 (IGF-1), and tumor necrosis factor- $\alpha$ , were measured using enzyme-linked immunosorbent assays. **Results:** Eight weeks of HIIT, MICT, and RE effectively improved macro- and microvascular endothelial function while reducing arterial stiffness in sedentary young individuals. Furthermore, exercise-induced increase in BDNF level was correlated with enhanced macrovascular endothelial function, whereas an increase in IGF-1 level was associated with enhanced microvascular endothelial function and reduced arterial stiffness. Notably, both HIIT and MICT, but not RE, efficiently enhanced Oxy-Hb level in certain brain regions, such as the frontopolar area and dorsolateral prefrontal cortex, leading to the improvement in EF performance. Exercise-induced increase in Oxy-Hb level and EF performance were correlated with enhanced BDNF level and endothelial function and reduced arterial stiffness. **Conclusions:** Our study demonstrated that 8 wk of HIIT, MICT, and RE effectively improved endothelial function in both macro- and microvessels, and arterial stiffness among sedentary young individuals. However, HIIT and MICT, but not RE, notably increased blood oxygen level in the frontopolar area and dorsolateral prefrontal cortex brain regions and improved EF performance. Due to the efficiency and time-saving features of HIIT, the present study highlights HIIT as an effective exercise prescription for promoting vascular function and EF in sedentary young individuals. Importantly, the observed improvements in cardiovascular function following exercise training are pivotal in improving EF, and elevated circulating levels of biomarkers like BDNF and IGF-1, induced by exercise, are involved in the regulatory mechanisms. **Key Words:** ARTERIAL STIFFNESS, EXECUTIVE FUNCTION, ENDOTHELIAL FUNCTION, EXERCISE, SEDENTARY BEHAVIOR

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According to the Sedentary Behaviour Research Network, sedentary behavior (SB) is a low energy expenditure behavior ( $\leq 1.5$  METs) in a sitting or lying position while awake (1), which has been considered as an independent risk factor for various chronic diseases, including cardiovascular disease (CVD) (2). SB can induce endothelial dysfunction, recognized as a critical early step in the pathogenesis of CVD (3,4). Pulse wave velocity (PWV) has emerged as the gold standard for evaluating arterial stiffness, whereas the augmentation index (AIx) is widely used to explore arterial stiffness dynamics (5). Notably, healthy young individuals (18–25 yr) had a mean increase of  $0.3 \text{ m}\cdot\text{s}^{-1}$  in PWV and an increase in AIx after 5 h of uninterrupted SB, suggesting that prolonged SB can adversely affect arterial stiffness in young individuals (6).

Furthermore, prolonged SB negatively affects executive function (EF) (7,8), which represents a higher-order cognitive function involving the advanced organization and execution of complex thoughts and behaviors (9). It is worth noting that cognitive dysfunction is commonly associated with CVD. For example, patients with severe arteriosclerosis are three times more likely to develop Alzheimer's disease than healthy individuals (10). In addition, prolonged SB-induced increase in blood pressure may intensify cerebrovascular resistance, potentially leading to a decline in cerebral blood flow (CBF) in specific regions of the frontal lobe (11–13). Indeed, many of detrimental cardiovascular effects induced by SB, such as hypertension and vascular stiffness, have been linked to a core feature of Alzheimer's disease (14), indicating that prolonged SB might be a risk factor for cognitive decline via its cardiovascular effects (15).

Due to current sedentary lifestyles in study and work environments, it is difficult for young adults to reduce their sedentary time. Therefore, it is crucial to identify effective interventions to mitigate or prevent the risks associated with prolonged SB in young individuals. Adequate physical activity is known to be beneficial in both the prevention and treatment of CVD and cognitive dysfunction (16). However, only 30% of young people meet the physical activity recommendations outlined in the World Health Organization guidelines on physical activity and SB (17). This proportion is even lower among young adults (18). Young individuals commonly conduct high-intensity interval training (HIIT), moderate-intensity continuous training (MICT), and resistance exercise (RE) for physical fitness (19,20). Although MICT is a well-known approach for improving cardiorespiratory fitness, it can be time-consuming and monotonous. HIIT has become popular among young individuals due to its efficiency and time-saving features. Furthermore, both HIIT and MICT appear to positively impact cognitive function (21). The Physical Activity Guidelines also recommend that healthy adults engage in resistance training twice per week (22). Nevertheless, the effects of RE on arterial stiffness remain controversial, because RE can lead to transient spikes in blood pressure during exercise. It is unknown whether these transient blood pressure fluctuations translate into chronic vascular remodeling (23).

Most studies investigating the effects of HIIT, MICT, and RE on cardiovascular and cognitive function have been conducted

in middle-aged and older adults, yielding inconsistent results. Studies comparing the effects and underlying mechanisms of these exercise modalities in young sedentary individuals are lacking, and the relationship between exercise-enhanced cardiovascular function and cognitive improvement remains unclear. Based on the aforementioned research background, we hypothesized that 8 wk of HIIT, MICT, and RE had different impacts on vascular function and EF in sedentary young individuals; in addition, the improvement in cardiovascular function was associated with the enhancement in EF following 8 wk of exercise intervention.

## METHODS

### Participants

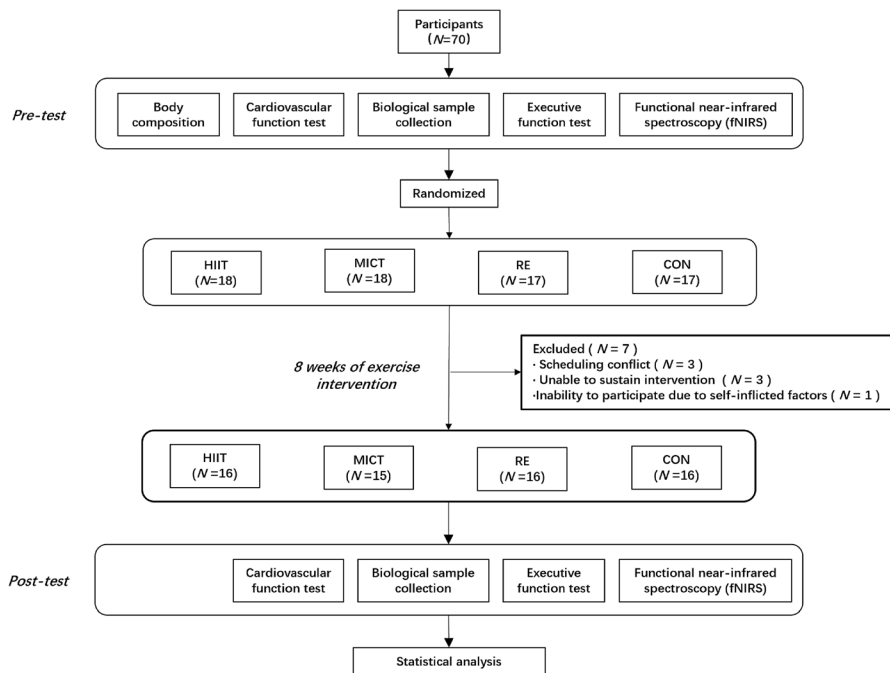
Seventy participants were recruited for the present study, with 63 completing the experiment as planned. The inclusion criteria for this study were as follows: 1) SBs, included watching TV, playing video games, using computer or mobile phone, driving a car, reading, and other sitting or lying behaviors while awake (cumulative sedentary time  $\geq 8 \text{ h}\cdot\text{d}^{-1}$  on  $\geq 5 \text{ d}\cdot\text{wk}^{-1}$ ); 2) irregular exercise habits ( $< 150$  min of moderate-intensity exercise or  $< 75$  min of vigorous-intensity exercise per week); 3) absence of CVD, such as hypertension, and body mass index (BMI)  $\leq 25 \text{ kg}\cdot\text{m}^{-2}$ ; and 4) absence of color blindness and cognitive dysfunction. All participants were provided both verbal and written information about the study and subsequently signed written informed consent. The Ethics Committee of Guangzhou Sport University approved the study (2022LCLL-04), and this trial has been approved by the Chinese Clinical Registry Centre (ChiCTR2400081215).

### Experimental Design

Each participant was randomly assigned to one of four groups: HIIT ( $n = 16$ ), MICT ( $n = 15$ ), RE ( $n = 16$ ), or control ( $n = 16$ ). All participants in each intervention group completed exercise training for 8 wk, with 3 times per week and a minimum of 24 h between each exercise session. The body composition test, vascular endothelial function tests (flow-mediated dilation [FMD] and reactive hyperemia index [RHI]), arterial stiffness tests (PWV, AIx, and ankle-brachial index [ABI]), functional near-infrared spectroscopy (fNIRS), EF performance tasks (Stroop and *N*-back tasks), and blood sampling were conducted 3 d before commencing the intervention and 24 h following its completion. All participants avoided eating 2 h before performing the tests. In addition, throughout the experimental period, all participants were requested to maintain a consistent dietary habit, refrain from alcohol and caffeine, and avoid dieting or binge eating behaviors (Fig. 1). According to Supplemental Table 1 (Supplemental Digital Content, <http://links.lww.com/MSS/D159>), there is no significant difference in the baseline of age, height, weight, BMI, resting heart rate, and resting blood pressure on HIIT, MICT, RE, and control group.

### Exercise Protocols

Participants in the exercise groups underwent exercise interventions in the Human Functional Training Room in the



**FIGURE 1—Experimental design. CON, control.**

Guangdong Provincial Key Laboratory of Physical Activity and Health Promotion, and the processes were supervised by 1–2 professional sports coaches. HIIT and MICT were conducted by individual on cycle ergometers, and RE was a group strength-training intervention led by professional coaches on Monday, Wednesday, and Friday from 7 to 9 PM. All interventions were strictly in accordance with the following exercise protocols: 1) HIIT group: started with a 2-min warm-up at 50% of  $\dot{V}O_{2max}$  intensity, followed by 1-min high-intensity exercise at 90% of  $\dot{V}O_{2max}$  interspersed with 1-min active recovery at 50% of  $\dot{V}O_{2max}$ , repeated for a total of 10 sets and ended with a 3-min cool-down at 50%  $\dot{V}O_{2max}$  intensity. 2) MICT group: started with a 2-min warm-up at 20% of  $\dot{V}O_{2max}$  intensity, followed by 35-min of cycling at 60% of  $\dot{V}O_{2max}$  intensity, and concluded with a 3-min cool-down at 20% of  $\dot{V}O_{2max}$  intensity. 3) RE group: performed six exercises for the upper and lower limbs and core muscles (dumbbell bench press, high pull-down, barbell squat, dumbbell pull-up, stability ball flat support, and V-pass stability ball). Each exercise was performed for 12 repetitions at 60% of the one-repetition maximum (1RM), with approximately 90-s rest intervals within each set and 3-min rest intervals between sets. Individuals in the control group maintained their usual SB (Supplemental Fig. 1, Supplemental Digital Content, <http://links.lww.com/MSS/D159>).

**Measurements**

**Participant characteristics and body composition.**

The following basic characteristics of all subjects were measured and recorded: sex, age, height, blood pressure, educational background, and personal medical history. Body weight, BMI, and body composition were measured using a body composition

analyzer (InBody370; Biospace, Seoul, Korea). Resting heart rate and blood pressure were measured using a portable sphygmomanometer (HEM-7301; Omron, Kyoto, Japan).

**$\dot{V}O_{2max}$  measurement.** A progressive exercise test was conducted on a cycle ergometer (Ergoselect 100; Ergoline, Windhagen, Germany). Participants started at 55 W at 60 rpm for 2 min and subsequently increased their workload by 15 W every 2 min until exhaustion. The fatigue of the subject was recorded at 2-min intervals, and heart rate and gas metabolic parameters were recorded continuously every 5 s using a respiratory metabolic device (Vyntus CPX, Jaeger, CareFusion, Hoechst, Germany). The subject’s  $\dot{V}O_{2max}$  and exercise load during the last minute of each phase were used to generate linear equations from standard curves to calculate the load values required to achieve 20%, 30%, 50%, 60%, and 90% of their  $\dot{V}O_{2max}$ .

**1RM measurement.** Our study employed a multi-RM test approach, involving the use of lighter loads to estimate the 1RM value. The estimated 1RM value was obtained using a 4RM to 8RM testing range that is commonly deemed a reasonable and accurate estimation method.

**FMD measurement.** The details for FMD measurement have been specifically depicted in our previous study (24). In brief, a noninvasive ultrasound detector (UNEXEF38G; UNEX, Nagoya, Japan) with a high-resolution Doppler ultrasound imaging and automatic edge tracking system was adopted to assess FMD.

Initially, following the acquisition of a sufficient brachial artery angiogram, the cuff was immobilized, and an ultrasound was conducted. Subsequently, the ultrasound apparatus remained in its position until the completion of the 1-min baseline scan, ensuring a complete and clear brachial artery image. The forearm cuff was then inflated to a pressure of 60 mm Hg

above the systolic pressure to induce ischemia stimulation. After 5 min, the cuff was deflated, and the resultant changes in peak responses and the internal diameters of the brachial artery were continuously recorded for 2 min. FMD and brachial artery mean shear rate (MSR) were calculated according to the following equations: FMD (%) = (maximal diameter – basal diameter)/basal diameter  $\times 100\%$ ; MSR ( $s^{-1}$ ) =  $(4 \times \text{mean blood flow velocity})/\text{mean basal diameter}$ .

**RHI and AIx measurements.** Peripheral microvascular endothelial function was evaluated with an EndoPat2000 machine (Itamar Medical Ltd., Caesarea, Israel). To implement the procedure, a BP cuff was worn on one upper arm, and the other arm was used as a control. Endo-PAT bio-sensors were placed on the index fingers of both arms. The occlusion of the brachial artery for 5 min was performed using a standard blood pressure cuff. The cuff was then released, and the blood flow surge that causes endothelium-dependent flow-mediated dilatation was measured, which manifest as RHI. AIx was also derived from the Endo-PAT software analysis. The aortic pressure wave is composed of a forward wave, created by ventricular contraction, and a reflected wave that returns to the aorta from the periphery. Augmentation pressure was calculated as the difference between the second and first systolic peaks. AIx was defined as the augmentation pressure expressed as a percentage of the aortic pulse pressure.

**PWV and ABI measurements.** The carotid–femoral PWV (cfPWV) and ABI were assessed using the oscillometric method with a Boso ABI-System 100 device (BOSCH & SOHN, Jungingen, Germany) that enables simultaneous systolic blood pressure measurement for all four extremities. Fluctuations in the individual measurement duration were reduced to a minimum through the simultaneous pump system and release speed regulation. After measurement, the data were transmitted to computer, and the values of cfPWV and ABI were automatically calculated.

**EF performance task measurement.** Participants arrived at the test room 10 min before the start of the test, sat in silence for 5 min, and then went into the room for the EF test. EF performance was determined using the Stroop and *N*-back tasks, which were written in E-prime 3.0 software, with a block design. It has been suggested that the reaction time is a more sensitive behavioral indicator of cognitive function than accuracy; in our study, reaction time was thus chosen to assess inhibitory control and working memory while ensuring over 90% accuracy.

**Stroop.** This task has a congruent condition, incongruent condition, and Stroop interference, where the Stroop interference effect is the incongruent condition outcome minus the congruent condition outcome. In the experiment, two rows of stimuli appeared on the screen, and the participants judged whether the colors of the top row matched the meanings of the bottom row, pressing the “F” key for incongruent and the “J” key for congruent.

**N-back.** The *N*-back task used an incremental memory load paradigm ( $N = 1,2,3$ ) to assess the working memory capacity, and the experimental stimuli used a total of 10 digits from 0 to 9. According to different levels of memory load,

the participants were asked to consistently compare the current digit with the digits of the previous *N* trials and not to make a keystroke response for the first *N* trials. The *N*-back cognitive load effect was calculated as the 3-back condition minus the 1-back condition.

**Cerebral Oxy-Hb level measurement.** Our study used a portable multichannel NIRSport near-infrared imaging system (NIRx Medical Technologies, LLC, Glen Head, NY) to monitor changes in prefrontal oxygenated hemoglobin concentration signals (Oxy-Hb) in real-time during a functional task. The device uses two NIR wavelengths, 760 and 850 nm, with eight light sources and seven detectors combined into 20 channels (CHs) at a sampling rate of 7.81 Hz. To further examine the effects of different exercises on the Oxy-Hb signal changes in each channel under different cognitive task conditions, 20 channels were classified into the following five brain regions: orbitofrontal area (OFA) (CH01 and CH02), frontopolar area (FPA) (CH03, CH04, CH05, CH08, CH09), pars triangularis Broca’s area (PTR) (CH13, CH15, CH16, CH17), left of dorsolateral prefrontal cortex (L-DLPFC) (CH06, CH07, CH12, CH18, CH19), and right of dorsolateral prefrontal cortex (R-DLPFC) (CH10, CH11, CH14, CH20).

**Biochemical factor measurements.** Fasting blood samples were collected in tubes with anticoagulant for plasma preparation by professional experts. Plasma was separated by centrifugation (3500 rpm for 10 min at 4°C) and stored in 1 mL aliquots at –80°C until further analysis. Circulating biomarkers in plasma (brain-derived neurotrophic factor (BDNF), insulin-like growth factor 1 (IGF-1), irisin, vascular endothelial growth factor (VEGF), and tumor necrosis factor  $\alpha$  (TNF- $\alpha$ )) were analyzed using ELISA kits (Cusabio, Wuhan, China) according to the manufacturer’s instructions.

## Statistical Analysis

The data were statistically analyzed using SPSS 22.0 and expressed as the mean  $\pm$  standard deviation (mean  $\pm$  SD). Statistical significance was determined for all indicators, matched-samples *t*-test was used for within-group comparisons, one-way ANOVA was used for between-group comparisons, and Bonferroni *post-hoc* test was used for simple effects analysis.

MATLAB was employed for preprocessing and motion artifact correction. At the individual level, a general linear model was used to detect the Oxy-Hb hemodynamic response, determine the Oxy-Hb of each channel of each subject under different conditions, and generate each channel’s beta value. The channels contained in the ROIs were averaged, and the mean value is the oxygen signal for that ROI.

Pearson correlation analysis was used to determine the correlations between tested indicators. The significance level for all statistical tests was  $P = 0.05$ . Regarding vascular function, similar trends existed for the left and right ABI, so only the results from the left-side test were used for correlation analyses. Previous studies suggest that the Stroop interference and cognitive load effect reflect the degree of improvement in inhibitory control and functional memory more than the other test components,

TABLE 1. Effects of 8 wk of different exercise on the body compositions of sedentary young individuals.

		HIIT	MICT	RE	CON
Weight (kg)	Pre	60.39 ± 7.39	57.65 ± 9.23	59.71 ± 9.06	62.52 ± 11.02
	Post	60.16 ± 6.36	56.32 ± 8.08	60.04 ± 9.55	63.45 ± 11.52
Fat (kg)	Pre	14.24 ± 2.03	13.56 ± 2.75	14.00 ± 2.37	14.01 ± 3.28
	Post	12.60 ± 2.42*, **	11.94 ± 3.68*, **	12.67 ± 2.56*	14.13 ± 3.53
SLM (kg)	Pre	45.03 ± 7.90	43.19 ± 9.6	47.06 ± 10.12	44.42 ± 8.06
	Post	45.29 ± 7.43	43.32 ± 9.25	48.41 ± 9.63*	44.20 ± 8.28
FFM (kg)	Pre	47.78 ± 8.26	45.39 ± 10.31	46.71 ± 9.08	45.26 ± 7.62
	Post	46.74 ± 8.80*	44.36 ± 9.93*	45.86 ± 9.19*	45.62 ± 8.22
SMM (kg)	Pre	26.70 ± 5.27	25.45 ± 6.20	26.71 ± 6.59	26.19 ± 5.26
	Post	26.90 ± 5.11	25.43 ± 6.69	28.04 ± 5.60*	26.09 ± 5.82
BMI (kg·m <sup>-2</sup> )	Pre	21.62 ± 2.35	21.03 ± 1.96	20.44 ± 2.06	22.34 ± 3.70
	Post	21.31 ± 2.14	20.41 ± 1.68	20.62 ± 1.74	22.65 ± 3.59
PBF (%)	Pre	21.46 ± 4.24	20.36 ± 3.76	20.08 ± 3.20	19.73 ± 5.85
	Post	20.08 ± 5.04*	18.36 ± 3.43*	19.74 ± 3.31	19.84 ± 5.34
Chest circumference (cm)	Pre	89.08 ± 5.86	86.75 ± 6.48	88.89 ± 6.57	89.61 ± 7.43
	Post	89.67 ± 5.42	86.31 ± 6.20	90.24 ± 5.87*	89.98 ± 9.03
Waist circumference (cm)	Pre	75.86 ± 5.85	74.29 ± 5.36	72.38 ± 3.49	79.15 ± 8.61
	Post	76.45 ± 4.11	73.9 ± 4.32	72.48 ± 4.36	78.54 ± 8.89
Hip circumference (cm)	Pre	92.93 ± 4.04	91.81 ± 4.24	90.39 ± 3.33	94.13 ± 6.07
	Post	92.84 ± 3.58	91.23 ± 3.65	90.79 ± 3.39	94.91 ± 5.89
Left arm circumference (cm)	Pre	28.14 ± 1.98	27.72 ± 2.19	26.97 ± 2.07	28.78 ± 3.1
	Post	28.3 ± 1.72	27.42 ± 1.94	27.1 ± 2.01	29.09 ± 3.24
Right arm circumference (cm)	Pre	28.49 ± 2.1	28.04 ± 2.21	27.37 ± 2.22	29.04 ± 3.07
	Post	28.61 ± 1.78	27.65 ± 1.95	27.36 ± 2.02	29.41 ± 3.2
Left thigh circumference (cm)	Pre	50.49 ± 2.97	49.81 ± 2.1	48.34 ± 2.21	51.24 ± 4.23
	Post	50.29 ± 2.84	49.47 ± 2.52	48.7 ± 2.19	51.86 ± 4.1
Right thigh circumference (cm)	Pre	50.71 ± 2.96	49.91 ± 2.66	48.37 ± 2.26	51.56 ± 4.84
	Post	50.38 ± 2.78	49.76 ± 2.26	48.76 ± 2.25	52.03 ± 4.26
WHR	Pre	0.82 ± 0.04	0.83 ± 0.04	0.83 ± 0.04	0.84 ± 0.05
	Post	0.81 ± 0.04	0.82 ± 0.03	0.83 ± 0.03	0.84 ± 0.04
Protein (kg)	Pre	9.53 ± 1.75	9.28 ± 1.93	9.73 ± 1.93	9.36 ± 1.73
	Post	9.58 ± 1.67	8.97 ± 2.03	9.96 ± 1.86	9.68 ± 2.02
BMR (kcal)	Pre	1458.13 ± 88.78	1453.73 ± 138.88	1443.50 ± 222.31	1450.56 ± 187.35
	Post	1482.00 ± 83.23*	1481.47 ± 140.10*	1463.06 ± 208.62	1444.31 ± 179.79

Values are the mean ± SD.

\* $P < 0.05$  versus pre-intervention.

\*\* $P < 0.05$  versus CON group.

CON, control; FFM, fat-free mass; PBF, percent body fat; SLM, soft lean mass; SMM, skeletal muscle mass; WHR, waist-hip ratio.

so only Stroop interference and cognitive load effect were used for correlation analyses in this study.

Mediation analysis was performed to understand the relationship between exercise training-related changes in endothelial function, mean share rate, EF performance, cerebrovascular hemodynamics, and plasma biomarkers. We used bootstrapping (5000 samples) to calculate bias-corrected 95% confidence intervals (CIs) of the explained associations using the PROCESS statistical package. The indirect effect of the mediation analysis was interpreted as significant if zero was not included in the 95% CI.

## RESULTS

### Anthropometric Measurements and Body Composition

As shown in Table 1, body fat mass and fat-free mass decreased significantly in all three intervention groups but not in the control group after 8 wk of intervention (all  $P < 0.05$ ). Notably, significant differences in body fat mass were specifically observed in the HIIT and MICT groups compared with the control group (both  $P < 0.05$ ). Moreover, compared with the baseline, 8 wk of HIIT and MICT but not RE intervention significantly reduced body fat percentages and significantly increased basal metabolic rates (BMR; all  $P < 0.05$ ), and

8 wk of RE significantly increased chest circumference, soft lean mass, and skeletal muscle mass (all  $P < 0.05$ ). No significant differences were found for body weight, BMI, waist-hip ratio, protein content, or waist, hip, arm, and thigh circumference across any of the groups after the 8-wk intervention.

### Endothelial Function

As shown in Table 2, compared with the baseline, resting diameters were not significantly different among all groups after 8 wk of intervention. However, FMD, MSR, and RHI significantly increased in all three intervention groups but not in the control group after 8 wk of intervention (all  $P < 0.05$ ), and peak diameter significantly increased in the HIIT group and MICT group after 8 wk of intervention ( $P < 0.05$ ). In addition, compared with the control group, there were significant differences in the changes of both FMD and peak diameter in HIIT and MICT groups (all  $P < 0.05$ ). Meanwhile, a significant difference in the change of RHI was observed solely between the HIIT group and the control group ( $P < 0.05$ ).

### Arterial Stiffness

Compared with the baseline, cfPWV significantly decreased in all three intervention groups after 8 wk of intervention (all  $P < 0.05$ ). Notably, 8 wk of HIIT and MICT but not

TABLE 2. Effects of 8 wk of different exercise on the endothelial function and arterial stiffness of sedentary young individuals.

		HIIT	MICT	RE	CON
Resting diameter (mm)	Pre	3.25 ± 0.41	3.40 ± 0.45	3.30 ± 0.71	3.55 ± 0.46
	Post	3.31 ± 0.42	3.40 ± 0.43	3.30 ± 0.59	3.46 ± 0.50
Peak diameter (mm)	Pre	3.60 ± 0.46	3.76 ± 0.48	3.66 ± 0.79	3.91 ± 0.51
	Post	3.77 ± 0.49*,**	3.92 ± 0.49*,**	3.69 ± 0.65	3.81 ± 0.54
FMD (%)	Pre	10.69 ± 0.76	10.98 ± 1.97	10.86 ± 0.71	10.31 ± 0.75
	Post	13.77 ± 1.37***,****	15.28 ± 0.85***,****	11.85 ± 1.62*	10.13 ± 1.03
MSR	Pre	2.89 ± 0.74	2.93 ± 1.08	2.90 ± 0.54	2.88 ± 0.74
	Post	3.76 ± 0.83*****	3.67 ± 0.87*	3.54 ± 1.00*	2.86 ± 0.95
RHI	Pre	1.31 ± 0.33	1.43 ± 0.35	1.41 ± 0.37	1.43 ± 0.25
	Post	2.05 ± 0.64*,**	1.67 ± 0.50*	1.83 ± 0.51*	1.31 ± 0.20
cfPWV (m·s <sup>-1</sup> )	Pre	6.05 ± 0.81	6.00 ± 0.48	6.07 ± 0.44	5.92 ± 0.65
	Post	5.49 ± 0.66***	5.62 ± 0.61*	5.65 ± 0.66*	5.78 ± 0.56
ABI L	Pre	1.05 ± 0.07	1.08 ± 0.07	1.06 ± 0.08	1.06 ± 0.08
	Post	1.06 ± 0.06	1.04 ± 0.09	1.07 ± 0.09	1.06 ± 0.07
ABI R	Pre	1.06 ± 0.06	1.07 ± 0.07	1.07 ± 0.07	1.08 ± 0.08
	Post	1.03 ± 0.06	1.05 ± 0.09	1.08 ± 0.09	1.07 ± 0.06
AIx (%)	Pre	15.64 ± 13.31	15.84 ± 2.50	16.17 ± 3.78	15.08 ± 2.61
	Post	13.31 ± 2.70***	14.21 ± 2.32*	15.33 ± 3.69	15.45 ± 4.45

Values are the mean ± SD.

\* $P < 0.05$  versus pre-intervention.

\*\* $P < 0.05$  versus CON group

\*\*\* $P < 0.01$  versus pre-intervention.

\*\*\*\* $P < 0.01$  versus CON group.

\*\*\*\*\* $P < 0.001$  versus pre-intervention.

CON, control; L, left; R, right.

RE significantly reduced AIx (both  $P < 0.05$ ). In contrast, ABI was not significantly different for any group after 8 wk of intervention (Table 2).

## EF Performance Tasks

**Stroop tasks.** Although no significant effect was observed on reaction time for the congruent task across all three groups compared with baseline, there was a significant reduction in reaction time for the incongruent task after 8 wk of both HIIT and MICT (both  $P < 0.05$ , Table 3). In addition, a significant decrease in reaction time for the Stroop interference was observed only in the HIIT group compared with the baseline ( $P < 0.05$ ).

**N-back tasks.** As shown in Table 3, there were no significant differences in the reaction time among all groups for the 1-back task and cognitive load effects after 8 wk of intervention. However, compared with the baseline, the reaction time for the 2-back task decreased significantly only in the HIIT group ( $P < 0.05$ ). The reaction time for the 3-back task also decreased significantly after 8 wk of both HIIT and MICT (both  $P < 0.05$ ).

## Changes in Cerebral Oxy-Hb Levels

**Cerebral Oxy-Hb levels during Stroop tasks.** Compared with the baseline, Oxy-Hb levels increased significantly in the FPA region after 8 wk of HIIT and MICT ( $P < 0.01$  and  $P < 0.05$ , respectively; Table 3). Compared with the baseline, significant changes in Oxy-Hb levels in the OFA region were observed only in the RE group, and significant changes in Oxy-Hb levels within the L-DLPFC and R-DLPFC regions were observed exclusively in the HIIT group (all  $P < 0.05$ ). In addition, a significant difference in the change of Oxy-Hb level within the FPA region was observed only between the control group and the HIIT group ( $P < 0.01$ ). However, there

were no significant differences in the Oxy-Hb levels in the PTR region among all groups after 8 wk of intervention (all  $P > 0.05$ ).

**Cerebral Oxy-Hb levels during N-back tasks.** As shown in Table 3, Oxy-Hb levels in the FPA region significantly increased after 8 wk of both HIIT and MICT compared with baseline (both  $P < 0.05$ ). Compared with the baseline, significant changes in Oxy-Hb levels in the L-DLPFC region were observed only in the HIIT group ( $P < 0.05$ ). However, there were no significant differences in the Oxy-Hb levels in the OFA, PTR, and R-DLPFC regions among all groups after 8 wk of intervention (all  $P > 0.05$ ).

## Plasma Biomarker Measurements

Compared with the baseline, circulating IGF-1 levels increased significantly in all three intervention groups, but not in the control group (all  $P < 0.05$ ). Moreover, 8 wk of both HIIT and MICT, but not RE, significantly increased circulating BDNF levels (both  $P < 0.05$ ). Circulating irisin levels increased significantly after 8 wk of both HIIT and RE, but not MICT (both  $P < 0.05$ ). However, TNF- $\alpha$  and VEGF levels were not significantly different among all groups (Table 4).

## Pearson's Correlation Analyses

**Correlation analyses of cardiovascular function variables.** Our correlation analyses showed that changes in FMD were positively correlated with changes in MSR and RHI after 8 wk of intervention, and changes in MSR were positively correlated with changes in RHI. Notably, changes in FMD were also positively correlated with changes in circulating BDNF levels after 8 wk of intervention. Changes in circulating IGF-1 levels were positively correlated with changes in

TABLE 3. Effects of 8 wk of different exercise interventions on the Stroop task, *N*-back task reaction time, and cerebral oxy-Hb levels of sedentary young individuals.

				HIIT	MICT	RE	CON	
Reaction time (ms)	Stroop	Congruent	Pre	774.01 ± 106.02	842.86 ± 108.12	800.35 ± 97.40	778.14 ± 141.26	
			Post	755.51 ± 107.46	783.98 ± 121.55	762.10 ± 128.13	804.51 ± 131.88	
		Incongruent	Pre	867.57 ± 112.63	952.02 ± 125.16	890.79 ± 138.24	885.17 ± 152.55	
			Post	777.95 ± 102.32*	846.42 ± 133.52*	811.37 ± 150.26	884.62 ± 158.92	
		Stroop interference	Pre	93.56 ± 82.45	109.16 ± 141.96	90.43 ± 114.96	107.03 ± 233.41	
			Post	22.44 ± 92.42*	62.44 ± 132.21	49.28 ± 160.58	80.11 ± 157.15	
	<i>N</i> -back	1-back	Pre	698.34 ± 109.33	715.72 ± 130.27	683.45 ± 111.28	706.50 ± 136.02	
			Post	641.01 ± 102.32	659.41 ± 114.59	649.25 ± 124.58	634.04 ± 130.14	
		2-back	Pre	876.54 ± 93.08	865.07 ± 123.22	864.97 ± 122.51	879.90 ± 116.21	
			Post	786.22 ± 124.54*	833.09 ± 141.84	846.96 ± 121.86	883.73 ± 123.95	
		3-back	Pre	888.29 ± 109.33	876.52 ± 130.27	883.75 ± 111.28	923.06 ± 137.37	
			Post	781.97 ± 104.55*	802.66 ± 114.59*	832.5 ± 124.58	897.70 ± 150.70	
	Cognitive load effects	Pre	189.95 ± 167.92	160.81 ± 163.68	200.30 ± 149.03	216.57 ± 169.79		
		Post	140.96 ± 147.27	143.26 ± 121.64	183.25 ± 167.96	254.66 ± 207.73		
Cerebral Oxy-Hb levels (10 <sup>-4</sup> mmol·L <sup>-1</sup> )	Stroop	OFA	Pre	0.99 ± 4.04	-0.12 ± 2.03	-1.38 ± 1.50	0.32 ± 3.04	
			Post	0.99 ± 2.45	0.43 ± 1.88	0.96 ± 1.53*	-1.20 ± 1.98	
		FPA	Pre	-1.28 ± 2.66	-0.04 ± 0.99	-0.82 ± 1.78	0.01 ± 2.44	
			Post	1.60 ± 1.68**,***	1.35 ± 1.70*	0.11 ± 2.0	-0.39 ± 2.81	
		PTR	Pre	-0.43 ± 3.65	0.03 ± 1.98	-0.28 ± 2.13	0.32 ± 1.72	
			Post	0.82 ± 2.49	1.07 ± 2.20	0.68 ± 1.92	0.32 ± 1.67	
		L-DLPFC	Pre	-0.86 ± 2.98	0.45 ± 1.98	-0.40 ± 3.62	1.58 ± 4.90	
			Post	1.19 ± 2.63*	-0.06 ± 2.00	3.28 ± 3.62	1.21 ± 3.70	
		R-DLPFC	Pre	-0.90 ± 2.49	-1.06 ± 2.62	-0.08 ± 1.68	-0.89 ± 2.00	
			Post	1.50 ± 2.46*	0.51 ± 3.20	0.45 ± 1.80	-1.96 ± 2.43	
		<i>N</i> -back	OFA	Pre	0.27 ± 1.75	-0.78 ± 3.46	0.18 ± 4.24	-1.23 ± 3.33
				Post	1.47 ± 2.70	0.15 ± 1.83	0.94 ± 2.34	0.18 ± 1.37
	FPA		Pre	-0.68 ± 1.15	-1.55 ± 2.33	0.79 ± 4.44	-0.53 ± 2.27	
			Post	0.15 ± 1.69*	0.58 ± 1.35*	0.78 ± 2.99	-0.49 ± 2.39	
	PTR		Pre	-0.16 ± 1.47	0.86 ± 2.28	-2.01 ± 3.37	-0.13 ± 2.04	
			Post	0.47 ± 3.74	1.24 ± 2.72	0.47 ± 2.68	-1.29 ± 3.37	
	L-DLPFC	Pre	0.16 ± 2.56	-0.32 ± 1.49	-0.36 ± 1.98	0.01 ± 2.12		
		Post	2.91 ± 4.49*	0.60 ± 2.26	0.72 ± 3.14	0.13 ± 2.61		
	R-DLPFC	Pre	-1.57 ± 2.48	-0.02 ± 1.33	-0.82 ± 1.98	-0.63 ± 2.98		
		Post	-0.11 ± 2.36	1.07 ± 2.73	0.58 ± 2.02	-1.74 ± 3.57		

Values are the mean ± SD.

\**P* < 0.05 versus pre-intervention.

\*\**P* < 0.01 versus pre-intervention.

\*\*\**P* < 0.01 versus CON group.

CON, control.

RHI and negatively correlated with changes in AIx after 8 wk of intervention (Fig. 2).

**Analyses of the correlations between cardiovascular function variables and cognitive function variables.**

Our correlation analyses showed that changes in FMD were positively correlated with changes in Oxy-Hb in the R-DLPFC region during the Stroop task (Fig. 3F) and negatively correlated with changes in *N*-back load effect reaction time (Fig. 3B) after 8 wk of intervention. Interestingly, changes in BDNF levels, which were positively correlated with changes in FMD, exhibited similar positive correlation with changes in Oxy-Hb levels in the R-DLPFC region during Stroop tasks (Fig. 3G) and negative

correlation with changes in reaction time during *N*-back cognitive load effects and Stroop interference (Fig. 3C). These results indicate that BDNF is a pivotal biomarker that plays an important role in exercise-improved endothelial function and thus cognitive function. Moreover, changes in cfPWV were negatively correlated with changes in Oxy-Hb in the FPA region during Stroop tasks (Fig. 3E) and positively correlated with changes in Stroop interference reaction time (Fig. 3D). Changes in irisin were positively correlated with changes in Oxy-Hb in the FPA region during Stroop tasks (Fig. 3A).

**Mediation analyses.** Based on the aforementioned correlation analysis results, we further examined whether changes

TABLE 4. Effects of 8 wk of different exercise interventions on plasma biomarkers of sedentary individuals.

		HIIT	MICT	RE	CON
BDNF (pg·mL <sup>-1</sup> )	Pre	453.60 ± 58.17	430.64 ± 41.82	444.64 ± 93.54	420.33 ± 41.83
	Post	476.68 ± 73.90*	458.53 ± 55.96*	466.18 ± 77.91	429.81 ± 39.70
VEGF (pg·mL <sup>-1</sup> )	Pre	131.02 ± 10.66	130.44 ± 18.32	130.86 ± 20.70	129.23 ± 18.84
	Post	136.80 ± 30.09	133.82 ± 22.90	133.33 ± 20.42	123.75 ± 20.85
IGF-1 (ng·mL <sup>-1</sup> )	Pre	161.95 ± 11.75	162.65 ± 12.49	164.42 ± 13.62	159.65 ± 11.15
	Post	169.63 ± 10.92*	167.52 ± 13.51*	171.65 ± 10.09*	158.73 ± 13.96
Irisin (ng·mL <sup>-1</sup> )	Pre	70.03 ± 11.24	71.62 ± 9.29	70.96 ± 7.40	69.27 ± 10.93
	Post	76.25 ± 12.90*	74.42 ± 9.33	77.63 ± 11.06*	67.21 ± 12.35
TNF-α (pg·mL <sup>-1</sup> )	Pre	46.75 ± 8.73	46.58 ± 9.84	47.59 ± 11.08	46.99 ± 10.64
	Post	45.99 ± 7.99	44.66 ± 8.82	45.16 ± 10.28	46.76 ± 9.36*

Values are the mean ± SD.

\**P* < 0.05 versus pre-intervention.

CON, control.

$\Delta$ FMD		0.577*	0.376*	0.061	-0.179	0.580*	0.128	0.130	-0.077	0.090	0.147
$\Delta$ MSR			0.356*	-0.100	-0.080	0.182	0.168	0.115	-0.013	-0.102	0.153
$\Delta$ RHI				-0.097	-0.122	0.071	0.118	-0.134	0.072	0.180	0.261*
$\Delta$ Aix					0.017	0.024	0.111	-0.050	-0.096	-0.114	-0.319*
$\Delta$ cfPWV						-0.127	-0.142	0.112	-0.175	-0.013	0.027
$\Delta$ BDNF							0.032	0.124	0.024	0.145	0.119
$\Delta$ ABI-L								0.112	-0.123	0.069	-0.149
$\Delta$ TNF- $\alpha$									-0.086	-0.190	0.117
$\Delta$ irisin										-0.148	0.188
$\Delta$ VEGF											0.003
	$\Delta$ FMD	$\Delta$ MSR	$\Delta$ RHI	$\Delta$ Aix	$\Delta$ cfPWV	$\Delta$ BDNF	$\Delta$ ABI-L	$\Delta$ TNF- $\alpha$	$\Delta$ irisin	$\Delta$ VEGF	$\Delta$ IGF-1

FIGURE 2—Correlation analysis of vascular function variables. Values are the Pearson's correlation coefficients. \* $P < 0.05$ .

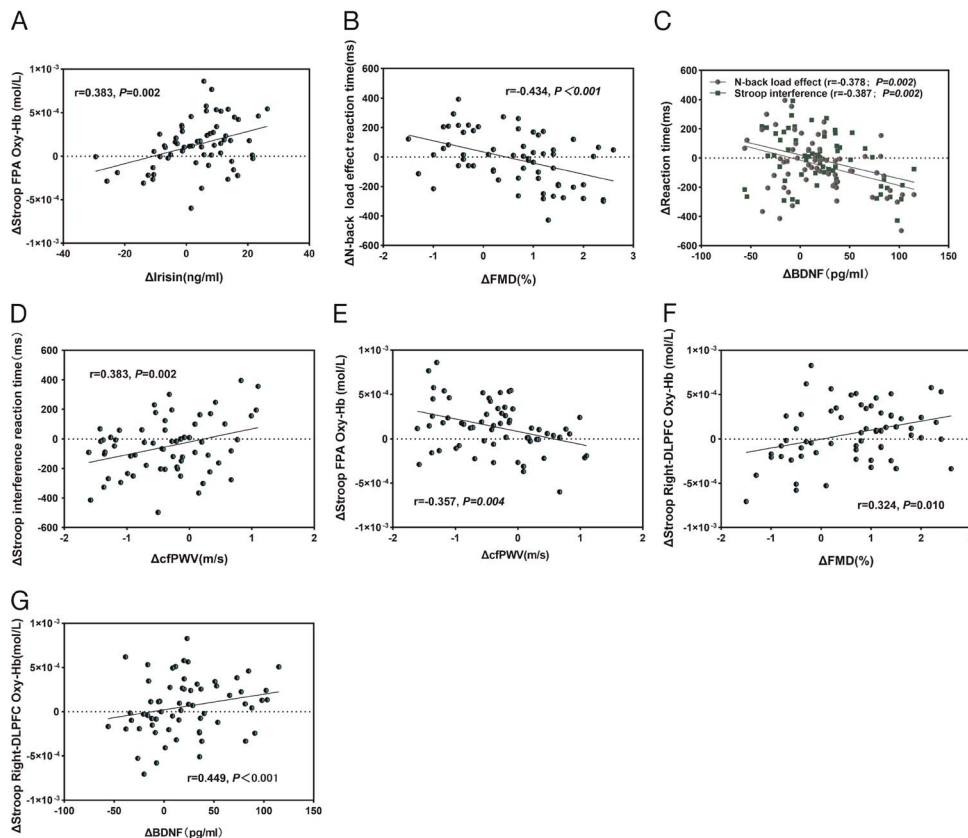
in the BDNF mediate the associations between changes in MSR and FMD (Fig. 4A), and whether changes in the FMD mediate the associations between changes in BDNF and *N*-back cognitive load effect (Fig. 4B). The results suggested that MSR indirectly influences FMD through BDNF. In addition, BDNF indirectly influences the *N*-back cognitive load effect through FMD.

## DISCUSSION

The present study aimed to determine the effects and underlying mechanisms of 8 wk of HIIT, MICT, and RE on body composition, cardiovascular function, and EF among sedentary young individuals. The main findings of this study were as follows: 1) Both HIIT and MICT interventions over 8 wk significantly reduced body fat percentage and increased BMR, whereas RE significantly increased skeletal muscle mass and chest muscle circumference. 2) Eight weeks of HIIT, MICT, and RE effectively improved macro- and microvascular endothelial function while reducing arterial stiffness in sedentary young individuals. Furthermore, exercise-induced increase in BDNF level was correlated with enhanced macrovascular endothelial function, whereas increase in IGF-1 level was associated with enhanced microvascular endothelial function and reduced arterial stiffness. 3) Both HIIT and MICT, but not RE, efficiently enhanced Oxy-Hb level in certain brain regions, such as the FPA and DLPFC, leading to the improvement in EF performance. Exercise-induced increase in Oxy-Hb level and EF performance

were correlated with enhanced BDNF level and endothelial function and reduced arterial stiffness.

Enhancing body composition through exercise is widely accepted by both researchers and fitness enthusiasts (25). Exercise triggers metabolic adaptations that promote fat loss by altering metabolic pathways within the body, such as reducing fatty acid synthase and increasing fat oxidation (26). Although the present study revealed no significant differences between HIIT and MICT in reducing body fat and increasing BMR, the fact that HIIT provided similar benefits to MICT in a shorter period may be due to the following reasons: 1) The greater involvement of muscle observed during HIIT led to increased blood flow, which may play a role in increasing the kinetics of fat oxidation, ultimately leading to a significant reduction in body fat content over time. 2) Even though the caloric expenditure during HIIT and MICT is equivalent, HIIT-induced body fat reduction is likely due to an increase in post-exercise oxygen consumption. 3) HIIT significantly increased maximal oxygen uptake and mitochondrial enzyme activity, leading to increased fat oxidation utilization and thus reduced body fat (27,28). Interestingly, although RE did not improve BMR in this study, it did reduce body fat of participants, possibly due to the use of low-intensity RE ( $\leq 60\%$  1RM). The primary objective of using this method was to enhance muscular endurance without consuming excessive time, thereby increasing the involvement of fat energy supply and reducing body fat content (29). Consistent with the findings of the present study, de Lima et al. reported that 28 sedentary adult women significantly reduced their body fat content after



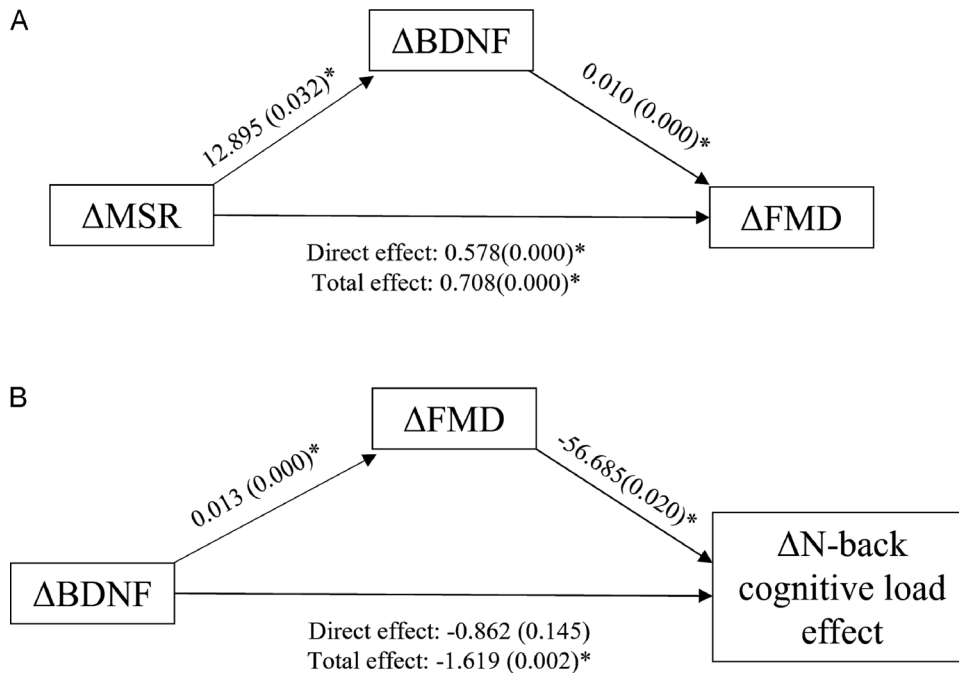
**FIGURE 3**—Analyses of the correlations between vascular function variables and cognitive function variables. Pearson analyses showing a correlation between changes in irisin and changes in the Oxy-Hb in FPA region during Stroop tasks (A), a correlation between changes in FMD and *N*-back load effect reaction time (B), a correlation between changes in BDNF and changes in reaction time during Stroop interference and *N*-back cognitive load effects (C), a correlation between changes in cfPWV and Stroop interference reaction time (D), a correlation between changes in cfPWV and changes in Oxy-Hb in the FPA region during Stroop tasks (E), a correlation between changes in FMD and changes in Oxy-Hb in the R-DLPFC region during Stroop tasks (F), and a correlation between changes in BDNF and changes in Oxy-Hb in the R-DLPFC region during Stroop tasks (G).

12 wk of high-frequency muscular endurance resistance training (30). Additionally, RE, but not HIIT or MICT, significantly increased soft lean mass and skeletal muscle mass without body weight changes.

Endothelial dysfunction is considered as an important early stage in the pathophysiology of CVD. FMD assesses macrovascular endothelial function by targeting the brachial artery, while RHI assesses endothelial function in peripheral microvessel (31). Despite many studies supporting the role of exercise in improving endothelial function, the effects of different exercise types on endothelial function in sedentary young individuals remain unclear. The present study showed that HIIT, MICT, and RE improved FMD, RHI, and MSR in sedentary young individuals, suggesting that these forms of exercise could improve artery shear stress and endothelial function in both macro- and microvessels. Interestingly, a positive correlation was observed between RHI and FMD, and both RHI and FMD were positively correlated with MSR. Previous studies have demonstrated that exercise-induced changes in hemodynamics are one of the primary mechanisms through which exercise enhances vascular endothelial function (31,32). Prolonged SB results in endothelial dysfunction by reducing artery shear stress, emphasizing its importance in maintaining

normal vascular endothelial function (4). Our study demonstrated that exercise increased artery shear stress, which was associated with improved endothelial function in both macro- and microvessels in sedentary young individuals.

Circulating biomarkers play a pivotal role in mediating the benefits of exercise on vascular function. IGF-1 has no metabolic or growth-promoting effects on large-vessel endothelial cells, but it does stimulate glucose accumulation and cellular DNA synthesis in dermal microvessels and the human retina (34). Consistent with previous studies, we found an association between IGF-1 level and RHI, but not FMD. Recently, BDNF has emerged as a key regulator of cardiovascular function. For example, exercise has been shown to reduce resting heart rate and increase heart rate variability by increasing BDNF level, thus enhancing cardiac parasympathetic activity (35). Interestingly, our study found a positive correlation between BDNF level and FMD post-exercise. Although a direct relationship between changes in BDNF and FMD in response to exercise has not been conclusively established, an *ex vivo* experiment reported an aortic vasodilation while the aorta was exposed to  $10^8 \text{ mol}\cdot\text{L}^{-1}$  BDNF. This marks the first evidence of BDNF directly acting on the aorta and inducing vasodilation (35). BDNF also promotes aortic endothelial cell



**FIGURE 4**—Mediation analyses. Mediation models to assess the relationship between exercise-induced changes in MSR and FMD with BDNF as a mediator (A), and the relationship between changes in BDNF and *N*-back cognitive load effect with FMD as a mediator (B). Data are unstandardized regression coefficient (*P* value).

differentiation by increasing microRNA-214 expression and inhibiting enhancer of zeste homolog 2 (EZH2) expression during embryonic stem cell differentiation, thereby increasing the mRNA expression of endothelial nitric oxide synthase (eNOS) (36). In addition, Prasain et al. reported that neuropilin-1 mediates enhanced VEGF receptor 2 (VEGF-R2) signaling through VEGF to differentiate endothelial cells (37). Related studies have also found that BDNF increases neuropilin-1 through microRNA-214 (36), VEGF-R2, and p130Cas, suggesting that BDNF may support endothelial cell generation and a stable arterial endothelial phenotype (37). Subsequently, BDNF may stimulate differentiation of aortic endothelial cells, thus improving endothelial function. However, BDNF may have a bidirectional role in endothelial function. Its stable function within endothelial cells may ensure the secretion and maintenance of peripheral BDNF concentration. Exercise has been shown to increase BDNF staining in aortic endothelial cells, and mature BDNF secretion by endothelial cells significantly rises in a high shear stress environment simulated by exercise. These findings suggest that elevated peripheral BDNF level following exercise may mainly originate from aortic endothelial cells upon increased blood flow shear stress (35). Interestingly, our mediation analysis showed that the positive association between exercise-induced changes in MSR and FMD was mediated by the increase in BDNF level. Taken together, the improvement of FMD by HIIT and MICT in sedentary young individuals may be attributed to the increase in MSR and circulating BDNF level. Because RE did not increase BDNF level in our study, the improvement of FMD induced by RE may be associated with MSR. Similarly, the enhancement of RHI by HIIT, MICT, and RE in sedentary

young individuals correlates with the exercise-induced increase in MSR, along with the augmentation of circulating IGF-1 level.

PWV and AIX are independent risk factors for predicting CVD and are commonly used indicators to assess arterial stiffness (5). Aerobic exercise effectively mitigates arterial stiffness, whereas RE increases the risk of arterial stiffness (38). In the present study, HIIT and MICT reduced cfPWV among sedentary young individuals. Our finding is similar to previous animal studies showing that HIIT and MICT increased aortic eNOS, Akt phosphorylation, and plasma NO<sub>x</sub> levels, as well as a negative correlation between aortic PWV and eNOS phosphorylation and plasma NO<sub>x</sub> levels (39). Human studies have similarly uncovered a negative correlation between cfPWV and NO<sub>x</sub> levels, suggesting that HIIT and MICT may reduce cfPWV by increasing aortic NO bioavailability (39). Similar to the effect of RE on endothelial function, low-intensity ( $\leq 60\%$  1RM) RE led to a decrease in arterial stiffness (evidenced by reduced cfPWV) in the present study. Meta-regression results from previous studies have demonstrated a correlation between RE intensity and PWV changes, indicating that, although high-intensity RE ( $>75\%$  1RM) did not significantly improve PWV, low-intensity RE significantly reduced PWV in young individuals (40). Transient increases in inflammation and sympathetic activation following high-intensity RE may contribute to a temporary increase in arterial stiffness. However, arterial compliance fostered by low-intensity RE may reduce arterial stiffness by effectively promoting NO bioavailability and stimulating angiogenic factor responses, including HIF-1 and EPO (41). Furthermore, HIIT and MICT, but not RE, displayed improvement in AIX, possibly due to AIX's greater sensitivity to aerobic exercise. HIIT

was more effective than MICT in improving AIx in healthy individuals, possibly due to the alternating high-low intensity exercise patterns of HIIT stimulating blood vessels to produce more NO (42). However, in our study, HIIT and MICT had comparable effects on improving AIx in sedentary young individuals. RE did not significantly decrease AIx, which was consistent with a previous study reporting that neither high- nor low-intensity RE had a significant effect on AIx (43). In addition, our study showed a significant negative correlation between IGF-1 level with AIx. Circulating IGF-1 level is inversely related to ultrasound measures of atherosclerosis, as well as the risk of ischemic heart disease, stroke, and coronary events, and cardiovascular mortality (44). In a study involving postmenopausal women, both IGF-1 level and arterial stiffness improved following exercise intervention. Remarkably, a strong correlation was found between changes in IGF-1 level and urinary NOx, suggesting that IGF-1–stimulated NO production may play a critical role in improving arterial stiffness post-exercise (45). Therefore, the observed improvement in AIx following exercise intervention in the present study may be related to the rise in IGF-1 level post-exercise.

Inhibitory control is central to EF, which enables the brain to filter out irrelevant or disturbing information and enables individuals to complete tasks accurately and achieve optimal results. However, the effects of different types of exercise on inhibitory control are still not fully understood. Smiley-Oyen et al. found that 10 months of aerobic exercise, but not RE, significantly improved performance in the Stroop incongruent task, suggesting that aerobic exercise may have a greater impact on brain activation (46). Consistent with this previous study, our study demonstrated that HIIT significantly decreased the reaction time for Stroop interference and incongruent tasks, whereas MICT significantly reduced the reaction time for Stroop incongruent tasks. Conversely, RE showed no significant effects on the reaction time for Stroop cognitive performance tasks, suggesting that sedentary young individuals may improve their ability to make judgments in complex situations through HIIT and MICT interventions, but not RE. Moreover, we observed significant enhancements in blood oxygen level in the FPA and DLPFC brain regions following HIIT intervention, whereas MICT significantly increased blood oxygen level only in the FPA region. Several studies have shown the crucial role of the FPA and DLPFC regions in regulating inhibitory control. Kujach et al. found that acute HIIT improved cognitive performance by reducing the reaction time for Stroop interference tasks and significantly activating the L-DLPFC region during Stroop tasks in young people (47). In addition, Byun et al. showed that improved Stroop interference induced by MICT was associated with the synchronized activation of the L-DLPFC and FPA regions (48). The mechanisms underlying exercise-induced improvements in inhibitory control in sedentary young individuals warrant further investigation. Plasma biomarkers may indirectly affect EF by modulating brain region activation. Of the relevant biomarkers, BDNF has been extensively studied for its important regulatory role in the neural mechanisms underlying cognitive

improvement (49). Correlational analyses in our study showed that increased BDNF level was significantly positively correlated with the enhanced blood oxygen level of the R-DLPFC region, as well as improved Stroop performance after exercise. As mentioned earlier, circulating BDNF levels increased following 8 wk of HIIT and MICT interventions, but not RE. Therefore, the increased BDNF levels induced by HIIT and MICT interventions appear to be involved in the improvements in brain blood oxygen level and inhibitory control.

Working memory stands out as a primary subfunction of EF, and the *N*-back task is a classic experimental paradigm for assessing working memory within EF (50). Our study revealed that HIIT significantly reduced the reaction time in 2-back and 3-back tasks, whereas MICT significantly reduced the reaction time in 2-back tasks. In contrast, RE had no significant effects on cognitive performance in these tasks, indicating that HIIT and MICT are more effective methods for improving working memory. In line with the findings from the inhibitory control experiment, our fNIRS results indicated that HIIT significantly increased blood oxygen level in FPA and L-DLPFC regions, whereas MICT significantly increased blood oxygen level in the FPA region. Conversely, RE had no significant effect on blood oxygen level in any brain regions. Therefore, HIIT and MICT are also effective in improving working memory by enhancing blood oxygen level in FPA and L-DLPFC regions. Importantly, our results showed a significant correlation between BDNF levels and working memory performance, indicating the critical role of BDNF in improving working memory performance through HIIT and MICT interventions. Furthermore, our mediation analysis showed that the positive association between exercise-induced changes in BDNF level and working memory performance was mediated by the increase in FMD. These results indicate that BDNF-induced cognitive performance improvement is likely mediated by increased endothelial function post-exercise.

Variations in cognitive domains due to distinct cardiovascular function may arise from differences in cerebrovascular hemodynamic changes in certain brain regions (51). Recent research has revealed that diminished arterial flexibility and endothelial dysfunction coincide with reductions in CBF. Elevated PWV increases the beat-to-beat energy of the heart's blood supply to the brain, hindering the adaptive remodeling of the cerebral vasculature and leading to reduced CBF, ultimately resulting in brain tissue damage and cognitive dysfunction (52). Endothelial cells constitute the brain–blood barrier and regulate CBF and control plasma permeability. A reduction in FMD could be associated with endothelial dysfunction within the brain–blood barrier, impairing neurovascular coupling due to the correlation between cardiovascular and cerebrovascular hemodynamics (51). Consistent with the present study, a 1-yr aerobic exercise intervention study in middle-aged and older adults showed that a decrease in carotid artery stiffness after aerobic exercise was associated with an increase in CBF and a decrease in cerebral vascular resistance (53). Therefore, our findings indicate that exercise-improved cardiovascular function may improve CBF and reduce cerebrovascular resistance in sedentary young individuals,

contributing to the increase in brain blood oxygen level and thus improving EF performance. Taken together, the present study provides a novel insight into the interplay between exercise-enhanced cardiovascular health and cognitive improvement, highlighting that the improvements in cardiovascular function following exercise training is pivotal in improving cognitive function.

**Limitations.** The present study offers valuable evidence regarding the correlation between improvements in cardiovascular function and improvements in cognitive function through exercise. However, further studies are warranted to examine the intrinsic link between cardiovascular function and cognitive function following various forms of exercise. Such endeavors would provide novel insights into the enhancements of cardiovascular and cognitive function facilitated by exercise interventions among healthy sedentary adults. Additionally, our study focused solely on evaluating EF through inhibitory control and working memory. Further research is required to explore the effect of different exercise modalities on the cognitive flexibility of healthy sedentary adults. Due to the small sample size, subgroup analyses based on gender were not feasible. Furthermore, our study only included healthy sedentary young adults, limiting the practical application of the findings to other populations. Future research should employ larger sample sizes and examine the effects of diverse exercise regimens on cardiovascular and cognitive function in other populations.

## CONCLUSIONS

In conclusion, our study demonstrated that 8 wk of HIIT, MICT, and RE effectively improved body composition, endothelial function in both macro- and microvessels, and arterial stiffness among sedentary young individuals. However, HIIT

and MICT, but not RE, notably increased blood oxygen level in the FPA and DLPFC brain regions and improved EF performance. Due to the efficiency and time-saving features of HIIT, the present study highlights HIIT as an effective exercise prescription for promoting vascular function and EF in sedentary young individuals. Importantly, the observed improvements in cardiovascular function following exercise training are pivotal in improving cognitive function. The mechanisms underlying this improvement involve increased shear rates and circulating levels of biomarkers such as BDNF and IGF-1.

The data that support the findings of this study are available on request from the corresponding author, Junhao Huang, upon reasonable request. The results of present study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The results of present study do not constitute endorsement by the American College of Sports Medicine. This work was supported by Guangdong Provincial Key Laboratory of Physical Activity and Health Promotion, Guangzhou Sport University. We also thank our colleagues for their help in completing this study, and finally, we thank the 63 participants who contributed to this study. This study is supported by the Guangdong Basic and Applied Basic Research Foundation (No. 2023A1515012011), the Guangdong Scientific Research Platform and Projects for the Higher-educational Institution (2023ZDZX2033), the Scientific Research Project of Sports Bureau of Guangdong Province (GDSS2022N012), the Science and Technology Innovation Project of the General Administration of Sport of China, the Open Fund of the Guangdong Provincial Key Laboratory of Physical Activity and Health Promotion (2021B1212040014), and the Macao Science and Technology Development Fund (002/2023/ALC). There is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

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