J. Electrical Systems 20-10s (2024):2096-2106

[1]Wang Wenping

[2*]Soh Kim Geok

[3]Mohd Rozilee Wazir Norjali Wazir

Effects of High-Intensity Interval Training on Cardiopulmonary Fitness and Blood Pressure of Obese Adolescent Girls in China

Abstract: - Objective: The objective of this study is to evaluate the effects of 12 weeks high-intensity interval training(HIIT) on the cardiopulmonary fitness (CPF)and blood pressure (BP)of obese adolescent girls in China. Methodology: This was a single-center, randomized, repeated-measures controlled trial (RCT), 44 girls were randomized into 1 interventional groups (HIIT group) or 1 control group (no training). In the HIIT group, set 100% MAS as the load intensity, and 50% MAS as interval intensity. A 15-second running (intensity of 100% MAS), followed by a 15-second walking (intensity of 50% MAS), which was regarded as 1 bout, each set includes 8 bouts, 4 sets each time, 3 minutes' rest between sets, 25 minutes of interval training time, plus warm-up and cooling time, the total training time was 35 minutes. Intervention period is 12 weeks; the frequency was three times a week. In the dependent variable of this study, there were 5 indicators, including body weight(BW), maximum oxygen uptake (VO2max), resting heart rate (HRrest), systolic blood pressure (SBP), and diastolic blood pressure (DBP). All dependent variables were measured at baseline, 6th weeks and 12th week. To examine the effect of the intervention on the outcomes of interest, Generalized Estimating Equation (GEE) was used. Results: 39 girls completed the 12-week intervention. 19 in the HIIT group and 20 in the control group. Results of GEE showed BW, HRrest, SBP and DBP in the HIIT group decreased and VO2max increased statistically over time. Conclusion: 12 weeks HIIT can improve cardiopulmonary fitness and blood pressure of obese adolescent girls in China.

Keywords: Childhood and adolescent obesity; High intensity interval training; Cardiovascular Health.

1 Introduction

The 2015 Global Burden of Disease Study showed that China has the largest number of obese children (Mathers, 2016). The Institute of Child Health at Peking University analyzed data from seven national student physical health surveys and showed that the obesity detection rate among Chinese students aged 7 to 18 has increased from 0.1% in 1985 to 9.6% in 2019, an increase of 75.6 times. Further polynomial regression models show that by 2030, the obesity prevalence may rise to 15.1% (Dong et al., 2023). The significant occurrence of obesity is an essential component that contributes to the suboptimal cardiovascular health status of school-aged children and adolescents in China (Wang et al., 2022). Currently, only 1.7% of children and adolescents aged seven to 17 meet the ideal cardiovascular health indexes (seven items). The number of girls (1.6%) is lower than that of boys (1.9%) (Zhu et al., 2022). Moreover, the crude prevalence of hypertension in primary and secondary school students in China is 9.74% (Yang et al., 2022), which is much higher than the global prevalence of childhood hypertension (4.0%)

[1] Department of Physical Education, Faculty of Educational Studies, University Putra Malaysia, Seri Kembangan, Malaysia.,

[*]Department of Sports Studies, Faculty of Educational Studies, University Putra Malaysia, Seri Kembangan, Malaysia.

[*]Email: correspondence: kims@upm.edu.my

(Song et al., 2019; Zhu et al., 2022). Notably, compared to children who are fit or thin (5.0%), the prevalence of hypertension in obese children (34.1%) was 7:1 (Yang et al., 2022). All of these remind us that it is urgent to improve the cardiovascular health (CVH) of obese children in China.

To avoid the side effects of dieting and medication on the physical and mental health development of children and adolescents, physical activity is considered the best strategy to help them control their weight and improve cardiovascular health. Currently, the most popular protocol in the field of weight control is high-intensity interval training (HIIT), which has jumped from a training tool for middle-distance runners more than 100 years ago (Atakan et al., 2021) to the top of global fitness trend surveys for 2014 and 2018 (Thompson, 2023). Systematic literature reviews and meta-analysis conclusions have confirmed that HIIT is effective in improving cardiopulmonary fitness (CPF) and blood pressure (BP) in obese adults. However, it is uncertain whether this conclusion is applicable to school-age children and adolescents. Although there are related studies on HIIT intervention in obese children and adolescents, there is a lack of experimental studies on HIIT intervention only in obese girls. Therefore, the general research objective of this study is to examine the effects of HIIT on cardiopulmonary fitness and blood pressure in Chinese adolescent girls and explore a new exercise therapy for improving cardiovascular health for them.

2 Methods

2.1 Study design

Using stratified sampling according to the severity of obesity, this single-center, randomised, repeated-measures controlled trial (RCT) randomly assigned participants who satisfied the inclusion criteria to one of two groups: the HIIT group, which was the intervention group, or the CONT group, which was the control group. Set the interval intensity to 50% MAS and the HIIT load intensity to 100% MAS in the HIIT Group. Each set consists of 8 bouts, 4 sets each, with 3 minutes of rest in between. The total training time is 35 minutes, which includes warm-up and cool-down periods in addition to the 25 minutes of interval training. A bout consists of 15 seconds of running (at 100% MAS) and 15 seconds of walking (at 50% MAS). The outcome markers were measured at baseline, the 6th week, and the last week of the intervention. The intervention was conducted three times a week for a total of 12 weeks.

2.2 Sample Size

The sample power was calculated in the software G*Power (Version 3.1 for Windows, Franz Faul, Germany), using the ANOVA test of repeated measures, within-between interaction (Leite et al., 2022), which was attributed power of 0.80, α of 0.05, ES of 0.22 (Batacan et al., 2017). An estimated sample size of 36 participants was seen. To consider the loss of samples and expand the total sample size by 20% to 44 persons. There are 2 groups in this study, 22 people in each group should be recruited to participate. Before enrollment, each participant and their parents signed an informed consent form. This study included specific criteria to determine which people were included and excluded.

Inclusion criteria:

(1) Female individuals who are currently enrolled in middle school or are eligible to enrol in middle school.

(2) The individual's BMI indicates obesity based on age and gender criteria.

(3) Refraining from using medicine that could potentially have an adverse effect on the trial protocol, such as heart problems, hypertension, and diabetes.

(4) There are no restrictions or limitations to engaging in physical exercise.

(5) The individual does not possess any distinctive athletic interests, such as swimming, football, basketball, or skipping, and has not engaged in any consistent sports training for the past two years.

Exclusion criteria

(1) Individuals with severe chronic conditions such as cardiovascular, neurological, pulmonary, renal, and motor system disorders.

(2) Individuals with a documented psychiatric disorder.

(3) The informed consent form was not signed by either the individual, the guardian, or both.

2.3 Measurement and Instrument

2.3.1 Dependent Variables

There were 5 indicators involved in this study: body weight (BW), maximum oxygen uptake (VO_2max), resting heart rate (HRrest), systolic blood pressure (SBP), and diastolic blood pressure (DBP). VO2max was measured using the 20-metre Shuttle Run Test (20-mSRT) (Léger et al., 1988; Mahar et al., 2011; Lemos & Gallagher, 2017). Resting heart rate (HRrest) is recorded for six minutes; the result is the average value of the last three minutes (Li et al., 2019; Gonzales et al., 2023). Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured three times with an interval of two minutes each time, and the average of the three measurements was taken (Pickering et al., 2005; Wingfield et al., 2002).

2.3.2 Covariates

Habitual physical activity (HHA) and daily dietary intake (DDI) were the main potential covariates in this study. Referring to the experience of other researchers, in this experiment, participants were required to try their best to maintain HHA and DDI throughout the intervention period. Detailed, 3-day records (2 weekdays and 1 weekend day) of weighed food and beverage intake are collected from each participant at baseline, 4^{th} week, 8^{th} week and 12^{th} week. Energy intake and diet composition(Casperson et al., 2015) were analyzed by an experienced dietitian using a food diary (ESHA Food Processor SQL version 10.7). Participants were also required to complete the Chinese version of Physical Activity Questionnaire for Older Children (PAQ-C)(J. J. Wang et al., 2016; Erdim et al., 2019). A pedometer (Tanita PD-637, Tokyo, Japan) was also required to be worn one week out of every four weeks. Experimenters collected PAQ-C scores and pedometer data at baseline, fourth, eighth and twelfth weeks.

2.4 Statistical Analysis

Data analysis statistically was done using SPSS27.0 (SPSS Inc., Chicago, IL, USA). Descriptive characteristics were presented as M ± SD. Categorical data was summarised as frequency and percentage. To compare baseline groups, t-test was employed for continuous data and chi-square for categorical variables. Shapiro–Wilk assessed data distribution normality. To assess variance homogeneity, Levene's test was done. The generalised estimating equation (GEE) was employed to assess intervention effects on outcomes. Test results were two-tailed, $P < 0.05$ was considered significant. Analysis of covariance (ANCOVA) was used to determine the impact of habitual physical activity and nutritional intake on experimental results when the group × time interaction was significant.

3 Results

44 people completed all components of the baseline test, but only 39 girls ended up completing the 12-week experiment, with a retention rate of 88.6%. 5 girls failed to complete the training program due to personal reasons, including 3 in the HIIT group and 2 in the CONT group, their data were therefore excluded from all analyses other than baseline.

3.1 Socio-Demographic Characteristics of Participants

The demographic characteristics of all participants before the intervention was shown in Table 1. The results of the chi-square test show there were no baseline differences in socio-demographic characteristics of participants between HIIT group and CONT group ($p > 0.5$). Therefore, these variables were considered as covariates for the all analysis to remove their probable effect on research variables.

Table 1 Socio-Demographic Characteristics of Participants

Variables	HIIT (N=22)		MICT (N=22)		χ2	p
	n	%	n	%		
Age (years)					0.778	0.678
12	5	22.7	7	31.8		
13	9	40.9	6	27.3		
14	8	36.4	9	40.9		
Ethnicity					0.613	0.591
Han	20	90.9	22	100.0		
Minority	2	9.1	0	0.0		
Degree of obesity					0.613	0.591
Mild	8	36.4	7	31.8		
Moderate	10	45.5	11	50.0		
Severe	4	18.2	4	18.2		

3.2 Comparison of Baseline Values of Dependent Variables

Table 2 presented the descriptive statistics of the three measurements of each dependent variable in the two groups, and baseline comparison. The results of t-test showed that there was no significant difference between the three groups in the selected variables at baseline ($p > 0.05$).

Table 2 Descriptive Statistics of Dependent Variables and Baseline Comparison (N = 59)

Variable	Group	Baseline	6^{th} week	12^{th} week	t	p
Weight (kg)	HIIT	56.5±6.0	55.5±6.0	53.8±5.7	0.188	0.829

	CONT	55.3±4.1	56.3±4.1	58.5±4.0		
VO_2max (mL/kg/min)	HIIT	42.7±1.7	42.3±2.0	48.6±2.3	0.454	0.638
	CONT	42.4±1.1	42.3±1.7	42.2±2.0		
HRrest (b.p.m)	HIIT	80±2	76±2	73±2	3.015	0.059
	CONT	80±3	79±3	79±2		
SBP (mmHg)	HIIT	115±6	112±5	110±4	1.097	0.343
	CONT	118±6	119±5	119±5		
DBP (mmHg)	HIIT	78±1	74±2	71±2	0.747	0.479
	CONT	77±3	77±3	78±3		

3.3 Analysis of Covariates

The results of GEE analysis of HHA and DDI showed (Table 3) that the time effect ($p > 0.08$), group effect ($p > 0.4$) and time*group interaction ($p > 0.1$) were not statistically significant, that is, both HHA and DDI did not differ within and between groups in the HIIT and CONT groups. This suggested to us that participants were strictly instructed to maintain their HHA and DDI during the intervention period. Hence, this outcome removed the possibility that then act as covariates affecting the analysis of the results.

Table 3 Results of GEE Analysis of HHA and DDI (N = 59)

		Time (df=3)		Group (df=1)		Group*Time (df=3)	
		Waldχ^2	p	Waldχ^2	p	Waldχ^2	p
HHA	PAC-C	2.379	0.497	1.392	0.499	7.550	0.273
	Steps (n)	6.425	0.093	0.296	0.862	2.597	0.857
	Calories (kcal)	4.099	0.251	0.615	0.735	25.427	0.060
DDA	Protein (g)	11.894	0.080	1.026	0.599	3.880	0.693
	Fat (g)	5.076	0.166	1.539	0.463	10.002	0.125
	Carbohydrate (g)	1.281	0.515	0.212	0.899	2.010	0.919

3.4 Effects of HIIT on Dependent Variables

The results of the GEE analysis of the dependent variable are presented in Table 4. The main effect of time, the main effect of group, and the interaction effect of time and group were all statistically significant ($p < 0.05$) for all five dependent variables. The time effect significantly indicated that the mean value changed with the extension of training time. The main effect of group was significant, indicating that there was a statistical difference between the groups. A significant interaction means that two groups had a different pattern over time (Baseline, 6^{th} week and 12^{th} week) for the variable.

Table 4 Main Effect and Interaction Effect Results of GEE for Dependent Variables (N = 59)

Variables	Time (df=2)		Group (df=1)		Time * Group (df=2)	
	Waldχ^2	p	Waldχ^2	p	Waldχ^2	p
BW (kg)	744.170*	0.000	11.961*	0.018	744.173*	0.000
VO_2max (mL/kg/min)	1423.853*	0.000	31.710*	0.000	1484.776*	0.000

HRrest (b.p.m)	425.361*	0.000	15.677*	0.000	447.535*	0.000
SBP (mmHg)	84.541*	0.000	12.832*	0.002	100.701*	0.000
DBP (mmHg)	667.372*	0.000	12.777*	0.002	766.239*	0.000

Table 5 showed the result of pairwise mean comparison of dependent variables at three-time points in the HIIT group, the mean scores of BW, VO_2max, HRrest, SBP and DBP were significantly different between baseline, 6^{th} week, and 12^{th} week ($p < 0.05$). The values of BW, HRrest, SBP, and DBP decreased and VO_2max increased statistically over time under the HIIT intervention. Furthermore, the results of the effect size analysis showed that there was a large effect size between the baseline and 12^{th} week for VO_2max (d = 2.42), HRrest (d = 2.76), and DBP (d = 2.86). There was a moderate effect size for SBP (d = 0.74), but a small effect size for BW (d = 0.37).

Table 5 Pairwise Mean Comparison for Variables Within the HIIT Group (N=59)

Variable	(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	p	Effect size (d)
BW (kg)	Baseline	6^{th} week	1.5880*	0.11972	0.000	
	Baseline	12^{th} week	2.6467*	0.19953	0.000	0.37(S)
	6^{th} week	12^{th} week	1.0587*	0.07981	0.000	
VO_2max (mL/kg/min)	Baseline	6th week	-3.5520*	0.10833	0.000	
	Baseline	12th week	-5.9200*	0.18055	0.000	2.42(L)
	6th week	12th week	-2.3680*	0.07222	0.000	
HRrest (b.p.m)	Baseline	6th week	4.0800*	0.22054	0.000	
	Baseline	12th week	6.8000*	0.36757	0.000	2.76 (L)
	6th week	12th week	2.7200*	0.14703	0.000	
SBP (mmHg)	Baseline	6th week	2.7600*	0.31394	0.000	
	Baseline	12th week	4.6000*	0.52324	0.000	0.74 (M)
	6th week	12th week	1.8400*	0.20930	0.000	
DBP (mmHg)	Baseline	6th week	4.0800*	0.16199	0.000	
	Baseline	12th week	6.8000*	0.26998	0.000	2.86(L)
	6th week	12th week	2.7200*	0.10799	0.000	

*The mean difference is significant at 0.05 level. Adjustment for multiple comparisons: Bonferroni.

4 Discussion

The 12-week HIIT in this study significantly lowered obese girls' BW (MD = 2.6467kg, p = 0.000), similar with other prior investigations of obese children and adolescents' HIIT interventions (Miguet et al., 2020; Costigan et al., 2015; Delgado-Floody et al., 2019; Dupuit et al., 2020; Ghardashi Afousi et al., 2018a). The duration of the interventions was at least 12 weeks, the frequency was more than twice a week, and the interval design used an alternating pattern of high-intensity at around 95% of HRmax and moderate-intensity at about 50% of HRmax. These are the three most important commonalities across these interventions.

The HIIT protocol in this study raised participants' VO_2max by 13.9% (p = 0.000), which is higher than the 4.2–13.4% increase reported in prior meta-analyses (Cao et al., 2021; MacInnis et al., 2017). The most significant improvement in cardiorespiratory fitness was seen in people with cardiovascular disease (CVD) who did medium-interval HIIT three times a week for more than 12 weeks (Yue et al., 2022). This was the conclusion of the first study that looked into which type of HIIT was best for improving cardiorespiratory fitness in people with CVD, and the HIIT used in the current study precisely aligns with this discovery. HIIT may improve VO2max by increasing cardiac output, stroke volume, mitochondrial biogenesis, and muscle ability to take oxygen from the blood and use it for energy (Vollaard et al., 2017). HIIT recruits a variety of muscle fibres and involves oxygen-dependent and anaerobic energy systems (Torma et al., 2019). The combination of aerobic and anaerobic exercise improves muscle fibre efficiency and ability, which is more advantageous to enhancing oxygen uptake (Islam & Gillen, 2023; Ryan et al., 2020). So, HIIT has been utilised instead of endurance training to change VO_2max (Storino et al., 2012). The extent of VO_2max improvement was linked to baseline and fatigue index index (Astorino et al., 2012). Unfortunately, most similar research has failed to track participants' fatigue index, which should be improved in future investigations.

HIIT in this study for 12 weeks significantly reduced the HRrest (MD = 6.8000b.p.m, p = 0.000) of obese girls, which supports previous studies that found an improvement in HRrest in HIIT protocols (Bhatia & Kayser, 2019; Grace et al., 2018) and two meta-analyses on HIIT intervention in cardiopulmonary function in coronary heart disease patients (Du et al., 2021; Leal et al., 2020). HIIT may increase HRrest through: HIIT alternates high-intensity activity with rest or low-intensity exercise. These workouts challenge and strengthen the cardiovascular system, especially the heart (Myers et al., 2015; Schaun et al., 2018). Stronger hearts pump blood more efficiently, lowering resting heart rate (Nystoriak & Bhatnagar, 2018). HIIT enhances stroke volume, enabling the heart to sustain the same amount of blood pumped per minute with fewer contractions, leading to a reduced HRrest (Atakan et al., 2021; Suryanegara et al., 2019). HIIT balances the sympathetic nervous system (fight-or-flight) and the parasympathetic nervous system (rest) (Daniela et al., 2022), lowering HRrest (Charkoudian & Rabbitts, 2009; Gordan et al., 2015) . In addition, it also improves cardiac oxygen consumption (Ito, 2019; Leal et al., 2020). The heart works less to sustain important functions during rest, resulting in a reduced resting heart rate (Gonzales et al., 2023).

Nearly 30% of obese children have hypertension, and the number is rising (Bell et al., 2019). Childhood hypertension causes a variety of cardiovascular problems and can persist until adulthood if untreated (Juhola et al., 2012; Chen & Wang, 2008). As with other recent studies on HIIT interventions in obese teens, this study found that after 12 weeks, SBP (MD = 4.6000mmHg, p = 0.000) and DBP (MD = 6.8000mmHg, p = 0.000) dropped significantly in obese Chinese girls. This is in line with what other studies have found, regardless of the gender of the study subjects (Kargarfard et al., 2016; Koubaa, 2013; Meng et al., 2022; Abassi et al., 2022; Vazir et al., 2018; Murphy et al., 2015; Starkoff, 2014; Farah et al., 2014; Boer et al., 2014; Corte de Araujo et al., 2012). A drop in blood pressure may be caused by HIIT in a number of complicated ways, including: A vasodilator called nitric oxide may be made more by the body during HIIT. This helps relax blood vessels and improves blood flow, which lowers BP (Jessica, 2021). HIIT may lower BP by reducing cardiac resistance (John et al., 2022). HIIT may reduce sympathetic nervous system activity. Intense exercise can help modulate the autonomic nervous system, particularly by decreasing sympathetic (fight or flight) activity associated with elevated blood pressure. BP may go down because the body can better control the activity of its sympathetic and parasympathetic nervous systems (Ramírez-Vélez et al., 2020). HIIT also lowers blood pressure by making insulin work better, lowering inflammation, and raising heart output and stroke volume (Bo et al., 2023).

5 Conclusion

12-week HIIT can improve cardiopulmonary fitness and blood pressure of obese adolescent girls. HIIT is an effective exercise intervention to enhance cardiovascular health for obese adolescent girls in China.

References

[1] Astorino, T. A., Allen, R. P., Roberson, D. W., & Jurancich, M. (2012). Effect of high-intensity interval training on cardiovascular function, V̇O 2max, and muscular force. *Journal of Strength and Conditioning Research*, *26*(1), 138–145. https://doi.org/10.1519/JSC.0b013e318218dd77

[2] Atakan, M. M., Li, Y., Koşar, Ş. N., Turnagöl, H. H., & Yan, X. (2021). Evidence-based effects of high-intensity interval training on exercise capacity and health: A review with historical perspective. *International Journal of Environmental Research and Public Health*, *18*(13). https://doi.org/10.3390/ijerph18137201

[3] Batacan, R. B., Duncan, M. J., Dalbo, V. J., Tucker, P. S., & Fenning, A. S. (2017). Effects of high-intensity interval training on cardiometabolic health: A systematic review and meta-analysis of intervention studies. *British Journal of Sports Medicine*, *51*(6), 494–503. https://doi.org/10.1136/bjsports-2015-095841

[4] Bell, C. S., Samuel, J. P., & Samuels, J. A. (2019). Prevalence of Hypertension in Children: Applying the New American Academy of Pediatrics Clinical Practice Guideline. *Hypertension*, *73*(1), 148–152. https://doi.org/10.1161/HYPERTENSIONAHA.118.11673

[5] Bhatia, C., & Kayser, B. (2019). Preoperative high-intensity interval training is effective and safe in deconditioned patients with lung cancer: A randomized clinical trial. *Journal of Rehabilitation Medicine*, *51*(9), 712–718. https://doi.org/10.2340/16501977-2592

[6] Bo, B., Guo, A., Kaila, S. J., Hao, Z., Zhang, H., Wei, J., & Yao, Y. (2023). Elucidating the primary mechanisms of high-intensity interval training for improved cardiac fitness in obesity. *Frontiers in Physiology*, *14*(August). https://doi.org/10.3389/fphys.2023.1170324

[7] Boer, P. H., Meeus, M., Terblanche, E., Rombaut, L., De Wandele, I., Hermans, L., Gysel, T., Ruige, J., & Calders, P. (2014). The influence of sprint interval training on body composition, physical and metabolic fitness in adolescents and young adults with intellectual disability: A randomized controlled trial. *Clinical Rehabilitation*, *28*(3), 221–231. https://doi.org/10.1177/0269215513498609

[8] Cao, M., Tang, Y., Li, S., & Zou, Y. (2021). *Effects of High-Intensity Interval Training and Moderate-Intensity Continuous Training on Cardiometabolic Risk Factors in Overweight and Obesity Children and Adolescents : A Meta-Analysis of Randomized Controlled Trials*.

[9] Casperson, S. L., Sieling, J., Moon, J., Johnson, L. A., Roemmich, J. N., & Whigham, L. (2015). A mobile phone food record app to digitally capture dietary intake for adolescents in a free-living environment: Usability study. *JMIR MHealth and UHealth*, *3*(1), 1–13. https://doi.org/10.2196/mhealth.3324

[10] Charkoudian, N., & Rabbitts, J. A. (2009). Sympathetic Neural Mechanisms in Cardiovascular Function. *Mayo Clinic Proceedings*, *84*(9), 822–830. www.mayoclinicproceedings.com

[11] Chen, X., & Wang, Y. (2008). Tracking of blood pressure from childhood to adulthood: A systematic review and meta-regression analysis. *Circulation*, *117*(25), 3171–3180. https://doi.org/10.1161/CIRCULATIONAHA.107.730366

[12] Corte de Araujo, A. C., Roschel, H., Picanço, A. R., do Prado, D. M. L., Villares, S. M. F., de Sá Pinto, A. L., & Gualano,

B. (2012). Similar health benefits of endurance and high-intensity interval training in obese children. *PLoS ONE*, *7*(8), 1–8. https://doi.org/10.1371/journal.pone.0042747

[13] Daniela, M., Catalina, L., Ilie, O., Paula, M., Daniel-Andrei, I., & Ioana, B. (2022). Effects of Exercise Training on the Autonomic Nervous System with a Focus on Anti-Inflammatory and Antioxidants Effects. *Antioxidants*, *11*(2). https://doi.org/10.3390/antiox11020350

[14] Dong, Y. H., Chen, L., Liu, J. Y., Ma, T., Zhang, Y., Chen, M. M., Zhong, P. L., Shi, D., Hu, P. J., Li, J., Dong, B., Song, Y., & Ma, J. (2023). *Epidemiology and prediction of overweight and obesity among children and adolescents aged 7-18 years in China from 1985 to 2019*. Zhonghua Yu Fang Yi Xue Za Zhi [Chinese Journal of Preventive Medicine]. https://doi.org/10.3760/cma.j.cn112150-20220906-00881

[15] Du, L., Zhang, X., Chen, K., Ren, X., Chen, S., & He, Q. (2021). Effect of high-intensity interval training on physical health in coronary artery disease patients: A meta-analysis of randomized controlled trials. *Journal of Cardiovascular Development and Disease*, *8*(11), 1–18. https://doi.org/10.3390/jcdd8110158

[16] Erdim, L., Ergün, A., & Kuğuoğlu, S. (2019). Reliability and validity of the turkish version of the physical activity questionnaire for older children (Paq-c). *Turkish Journal of Medical Sciences*, *49*(1), 162–169. https://doi.org/10.3906/sag-1806-212

[17] Farah, B. Q., Ritti-Dias, R. M., Balagopal, P., Hill, J. O., & Prado, W. L. (2014). Does exercise intensity affect blood pressure and heart rate in obese adolescents? A 6-month multidisciplinary randomized intervention study. *Pediatric Obesity*, *9*(2), 111–120. https://doi.org/10.1111/j.2047-6310.2012.00145.x

[18] Gonzales, T. I., Jeon, J. Y., Lindsay, T., Westgate, K., Perez-Pozuelo, I., Hollidge, S., Wijndaele, K., Rennie, K., Forouhi, N., Griffin, S., Wareham, N., & Brage, S. (2023). Resting heart rate is a population-level biomarker of cardiorespiratory fitness: The Fenland Study. *PLoS ONE*, *18*(5 May), 1–17. https://doi.org/10.1371/journal.pone.0285272

[19] Gordan, R., Gwathmey, J. K., & Xie, L.-H. (2015). Autonomic and endocrine control of cardiovascular function. *World Journal of Cardiology*, *7*(4), 204. https://doi.org/10.4330/wjc.v7.i4.204

[20] Grace, F., Herbert, P., Elliott, A. D., Richards, J., Beaumont, A., & Sculthorpe, N. F. (2018). High intensity interval training (HIIT) improves resting blood pressure, metabolic (MET) capacity and heart rate reserve without compromising cardiac function in sedentary aging men. *Experimental Gerontology*, *109*(2016), 75–81. https://doi.org/10.1016/j.exger.2017.05.010

[21] Islam, H., & Gillen, J. B. (2023). Skeletal muscle mechanisms contributing to improved glycemic control following intense interval exercise and training. *Sports Medicine and Health Science*, *5*(1), 20–28. https://doi.org/10.1016/j.smhs.2023.01.002

[22] Ito, S. (2019). High-intensity interval training for health benefits and care of cardiac diseases - The key to an efficient exercise protocol. *World Journal of Cardiology*, *11*(7), 171–188. https://doi.org/10.4330/wjc.v11.i7.171

[23] Jessica, L. (2021). *Effects of high intensity exercise in hypoxia on vascular function in mouse models Effects of high intensity exercise in hypoxia on vascular function in mouse models Thèse de doctorat ès sciences de la vie (PhD) Jessica Lavier Master en Biologie Médical*.

[24] John, A. T., Chowdhury, M., Islam, M. R., Mir, I. A., Hasan, M. Z., Chong, C. Y., Humayra, S., & Higashi, Y. (2022). Effectiveness of High-Intensity Interval Training and Continuous Moderate-Intensity Training on Blood Pressure in Physically Inactive Pre-Hypertensive Young Adults. *Journal of Cardiovascular Development and Disease*, *9*(8). https://doi.org/10.3390/jcdd9080246

[25] Juhola, J., Oikonen, M., Magnussen, C. G., Mikkilä, V., Siitonen, N., Jokinen, E., Laitinen, T., Würtz, P., Gidding, S. S., Taittonen, L., Seppälä, I., Jula, A., Kähönen, M., Hutri-Kähönen, N., Lehtimäki, T., Viikari, J. S. A., Juonala, M., & Raitakari, O. T. (2012). Childhood physical, environmental, and genetic predictors of adult hypertension: The cardiovascular risk in young finns study. *Circulation*, *126*(4), 402–409. https://doi.org/10.1161/CIRCULATIONAHA.111.085977

[26] Kargarfard, M., Lam, E. T. C., Shariat, A., Asle Mohammadi, M., Afrasiabi, S., Shaw, I., & Shaw, B. S. (2016). Effects of endurance and high intensity training on ICAM-1 and VCAM-1 levels and arterial pressure in obese and normal weight adolescents. *Physician and Sportsmedicine*, *44*(3), 208–216. https://doi.org/10.1080/00913847.2016.1200442

[27] Leal, J. M., Galliano, L. M., & Del Vecchio, F. B. (2020). Effectiveness of High-Intensity Interval Training Versus Moderate-Intensity Continuous Training in Hypertensive Patients: a Systematic Review and Meta-Analysis. *Current Hypertension Reports*, *22*(3). https://doi.org/10.1007/s11906-020-1030-z

[28] Leite, N., Pizzi, J., de Menezes Junior, F. J., Tadiotto, M. C., de Jesus, Í. C., Corazza, P. R. P., Schiavoni, D., Mota, J., & Radominski, R. B. (2022). Effect of Mict and Hiit on Cardiometabolic Risk and Body Composition in Obese Boys. *Revista Brasileira de Medicina Do Esporte*, *28*(4), 274–280. https://doi.org/10.1590/1517-8692202228042020_0129

[29] Mathers, C. (2016). *Global Burden of Disease*. International Encyclopedia of Public Health. https://doi.org/10.1016/B978-0-12-803678-5.00175-2

[30] Miguet, M., Fearnbach, N. S., Metz, L., Khammassi, M., Julian, V., Cardenoux, C., Pereira, B., Boirie, Y., Duclos, M., & Thivel, D. (2020). Effect of HIIT versus MICT on body composition and energy intake in dietary restrained and unrestrained adolescents with obesity. *Applied Physiology, Nutrition and Metabolism*, *45*(4), 437–445. https://doi.org/10.1139/apnm-2019-0160

[31] Murphy, A., Kist, C., Gier, A. J., Edwards, N. M., Gao, Z., & Siegel, R. M. (2015). The feasibility of high-intensity interval exercise in obese adolescents. *Clinical Pediatrics*, *54*(1), 87–90. https://doi.org/10.1177/0009922814528038

[32] Myers, T. R., Schneider, M. G., Schmale, M. S., & Hazell, T. J. (2015). Whole-body aerobic resistance training circuit improves aerobic fitness and muscle strength in sedentary young females. *Journal of Strength and Conditioning Research*, *29*(6), 1592–1600. https://doi.org/10.1519/JSC.0000000000000790

[33] Nystoriak, M. A., & Bhatnagar, A. (2018). Cardiovascular Effects and Benefits of Exercise. *Frontiers in Cardiovascular Medicine*, *5*(September), 1–11. https://doi.org/10.3389/fcvm.2018.00135

[34] Ramírez-Vélez, R., Tordecilla-Sanders, A., Téllez-T, L. A., Camelo-Prieto, D., Hernández-Quiñonez, P. A., Correa-Bautista, J. E., Garcia-Hermoso, A., Ramírez-Campillo, R., & Izquierdo, M. (2020). Effect of Moderate- Versus High-Intensity Interval Exercise Training on Heart Rate Variability Parameters in Inactive Latin-American Adults: A Randomized Clinical Trial. In *Journal of strength and conditioning research* (Vol. 34, Issue 12). https://doi.org/10.1519/JSC.0000000000001833

[35] Ryan, B. J., Schleh, M. W., Ahn, C., Ludzki, A. C., Gillen, J. B., Varshney, P., Van Pelt, D. W., Pitchford, L. M., Chenevert, T. L., Gioscia-Ryan, R. A., Howton, S. M., Rode, T., Hummel, S. L., Burant, C. F., Little, J. P., & Horowitz, J. F. (2020). Moderate-Intensity Exercise and High-Intensity Interval Training Affect Insulin Sensitivity Similarly in Obese Adults. *Journal of Clinical Endocrinology and Metabolism*, *105*(8), E2941–E2959. https://doi.org/10.1210/clinem/dgaa345

[36] Schaun, G. Z., Pinto, S. S., Silva, M. R., Dolinski, D. B., & Alberton, C. L. (2018). Whole-body high-intensity interval training induce similar cardiorespiratory adaptations compared with traditional high-intensity interval training and moderate-intensity continuous training in healthy men. *Journal of Strength and Conditioning Research*, *32*(10), 2730–2742. https://doi.org/10.1519/JSC.0000000000002594

[37] Song, P., Zhang, Y., Yu, J., Zha, M., Zhu, Y., Rahimi, K., & Rudan, I. (2019). Global Prevalence of Hypertension in Children: A Systematic Review and Meta-analysis. *JAMA Pediatrics*, *173*(12), 1154–1163. https://doi.org/10.1001/jamapediatrics.2019.3310

[38] Starkoff, B. E. (2014). Estimated Aerobic Capacity Changes in Adolescents with Obesity Following High Intensity Interval Exercise. *International Journal of Kinesiology and Sports Science*, *2*(3), 1–8. https://doi.org/10.7575/aiac.ijkss.v.2n.3p.1

[39] Storino, T. O. D. D. A. A., Llen, R. Y. A. N. P. A., & Oberson, D. A. W. R. (2012). *E h -i i t _ , c f , v m f.* 138–145.

[40] Suryanegara, J., Cassidy, S., Ninkovic, V., Popovic, D., Grbovic, M., Okwose, N., Trenell, M. I., MacGowan, G. G., & Jakovljevic, D. G. (2019). High intensity interval training protects the heart during increased metabolic demand in

patients with type 2 diabetes: a randomised controlled trial. *Acta Diabetologica*, *56*(3), 321–329. https://doi.org/10.1007/s00592-018-1245-5

[41] Thompson, W. R. (2023). Worldwide Survey of Fitness Trends for 2023. *ACSM's Health and Fitness Journal*, *27*(1), 9–18. https://doi.org/10.1249/FIT.0000000000000834

[42] Torma, F., Gombos, Z., Jokai, M., Takeda, M., Mimura, T., & Radak, Z. (2019). High intensity interval training and molecular adaptive response of skeletal muscle. *Sports Medicine and Health Science*, *1*(1), 24–32. https://doi.org/10.1016/j.smhs.2019.08.003

[43] Vollaard, N. B. J., Metcalfe, R. S., & Williams, S. (2017). Effect of number of sprints in an SIT session on change in v O2max: A meta-analysis. *Medicine and Science in Sports and Exercise*, *49*(6), 1147–1156. https://doi.org/10.1249/MSS.0000000000001204

[44] Wang, J. J., Baranowski, T., Lau, W. C. P., Chen, T. A., & Pitkethly, A. J. (2016). Validation of the Physical Activity Questionnaire for Older Children (PAQ-C) among Chinese Children. *Biomedical and Environmental Sciences*, *29*(3), 177–186. https://doi.org/10.3967/bes2016.022

[45] Wang, J., Lin, H., Chiavaroli, V., Jin, B., Yuan, J., Huang, K., Wu, W., Dong, G., Derraik, J. G. B., & Fu, J. (2022). High Prevalence of Cardiometabolic Comorbidities Among Children and Adolescents With Severe Obesity From a Large Metropolitan Centre (Hangzhou, China). *Frontiers in Endocrinology*, *13*(May), 1–10. https://doi.org/10.3389/fendo.2022.807380

[46] Yang, Y., Dai, J., Min, J., Wu, H., Huang, S., Li, Q., & Chai, J. (2022). Prevalence trends of hypertension and influence factors among children and adolescents aged 7–17 years in China, 2011–2015: A serial cross-sectional study. *Frontiers in Public Health*, *10*. https://doi.org/10.3389/fpubh.2022.887285

[47] Yue, T., Wang, Y., Liu, H., Kong, Z., & Qi, F. (2022). Effects of High-Intensity Interval vs. Moderate-Intensity Continuous Training on Cardiac Rehabilitation in Patients With Cardiovascular Disease: A Systematic Review and Meta-Analysis. *Frontiers in Cardiovascular Medicine*, *9*(February). https://doi.org/10.3389/fcvm.2022.845225

[48] Zhu, Y., Guo, P., Zou, Z., Li, X., Cao, M., Ma, J., & Jing, J. (2022). Status of Cardiovascular Health in Chinese Children and Adolescents: A Cross-Sectional Study in China. *JACC: Asia*, *2*(1), 87–100. https://doi.org/10.1016/j.jacasi.2021.09.007