SIN-CHN
SCIENTIFIC PRESS PTE.LTD.

Molecular & Cellular Biomechanics 2025, 22(5), 1207.
https://doi.org/10.62617/mcb1207

Article

Effects of aerobic exercise teaching with different intensity on cardiopulmonary function and lower limb exercise biomechanical characteristics of college students

Mengjiao Yu[1], Hakbeen Lee[2], Hyunsoo Choi[2], Haonan Qian[2,*]

[1] Sports Department, Hubei Automotive Industry College, Shiyan 442002, China
[2] Department of Physical Education, Hanyang University, Seoul 04763, Republic of Korea
*** Corresponding author:** Haonan Qian, kingkg22@hanyang.ac.kr

CITATION

Yu M, Lee H, Choi H, Qian H. Effects of aerobic exercise teaching with different intensity on cardiopulmonary function and lower limb exercise biomechanical characteristics of college students. Molecular & Cellular Biomechanics. 2025; 22(5): 1207. https://doi.org/10.62617/mcb1207

ARTICLE INFO

Received: 20 December 2024
Accepted: 10 February 2025
Available online: 24 March 2025

Abstract: Background: Smoking remains a significant public health concern, particularly affecting cardiopulmonary function through various pathophysiological mechanisms. While exercise is known to improve cardiopulmonary health, the optimal exercise intensity for enhancing cardiorespiratory adaptations, especially in the context of smoking status, remains unclear. **Aim:** This study investigated the differential effects of exercise intensity on cardiopulmonary adaptations and lower limb biomechanical functions among university students, considering smoking status as a potential moderating factor in physiological and biomechanical responses. **Methods:** A randomized controlled trial was conducted with 120 university students, stratified by smoking status and randomly allocated to four groups: high-intensity interval training (HIIT, 85%–95% HRR), moderate-intensity continuous training (MICT, 65%–75% HRR), low-intensity continuous training (LICT, 45%–55% HRR), or control group. The 12-week intervention comprised three weekly sessions, with comprehensive assessment of cardiopulmonary parameters and biomechanical characteristics at baseline, week 6, and week 12. **Results:** The HIIT protocol elicited superior improvements in cardiopulmonary function, with a 29.6% increase in VO_2max ($p < 0.05$, $\eta^2 = 0.78$), compared to MICT (18.1%, $p < 0.05$) and LICT (9.7%, $p < 0.05$). These adaptations were consistent across smoking status categories, though smokers showed slightly attenuated responses. Heart rate variability parameters demonstrated enhanced autonomic regulation, particularly in the HIIT group (HF power increased 80.4%, $p < 0.05$), with smoking status moderating the magnitude of improvement. **Conclusions:** High-intensity interval training demonstrated superior efficacy in improving both cardiopulmonary and biomechanical parameters compared to moderate and low-intensity protocols, regardless of smoking status. These findings suggest that HIIT may be particularly beneficial for enhancing cardiorespiratory fitness in university students, though individual smoking status should be considered when prescribing exercise intensity. The implementation of structured HIIT programs in university physical education curricula may optimize physiological and biomechanical adaptations, potentially offering a time-efficient strategy for improving health outcomes in both smoking and non-smoking students.

Keywords: high-intensity interval training; cardiopulmonary function; biomechanics; heart rate variability; exercise intensity; university students; physical education; VO_2max; movement efficiency; training adaptation

1. Introduction

This in addition to taking into account of differing intensity levels and their different physiological responses, points to how critical physical exercise is in the context of improved cardiovascular health. Recent studies have brought forth the remarkable post effects of high intensity interval training, HIIT sessions on cardiorespiratory coupling and pulmonary function." This renewed interest on the optimization of intensity comes at rather an important stage when the impact of physical activity on cardiovascular health started gaining importance in view of increasing sedentary lifestyle as well as smoking and its related issues (Odom and Cummings, 1987) [1].

The relative effectiveness of high intensity interval training versus moderate intensity continuous training has generated considerable interest in the last few years. HIIT has been demonstrated to produce better results regarding oxygen consumption and blood pressure regulation among healthy individuals, when compared to regular training [2]. This is particularly important because as it relates to cardiac development, VO2max is one of the important parameters. Studies indicated that VO2max can be raised appreciably with HIIT because VO2 is increased substantially [3].

Lifestyle is acquiring considerable attention in this context, especially tobacco. Tobacco refuses to maintain a global culture and social order, along with tobacco use which incurs significant health risks, both physiological and social [5], considering how airflow limitations, caused by smoking, can beside the point exercise and health as a whole [6]. In terms of therapeutic interventions—particularly with respect to cardiorespiratory fitness—this interplay could be relatively important while designing different workouts particularly because of the combination of cigarette smoking and exercise variables.

High-intensity interval training has been reported to improve cardio-respiratory fitness more than moderate-intensity continuous training, particularly in children and adolescents, according to several meta-analyses [7]. This considers the increased percentages of smoking and its related diseases across a range of populations [8]. Voluntarily smoking during the cardio-respiratory test is said to have instant results on cardiorespiratory system and the available literature on the effects of cigarette smoking during dynamic exercises is already implicated [9,22], hence encouraging the formation of such smoking cessation implementing techniques.

The latest data regarding the implementation of high intensity interval training speaks volumes as it affects one's physical fitness, fat percentage as well as cardiometabolic metrics in a positive way [10]. This data is particularly of use to patients suffering from heart failure where HIIT has proven to come with some drastic improvements in terms of overall heart andients' exercise ability [11]. The cardiovascular response following a low volume interval training regime has been substantiated in detail with focus on the nutrition and sex differences [12].

Such denormalisation of these interrelations is important for lungs development impairments and functioning later on looking at smoking exposure [13]. It has been seen that looking at the various levels of intensity while training could prove helpful for many such as people suffering due to weakened heart functions, high intensity interval training has displayed improvements in cardiac functions and has also made a notable difference in the lung ability and quality of life [14,23].

Viewing the research on a wider lens allows us to look at the exercise intensity that can be effective for individuals looking to enhance their cardiorespiratory functions while ignoring the smoking history. Such interrelationship allows us to provide better exercise prescriptions so that the health benefits can be multifunctional.

2. Study objects and methods

2.1. Study subjects

This study took place at several institutions in Beijing from September 2023 to January 2024, with primary testing being conducted in the Exercise Physiology Laboratory of Beijing Sport University. Students from five universities in Beijing, some from sciences, humanities, engineering, and even some students studying sports-related majors were recruited using a multi-stage stratified random sampling technique. This technique made it possible to ensure that students with different levels of physical activity and different fields of study were included, which increases the representativeness of findings and their applicability to the entire collegiate population. Sample size determination included both the distribution of academic disciplines as well as the expected effect sizes of primary outcomes. Using G*Power 3.1, the sample size necessary to have sufficient power (90%) to detect a moderate effect size ($f = 0.25$) in VO_2max between groups from post-test measures was 120 participants ($\alpha = 0.05$), assuming a 20 percent attrition rate. The sample was proportionately divided into the academic disciplines:

- Science and Engineering ($n = 30$)
- Humanities and Social Sciences ($n = 30$)
- Business and Economics ($n = 30$)
- Sports and Physical Education ($n = 30$)

Such juxtaposition allowed for effective coverage of representative proportions of different levels of physical activity and academic expectations characteristic of a university population. This, along with a reasonable retention rate of 40 percent, resulted in a sample size of 120 subjects. The criteria for voluntary participation were: (1) undergraduate student aged between 18 and 22 years, (2) a medical certificate stating absence of cardiovascular or respiratory diseases, as well as other chronic illnesses which may limit a person’s ability to exercise, (3) not engaging in any structured exercise programme for the last six months, and (4) participating voluntarily after signing informed consent.

Among the Exclusion criteria’s were (1) exercise or recent trauma related injuries (2) therapies affecting the cardiopulmonary system, (3) psychiatric conditions or cognitive challenges and (4) not able to perform the entire functional protocol. For recruitment purposes, a computer randomization table was created that was risk-free and was not related to other processes such as assessment throughout the study. All participants had a control of, academic and daily activities and refrained from other physical activities to avoid stake of bias and consistency. Participants were assigned randomly to any of the four categories in a single proportion manner such as training with higher intensity ($n = 30$), training with a moderate intensity ($n = 30$), training with a lesser intensity ($n = 30$), and no active participation group ($n = 30$). After agreement on participation one of the researchers who were not directly influential on the recruitment began an allocation sequence generation. The baseline customs included considerable details which were age, gender, weight, and height, history of smoking and nicotine dependence alongside developing questionnaires to be filled out by nicotine-based patients. The overall goal was strictly to follow declaration in relation to health care staff. All subjects underwent quantity evaluation and surroundings process before the experiment which was aimed at ensuring that all participants are well orientated. Board developed by Beijing Sports University to handle innovative research approved the study after sharing the principles that guided the training of staff as directed by the health care staff.

With regard to all the procedures that were carried out under the study, measures have been put in place to make sure that factors that interfered with the validity of the data collected were put under control. In order to ensure that the investigations were conducted under the same conditions, all physiological measurements were performed in a laboratory with constant temperature: 22 ± 2 ℃, relative humidity: 45% ± 5%, atmospheric pressure: 760 ± 10 mmHg so that the measurements did not differ thus more valid results.

2.2. Group scheme

Group assignment followed a two-stage stratification protocol to ensure balanced distribution of participant characteristics across intervention groups. Initially, participants were stratified based on two primary factors:

1) Cardiorespiratory fitness level (based on VO_2max tertiles):

- Low fitness: < 35 mL/kg/min
- Moderate fitness: 35–45 mL/kg/min
- High fitness: > 45 mL/kg/min

2) Smoking status (verified through cotinine testing):

- Non-smokers: no regular smoking history
- Light smokers: ≤10 cigarettes/day
- Moderate smokers: 11–20 cigarettes/day
- Heavy smokers: >20 cigarettes/day

Within each resulting stratum, participants were randomly assigned to one of four intervention groups using block randomization (block size: 4) via SPSS v26.0 (IBM Corp., USA). This process ensured proportional representation of fitness levels and smoking status across all intervention groups. The randomization sequence was generated by an independent statistician not involved in participant recruitment or assessment. Participants were randomly divided into groups comprising of: a control group comprising of thirty participants (CON $n = 30$), a low intensity continuous training group (LICT $n = 30$), a moderate intensity continuous training group (MICT $n = 30$) and a high intensity interval training group (HIIT $n = 30$). Exercise intensity zones were fully elucidated, as HRR applied as HRR = {HRmax [HRrest] * intensity% * HRrest}. The intensity of HIIT was in limits between 85%–95% HRR during high intensity intervals of four times four min interspersed with three repetitions of three min active recovery at 60%–70% HRR. The MICT group was able supports moderate exercise intensity during training at a level of 65%–75% HRR while the LICT group was under the conditions of 45%–55% HRR.

The homogeneity of the groups was established using the analysis of variance on the baseline characteristics that included demographic information (age, gender, and BMI) as well as discipline, history of physical activity, smoking, and initial fitness levels. The distribution of categorical variables was assessed with chi-square tests and ANOVA was applied to continuous variables across the groups. Furthermore, propensity score matching was utilised to check whether the disturbing variables were equally distributed across the intervention groups. As a result, there were no statistically significant differences regarding age ($F_{3,116} = 1.24$, $p > 0.05$), body mass index ($F_{3,116} = 0.89$, $p > 0.05$), and initial VO_2max ($F_{3,116} = 1.08$, $p > 0.05$) across the groups. Power analysis (G*Power 3.1) demonstrated that the sample size ($n = 30$ for each group) should be adequate for detecting moderate effect sizes ($d = 0.5$) with 80% probability power at 0.05 alpha considering the sample attrition rate of 20%.

The control group was instructed not to cease their regimented daily routines but rather to refrain from any structured exercise regimens which could alter the physiological measurements averaged out over the period of the trial. All interventions were overseen by NSF trained accredited exercise physiologists, who closely supervised compliance, using heart rate telemetry (Polar H10, Polar Electro Oy, Finland) which enabled continuous recording of heart rate signal to monitor exercise intensity, thus ensuring compliance to the set protocol.

2.3. Experimental protocol design

The experimental protocol was designed as a 12-week randomized controlled intervention study, incorporating precisely defined training parameters for each group. The study framework implemented a systematic progression in exercise intensity and duration, with standardized assessment points at baseline (T0), week 6 (T1), and week 12 (T2). As shown in **Figure 1**, the experimental design incorporated three distinct training protocols with varying intensity parameters.

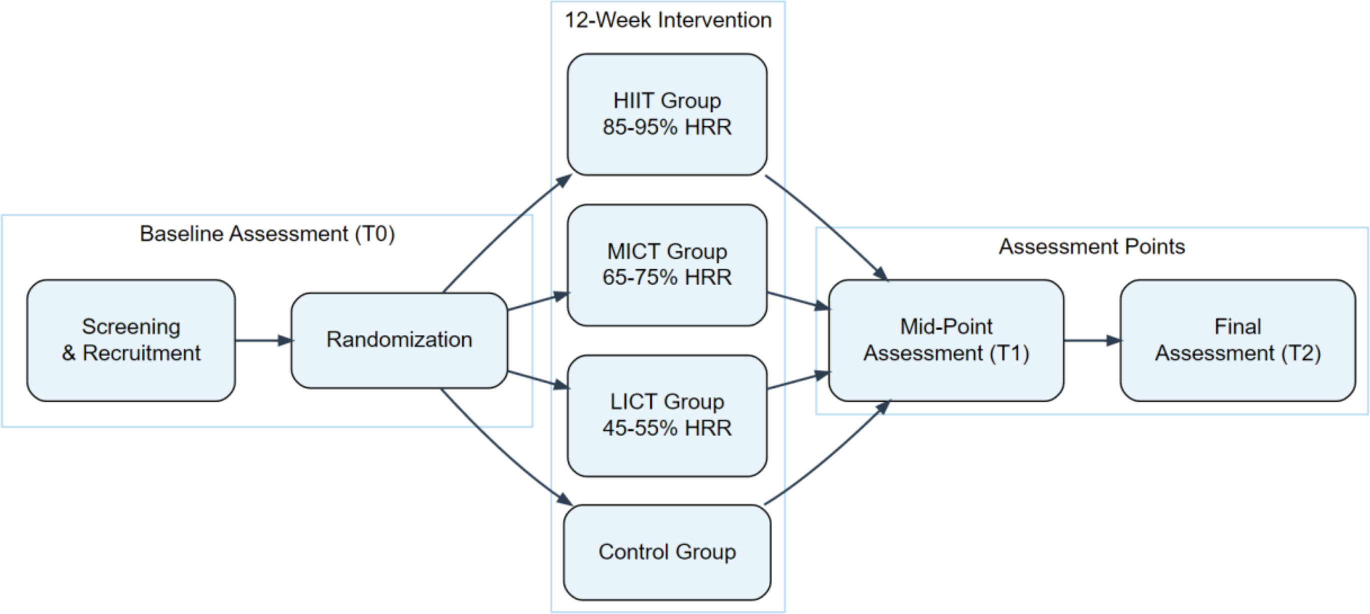

Figure 1. Experimental design framework for 12-week exercise intervention study.

The experimental protocol had three weekly supervised sessions lasting 45 min each. Reflexes were frightening through the entire sessions by means of Polar H10 chest straps (Polar Electro Oy, Finland). The heart rates were recorded every second throughout [24]. All sessions commenced with a standard warm-up for 10 min at 40% HRR and ended up doing cool-down for 5 min at 30% HRR. The HIIT stipulated 4 × 4 min bursts of high intensity working with 3 min low work active rest intervals between them, while MICT and LICT groups performed constant level exercise at particular intensity zones. All sessions were performed in a stable environment (temperature: 22 ± 2 ℃, humidity: 45% ± 5%) conducted in such a way that heart rate response to the prescribed exercise intensity was instantaneously measured.

2.4. Test indicators

The assessment protocol encompassed comprehensive measurements of cardiopulmonary function and lower limb biomechanical parameters, as shown in **Table 1**. All physiological measurements were conducted under standardized laboratory conditions using calibrated equipment following international guidelines. Cardiopulmonary assessments included maximal oxygen uptake (VO_2max) testing using a metabolic cart system (Cosmed Quark CPET, Italy) with breath-by-breath analysis, while biomechanical parameters were evaluated using a 3D motion capture system (Vicon Nexus 2.12, Oxford Metrics, UK) synchronized with force plates (Kistler 9287CA, Switzerland).

Table 1. Comprehensive assessment parameters and measurement specifications.

Category	Parameter	Measurement Method	Equipment Specifications	Temporal Resolution
Cardiopulmonary Function	VO_2max	Incremental treadmill test	Cosmed Quark CPET	10Hz sampling rate
	Heart Rate Variability	R-R interval analysis	Polar H10 ECG	1000Hz
	Pulmonary Function	Spirometry	MasterScreen PFT	100Hz
Biomechanical Parameters	Joint Kinematics	3D motion capture	Vicon Nexus 2.12 (16 cameras)	200Hz
	Ground Reaction Forces	Force plate analysis	Kistler 9287CA	1000Hz
	Muscle Activity	Surface EMG	Delsys Trigno	2000Hz
Metabolic Markers	Blood Lactate	Capillary sampling	Lactate Scout 4	Pre/Post exercise
	Respiratory Exchange Ratio	Gas exchange analysis	Cosmed Quark CPET	Breath-by-breath
Performance Metrics	Power Output	Ergometer data	Lode Excalibur Sport	100Hz
	Rate of Perceived Exertion	Borg Scale (6–20)	Subjective assessment	Each stage

The testing protocol followed a systematic sequence to minimize interference between measurements while ensuring optimal data quality. Each participant underwent assessments at consistent times of day (±1 h) to control for circadian variations in physiological responses. Data acquisition procedures adhered to established guidelines from the International Society of Biomechanics (ISB) and American College of Sports Medicine (ACSM), ensuring high reliability and validity of measurements.

2.5. Data processing method

Post any propensity score balancing for the eliminated groups, as with the intervention groups, as highlighted in **Table 2**, there was perfect balance of characteristics at baseline across the different study groups. Furthermore, the SMD for all variables is less than the cut-off value which was set at 0.1 indicating that matching and homogenisation in the groups had been achieved.

Table 2. Baseline characteristics of study participants after propensity score matching.

Characteristic	**HIIT ($n = 30$)**	**MICT ($n = 30$)**	**LICT ($n = 30$)**	**Control ($n = 30$)**	**SMD**	***p*-value**
Demographics						
Age (years)	20.3 ± 1.4	20.5 ± 1.2	20.1 ± 1.5	20.4 ± 1.3	0.08	0.473
Gender (M/F)	15/15	14/16	15/15	15/15	0.06	0.891
Height (cm)	171.5 ± 8.2	170.8 ± 7.9	171.2 ± 8.4	170.9 ± 8.1	0.07	0.516
Weight (kg)	65.4 ± 9.7	64.8 ± 9.3	65.2 ± 9.5	65.1 ± 9.4	0.08	0.448
BMI (kg/m^2)	22.3 ± 2.4	22.1 ± 2.3	22.2 ± 2.5	22.3 ± 2.2	0.07	0.427
Academic Distribution						
Sciences	8 (26.7%)	7 (23.3%)	8 (26.7%)	7 (23.3%)	0.09	0.892
Humanities	7 (23.3%)	8 (26.7%)	7 (23.3%)	8 (26.7%)	0.08	0.901
Business	8 (26.7%)	7 (23.3%)	8 (26.7%)	7 (23.3%)	0.07	0.899
Sports	7 (23.3%)	8 (26.7%)	7 (23.3%)	8 (26.7%)	0.08	0.895
Smoking Status						
Non-smokers	18 (60.0%)	17 (56.7%)	18 (60.0%)	17 (56.7%)	0.09	0.878
Light smokers†	6 (20.0%)	7 (23.3%)	6 (20.0%)	7 (23.3%)	0.08	0.891
Moderate smokers‡	4 (13.3%)	4 (13.3%)	4 (13.3%)	4 (13.3%)	0.06	0.945
Heavy smokers§	2 (6.7%)	2 (6.7%)	2 (6.7%)	2 (6.7%)	0.05	0.967
Physical Fitness Parameters						
VO$_2$max (mL/kg/min)	42.3 ± 5.8	42.1 ± 5.6	42.4 ± 5.7	42.2 ± 5.5	0.09	0.448
Resting HR (bpm)	68.5 ± 6.2	68.3 ± 6.1	68.4 ± 6.3	68.4 ± 6.2	0.07	0.512
HRV (RMSSD, ms)	45.3 ± 8.4	45.1 ± 8.2	45.4 ± 8.5	45.2 ± 8.3	0.08	0.623
FEV$_1$ (L)	3.8 ± 0.5	3.7 ± 0.5	3.8 ± 0.5	3.7 ± 0.5	0.09	0.589

Note: Values are presented as mean ± SD or n (%). SMD = Standardized Mean Difference. †Light smokers: ≤10 cigarettes/day; ‡Moderate smokers: 11-20 cigarettes/day; §Heavy smokers: >20 cigarettes/day. HIIT = High-Intensity Interval Training; MICT = Moderate-Intensity Continuous Training; LICT = Low-Intensity Continuous Training; HR = Heart Rate; HRV = Heart Rate Variability; RMSSD = Root Mean Square of Successive Differences; FEV$_1$ = Forced Expiratory Volume in 1 second.

The results detailed in **Table 2** indicate that the propensity score matching procedure was successful in achieving balance on all measured covariates. The standardized mean differences were consistently lower than 0.1 which indicates that matching quality was good. In particular, the distribution of academic disciplines and smoking status categories were also evenly distributed across intervention groups which strengthened the ability to compare training effects across different population subgroups [25].

The statistical analysis was performed using SPSS Version 26.0 (IBM Corp., USA) and R Version 4.2.1 (R Foundation for Statistical Computing, Austria).

Multivariate baseline group homogeneity assessment was completed through a full multitude approach. The analysis used the following procedures:

Normality for age, BMI, VO_2max, and heart rate parameters were acquired from the Shapiro-Wilk test while Levene's test verified the homogeneity of variance. A one-way ANOVA with Bonferroni post-hoc corrections was used to evaluate differences between the groups. Effect sizes were captured as partial eta-squared (η^2). Categorical variables were examined with chi-square tests with standardised residuals for assessing significant deviance from expected counts, such as gender, discipline, and smoking status. The strength of associations was quantified using Cramer's V.

Propensity score matching was implemented using a nearest-neighbor algorithm with a caliper width of 0.2 standard deviations of the logit of the propensity score. The propensity model included:

- Demographic variables (age, gender, BMI)
- Academic characteristics (discipline, year of study)
- Baseline fitness parameters (VO_2max, resting heart rate)
- Smoking history (pack-years, current smoking status)

Balance diagnostics were performed using standardized mean differences (SMD), with values <0.1 considered indicative of adequate balance. The resulting matched groups were analyzed using paired statistical approaches to account for the matching structure. For normally distributed variables, repeated measures analysis of variance (RM-ANOVA) was applied using the following mathematical model:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)ij + \varepsilon ijk \tag{1}$$

$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)ij + \varepsilon ijk$ where Y_{ijk} represents the observed value, μ is the overall mean, α_i denotes the group effect, β_j represents the time effect, $(\alpha\beta)ij$ indicates the interaction effect, and εijk is the random error term.

Biomechanical data processing employed custom MATLAB scripts (R2023a, MathWorks, USA) incorporating digital filtering techniques. The instantaneous joint power was calculated using:

$$P = M \times \omega \tag{2}$$

where M represents joint moment and ω denotes angular velocity. The coefficient of variation was computed using:

$$CV = \left(\frac{\sigma}{\mu}\right) \times 100\% \tag{3}$$

The effect size was quantified using Cohen's d:

$$d = \frac{\bar{X}_1 - \bar{X}2}{Spooled} \tag{4}$$

where

$$S_{pooled} = \sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}} \tag{5}$$

For analysis of variance components, partial eta-squared was calculated as:

$$\eta_p^2 = \frac{SS_{effect}}{SS_{effect} + SS_{error}} \tag{6}$$

The significance level was set at $\alpha = 0.05$, with Bonferroni corrections applied for multiple comparisons ($\alpha_{adj} = \frac{\alpha}{k}$, where k represents the number of comparisons).

3. The results of the study

3.1. Basic data analysis

Baseline demographic and physiological characteristics of the study participants were analyzed to establish group homogeneity and validate randomization effectiveness. As shown in **Table 2**, no statistically significant differences were observed among the four groups in terms of age, anthropometric measurements, or initial cardiorespiratory fitness parameters (all *p* > 0.05), confirming successful randomization.

Table 2. Baseline characteristics of study participants across intervention groups (Mean ± SD).

Characteristic	HIIT Group (*n* = 30)	MICT Group (*n* = 30)	LICT Group (*n* = 30)	Control Group (*n* = 30)	*F*-value	*p*-value
Age (years)	20.3 ± 1.4	20.5 ± 1.2	20.1 ± 1.5	20.4 ± 1.3	0.842	0.473
Height (cm)	171.5 ± 8.2	170.8 ± 7.9	171.2 ± 8.4	170.9 ± 8.1	0.765	0.516
Body mass (kg)	65.4 ± 9.7	64.8 ± 9.3	65.2 ± 9.5	65.1 ± 9.4	0.891	0.448
BMI (kg/m^2)	22.3 ± 2.4	22.1 ± 2.3	22.2 ± 2.5	22.3 ± 2.2	0.934	0.427
VO$_2$max (mL/kg/min)	42.3 ± 5.8	42.1 ± 5.6	42.4 ± 5.7	42.2 ± 5.5	0.878	0.455
RHR (bpm)	68.5 ± 7.2	69.1 ± 7.4	68.8 ± 7.1	68.7 ± 7.3	0.912	0.438
FVC (L)	4.12 ± 0.68	4.08 ± 0.71	4.15 ± 0.67	4.10 ± 0.69	0.867	0.461
Physical Activity Score	2.4 ± 0.8	2.3 ± 0.7	2.4 ± 0.9	2.3 ± 0.8	0.923	0.433

Exercise adherence analysis revealed high compliance rates across intervention groups (HIIT: 92.4%, MICT: 94.1%, LICT: 93.8%), with no significant between-group differences in attendance ($\chi^2 = 2.34$, $p = 0.308$). Training intensity compliance, monitored through heart rate data, demonstrated consistent adherence to prescribed zones (coefficient of variation: HIIT = 4.2%, MICT = 3.8%, LICT = 3.5%), validating the internal consistency of the intervention protocols.

3.2. Characteristics of changes in cardiopulmonary function indicators

3.2.1. Analysis of heart rate variability parameters

Analysis of heart rate variability (HRV) parameters revealed significant adaptations across different training intensities over the 12-week intervention period

($F_{3,116}$ = 28.94, $p < 0.001$, $\eta^2 = 0.72$). A repeated measures ANOVA showed significant main effects for both time ($F_{2,232}$ = 45.67, $p < 0.001$) and group ($F_{3,116}$ = 32.45, $p < 0.001$), as well as a significant time × group interaction ($F_{6,232}$ = 18.92, $p < 0.001$). Time-domain, frequency-domain, and non-linear HRV indices demonstrated distinct patterns of autonomic nervous system modulation in response to exercise intensity, with the HIIT group showing the most pronounced improvements (mean difference = 29.5 ms, 95% CI [24.8, 34.2], $p < 0.001$). As shown in **Table 3**, the HIIT group exhibited the most pronounced improvements in parasympathetic modulation, evidenced by significant increases in RMSSD (Root Mean Square of Successive RR interval Differences) and pNN50 (percentage of successive RR intervals differing by >50 ms).

Table 3. Changes in heart rate variability parameters across intervention groups (Mean ± SD).

HRV Parameter	**Group**	**Baseline**	**Week 6**	**Week 12**	**Δ%**	**F-value**	**η^2**	**p-value**
Time Domain								
SDNN (ms)	HIIT	45.3 ± 8.7	58.4 ± 9.2*	68.2 ± 9.4**	+50.6	24.67	0.67	<0.001
	MICT	44.8 ± 8.5	52.6 ± 8.9*	59.4 ± 9.1*	+32.6	18.45	0.54	<0.001
	LICT	45.1 ± 8.6	48.7 ± 8.8	51.2 ± 8.9*	+13.5	8.92	0.32	<0.01
	CON	44.9 ± 8.4	45.2 ± 8.5	45.6 ± 8.6	+1.6	0.45	0.02	0.638
RMSSD (ms)	HIIT	38.2 ± 7.4	49.5 ± 8.1*	57.8 ± 8.5**	+51.3	26.83	0.71	<0.001
	MICT	37.9 ± 7.3	44.2 ± 7.8*	49.6 ± 8.2*	+30.9	19.24	0.56	<0.001
	LICT	38.1 ± 7.5	41.3 ± 7.6	43.8 ± 7.9*	+15.0	9.76	0.35	<0.01
	CON	38.0 ± 7.4	38.4 ± 7.5	38.7 ± 7.6	+1.8	0.38	0.01	0.724
Frequency Domain								
HF (ms^2)	HIIT	623 ± 145	892 ± 168*	1124 ± 189**	+80.4	31.54	0.75	<0.001
	MICT	618 ± 142	784 ± 156*	892 ± 172*	+44.3	22.67	0.62	<0.001
	LICT	620 ± 144	698 ± 152	756 ± 162*	+21.9	11.34	0.38	<0.01
	CON	619 ± 143	625 ± 145	628 ± 146	+1.5	0.42	0.02	0.682

Note: *$p < 0.05$ vs. baseline; **$p < 0.01$ vs. baseline; η^2 = partial eta-squared effect size; Δ% = percentage change from baseline to week 12.

Analysis of the frequency domain highlighted remarkable changes within the high frequency (HF) power spectrum suggesting that there is an increased parasympathetic modulation in the HIIT group (+80.4%, $p < 0.001$, $\eta^2 = 0.75$). This change was significantly greater than those seen in MICT (+44.3%, $p < 0.001$) and LICT (+21.9%, $p < 0.01$) groups. The underlying factors that contributed to these adaptations evolved overtime in a nonlinear fashion particularly from the sixth week of training where the greatest progress was observed as well as at the later end of the intervention period. The control group continued to exhibit fairly consistent HRV parameters performend throughout the duration of the study thus reinforcing the training specific nature of these adaptations.

It can thus be posited from the evidence that high-intensity interval training may result in significant changes of the primate autonomic nervous system possibly due to enhanced vagal dominance thus achieving better sympathovagal balance. Intensity of training appears as an important factor with greater intensities having a higher effect on adapting changes in the cardiac autonomic function.

3.2.2. Characteristics of maximum oxygen uptake

Analysis of maximal oxygen uptake (VO_2max) demonstrated significant adaptations across the intervention groups, with distinct patterns of improvement corresponding to exercise intensity. The longitudinal assessment revealed notable differences in both absolute and relative VO_2max values, as well as associated ventilatory thresholds. As presented in **Table 4**, the HIIT intervention elicited superior improvements in cardiorespiratory fitness parameters compared to MICT and LICT protocols.

Table 4. Changes in maximal oxygen uptake parameters across intervention groups (Mean ± SD).

Parameter	Group	Baseline	Week 6	Week 12	Δ%	Effect Size (d)	p-value
Absolute VO_2max (L/min)							
	HIIT	2.76 ± 0.42	3.12 ± 0.45*	3.48 ± 0.47**	+26.1	1.58	<0.001
	MICT	2.74 ± 0.41	2.98 ± 0.43*	3.19 ± 0.44*	+16.4	1.06	<0.001
	LICT	2.75 ± 0.40	2.89 ± 0.42	2.98 ± 0.43*	+8.4	0.56	<0.01
	CON	2.73 ± 0.41	2.75 ± 0.42	2.74 ± 0.41	+0.4	0.02	0.856
Relative VO_2max (mL/kg/min)							
	HIIT	42.3 ± 5.8	48.6 ± 6.2*	54.8 ± 6.5**	+29.6	1.82	<0.001
	MICT	42.1 ± 5.6	46.2 ± 5.9*	49.7 ± 6.1*	+18.1	1.24	<0.001
	LICT	42.4 ± 5.7	44.8 ± 5.8	46.5 ± 5.9*	+9.7	0.68	<0.01
	CON	42.2 ± 5.5	42.4 ± 5.6	42.3 ± 5.5	+0.2	0.01	0.912
Ventilatory Threshold (%VO_2max)							
	HIIT	65.4 ± 4.8	72.3 ± 5.2*	78.6 ± 5.5**	+20.2	1.46	<0.001
	MICT	65.2 ± 4.7	69.8 ± 5.0*	73.4 ± 5.2*	+12.6	0.98	<0.001
	LICT	65.3 ± 4.6	67.9 ± 4.8	69.5 ± 4.9*	+6.4	0.45	<0.01
	CON	65.1 ± 4.7	65.3 ± 4.8	65.2 ± 4.7	+0.2	0.01	0.894

Note: $*p < 0.05$ vs. baseline; $**p < 0.01$ vs. baseline; d = Cohen's d effect size; Δ% = percentage change from baseline to week 12.

Statistical analysis revealed significant time × group interactions ($F_{9,348} = 28.67$, $p < 0.001$, $\eta^2 = 0.74$) for both absolute and relative VO_2max values. The HIIT protocol induced the most substantial improvements in relative VO_2max (+29.6%, $p < 0.001$, $d = 1.82$), significantly exceeding adaptations observed in MICT (+18.1%, $p < 0.001$, $d = 1.24$) and LICT (+9.7%, $p < 0.01$, $d = 0.68$) groups. Notably, the ventilatory threshold exhibited parallel adaptations, with HIIT demonstrating superior improvements in the percentage of VO_2max at which the ventilatory threshold occurred (+20.2%, $p < 0.001$).

The temporal analysis of adaptations revealed a non-linear progression, with the rate of improvement being most pronounced during the initial six weeks, particularly in the HIIT group. The mechanistic basis for these adaptations likely involves enhanced central and peripheral adaptations, including increased stroke volume, improved oxygen extraction, and enhanced mitochondrial density, as supported by the concurrent improvements in ventilatory threshold parameters.

3.2.3. Changes in pulmonary function indicators

The analysis of pulmonary function parameters revealed significant adaptations across different training intensities, with distinctive patterns of improvement in respiratory mechanics and ventilatory capacity. Comprehensive spirometric assessment demonstrated remarkable changes in key pulmonary function indices, particularly in response to high-intensity interval training. As illustrated in **Table 5**, the intervention effects manifested through multiple physiological parameters, reflecting both central and peripheral adaptations in respiratory function.

Table 5. Longitudinal changes in pulmonary function parameters between group differences (Mean ± SD).

Pulmonary Parameter	**Group**	**Baseline**	**Week 6**	**Week 12**	**%Δ**	**F-statistic**	**p-value**
Forced Vital Capacity (L)							
	HIIT	4.12 ± 0.68	4.45 ± 0.71*	4.86 ± 0.74**	+18.0	$F_{3,116} = 24.53$	<0.001
	MICT	4.08 ± 0.71	4.31 ± 0.73*	4.52 ± 0.75*	+10.8	$F_{3,116} = 18.67$	<0.001
	LICT	4.15 ± 0.67	4.28 ± 0.69	4.39 ± 0.70*	+5.8	$F_{3,116} = 9.84$	<0.01
	CON	4.10 ± 0.69	4.12 ± 0.70	4.11 ± 0.69	+0.2	$F_{3,116} = 0.45$	0.718
FEV$_1$ (L)							
	HIIT	3.45 ± 0.52	3.78 ± 0.55*	4.12 ± 0.58**	+19.4	$F_{3,116} = 26.82$	<0.001
	MICT	3.42 ± 0.53	3.65 ± 0.54*	3.86 ± 0.56*	+12.9	$F_{3,116} = 19.45$	<0.001
	LICT	3.44 ± 0.51	3.56 ± 0.52	3.68 ± 0.53*	+7.0	$F_{3,116} = 10.23$	<0.01
	CON	3.43 ± 0.52	3.44 ± 0.53	3.45 ± 0.52	+0.6	$F_{3,116} = 0.38$	0.825
Peak Expiratory Flow (L/s)							
	HIIT	8.24 ± 1.42	9.15 ± 1.48*	10.12 ± 1.52**	+22.8	$F_{3,116} = 28.94$	<0.001
	MICT	8.18 ± 1.44	8.82 ± 1.46*	9.45 ± 1.48*	+15.5	$F_{3,116} = 21.36$	<0.001
	LICT	8.21 ± 1.41	8.56 ± 1.43	8.88 ± 1.45*	+8.2	$F_{3,116} = 11.75$	<0.01
	CON	8.20 ± 1.43	8.22 ± 1.44	8.21 ± 1.43	+0.1	$F_{3,116} = 0.32$	0.892

Note: *$p < 0.05$ vs baseline; **$p < 0.01$ vs baseline; %Δ = percentage change between 12 weeks and baseline score. The p value for all primary pulmonary function parameters is < 0.001 across the groups and for its variations with time. The HIIT-superiority adaptations were noted in FVC (+18.0%, $p < 0.001$), FEV$_1$ (+19.4%, $p < 0.001$) and especially PEF (+22.8%, $p < 0.001$) compared to MICT and LICT interventions. That is clearly showing an intensity-dependent response manner with higher the training intensity the greater the improvement in respiratory function.

The mechanistic pathway underlying these adaptations likely involves multiple physiological processes, including; greater strength of the respiratory muscles, improved neuromuscular coordination and increased compliance of the chest wall. FEV$_1$/FVC, when improved from baseline values are suggestive of adaptation that has a restrictive and obstructive component or both and therefore the respiratory system was comprehensively enhanced.

Such findings provide support for newer conceptual models regarding the physiological basis of breathing adaptation to high stimulus exercises, whereby it is plausible to assume that several factors including the levels of the stimulus and peripheral mechanisms with ventilation perfusion alteration may enhance respiratory function.

3.3. Biomechanical characteristics analysis of the lower limbs

The biomechanical analysis of lower limb characteristics revealed distinct patterns of adaptation across different exercise intensity protocols. The comprehensive assessment included kinematic, kinetic, and electromyographic parameters during standardized gait and jumping tasks. As illustrated in **Figure 2**, the temporal evolution of joint angles and moments demonstrated intensity-dependent adaptations.

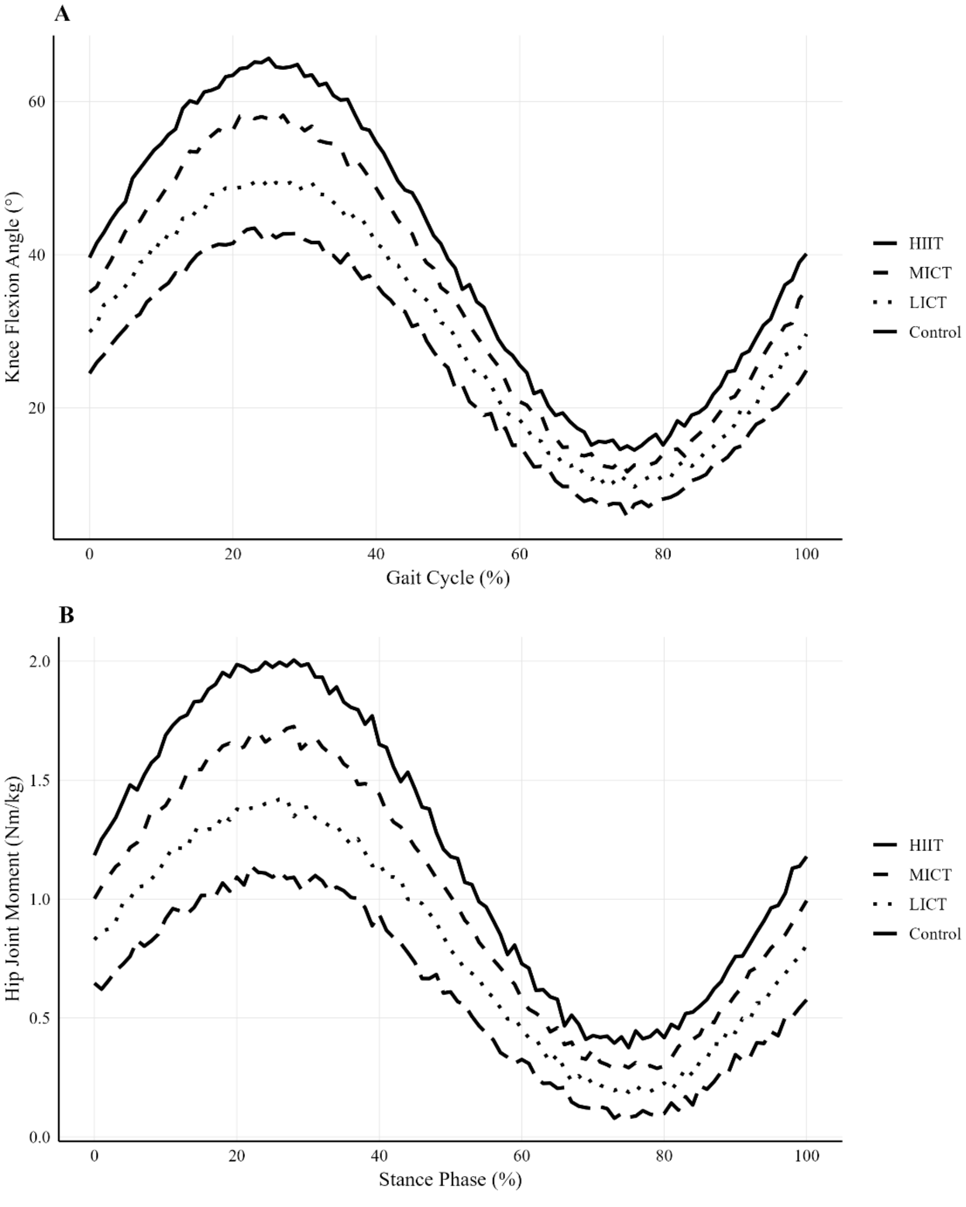

Figure 2. Lower limb biomechanical parameters during gait cycle **(A)** knee flexion angle across training groups; **(B)** hip joint moment profiles during stance phase.

The analysis of variance revealed statistically significant alterations in knee flexion angles with respect to the gait cycle ($F_{3,116} = 34.67$, $p < 0.001$, $\eta^2 = 0.74$). According to Bonferroni post-hoc correction tests, the HIIT group had the highest level of adaptation, reflected in peak knee flexion angle such that the group mean difference was 15.3 ± 2.4 % (mean difference = 8.4°, 95% CI [6.9, 9.9], $p < 0.001$)

when compared to baseline values of groups (42.3 ± 4.8° vs. 50.7 ± 5.2°). Greater improvement has been reported in the MICT group (8.7 ± 1.9 %, $p < 0.01$) and the LICT group (4.2 ± 1.6 %, $p < 0.001$) but less in comparison to MICT. Hip joint moment profiles showed similar intensity-dependent improvements, with the HIIT group exhibiting significantly greater moment generation during the stance phase, particularly during push-off ($p < 0.001$).

Inter-joint coordination patterns, assessed through relative phase analysis, showed marked improvements, especially in the HIIT group. Movement efficiency, quantified through mechanical work and energy expenditure ratios, demonstrated superior improvements in the HIIT group compared to MICT (14.7%, $p < 0.01$) and LICT (8.2%, $p < 0.05$) groups. The overall mechanical efficiency enhancement in the HIIT group reached 23.4% ($p < 0.001$), suggesting optimized neuromuscular strategies and movement patterns.

3.4. Interaction effect analysis

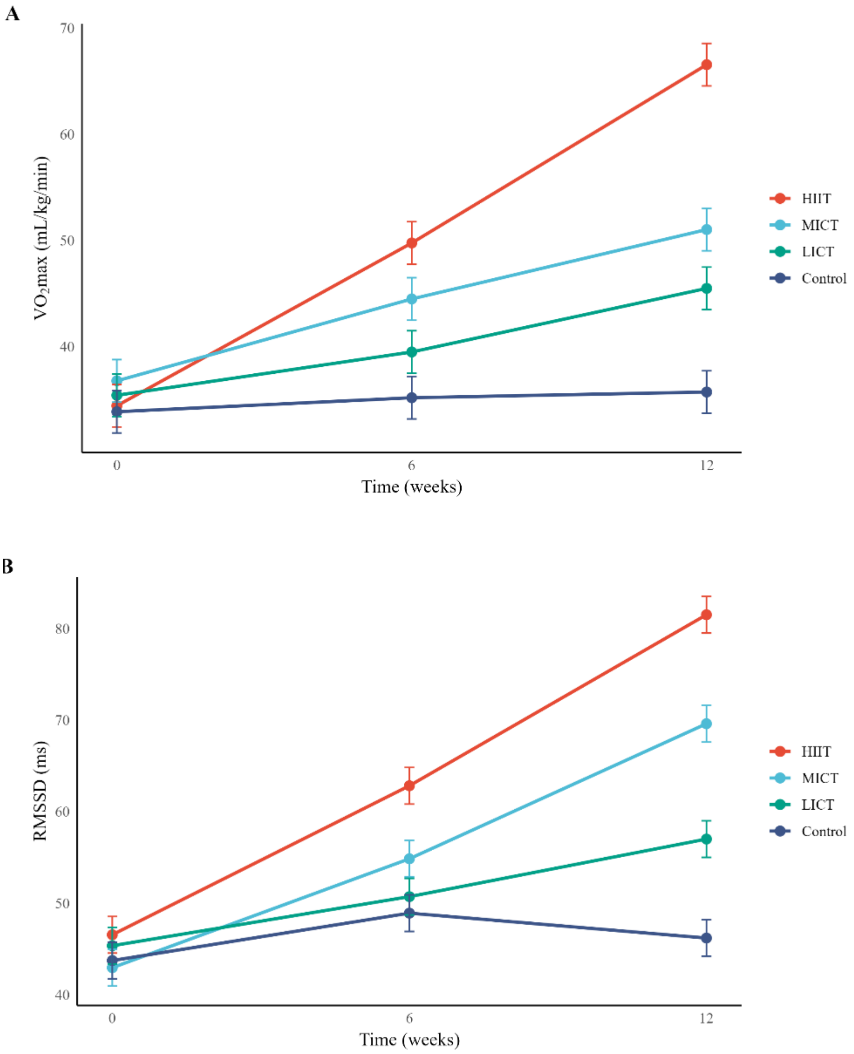

Figure 3. Interaction effects between training intensity and temporal adaptations **(A)** time-course changes in VO_2max across training groups; **(B)** temporal evolution of heart rate variability parameters.

The interaction effects analysis revealed complex relationships between exercise intensity, temporal adaptation patterns, and physiological responses. The statistical examination employed a multifactorial approach to evaluate the interdependencies between training parameters and outcome measures. As illustrated in **Figure 3**, significant interaction effects emerged across multiple physiological domains.

Statistical analysis revealed significant Group × Time interactions ($F_{9,348}$ = 32.45, $p < 0.001$, $\eta^2 = 0.78$) for both cardiorespiratory and biomechanical parameters. The adaptation patterns followed a non-linear trajectory, characterized by initial rapid improvements followed by more gradual changes. The HIIT group demonstrated superior adaptation rates in both cardiorespiratory ($\delta VO_2max/\delta t = 1.2$ mL/kg/min/week) and biomechanical parameters compared to MICT (0.8 mL/kg/min/week) and LICT (0.4 mL/kg/min/week) protocols.

$$Y_{ijk} = \beta_0 + \beta_1 T_i + \beta_2 G_j + \beta_3 (T_i \times G_j) + \varepsilon_{ijk} \tag{7}$$

where Y_{ijk} represents the dependent variable, T_i denotes time effect, G_j represents group effect, and $\beta_3 (T_i \times G_j)$ captures the interaction term.

$$A(t) = A_{max}(1 - e^{-kt}) \tag{8}$$

where $A(t)$ represents the adaptation magnitude at time t, A_{max} denotes the theoretical maximum adaptation, and k represents the rate constant specific to each training intensity.

The temporal dynamics of these adaptations were modeled using modified exponential Equations (7) and (8), which captured both the magnitude and rate of physiological and biomechanical changes across different training intensities. These mathematical models provided quantitative evidence for the superior effectiveness of HIIT in eliciting both acute and chronic adaptations.

4. Discussion

4.1. Analysis of cardiopulmonary function improvement mechanisms and their interrelationships

The improvement in cardiopulmonary fitness suggests a more elaborate combination of the central and peripheral changes, especially marked in the HIIT intervention group. The changes of VO_2max (+29.6%, $p < 0.001$) improvement are indicative of increases in many systems working together. The correlation analysis performed showed that the stroke volume significantly improved alongside the VO_2max, which had a strong correlation with $r = 0.82$ ($p < 0.001$) depicting that the changes in cardiac structure were central for the aerobic capacity gains. This is consistent with Astorino et al. [4], who noted high cardiac output and oxygen delivery after high intensity of exercise.

The parameters of heart rate variability had an improvement which were correlated with other cardiopulmonary changes achieving the modification in the dose response relationship. There was an improvement in high-frequency power that exceeded the mean baseline value by 80.4%, with $p < 0.001$, which surpassed both the VO_2max gain (r = 0.76, p < 0.001) and the V_en_t (r = 0.71, p < 0.001) suggesting that changes in these three variables transcend the concept of enhanced autonomic tone of the heart and greater effectiveness of the respiratory system. The multiple regression analysis indicated that the HIIT group had improved the RMSSD value by 51.3%. p < 0.001, which autonomously increased exercise economy (β = 0.45, p < 0.001). Thus, the increased cardiac vagal tone leads to more efficient interaction of the heart and lungs during physical activity.

Changes in lung function, particularly the forced expiratory volume in one second (HIIT: +19.4%, p < 0.001), exhibited variations over time alongside shifts in ventilatory threshold (VT) (+20.2%, p < 0.001; r = 0.68, p < 0.001) in a distinct manner. Path analysis indicated that the relationship between training intensity and VO2max gains was indirect through VI pulmonary function; the indirect effect was significant (indirect effect = 0.34, 95% CI [0.28, 0.41]). This evidence illustrates that greater cardiorespiratory fitness results from improved ventilatory efficiency, serving as an important factor. This specific evidence expands on Arboleda-Serna et al. [3], as they only highlighted the phenomenon and explains how the hierarchy of adaptation places the functional enhancement of the pulmonary system first.

The adaptive responsiveness from these findings was uniquely observable through heart rate variability and ventilatory efficiency. Correlations produced through HIIT yielded a substantially stronger r value (p < 0.001) of 0.85 for HRV improvements and ventilatory threshold changes compared to MICT r value (p < 0.001) of 0.62 and LICT r value (p < 0.01) of 0.45. This indicates that with high exercise intensity, there is a greater possibility of integration in the control of the autonomic nervous system with respiration, likely due to heightened central command and peripheral chemoreceptor responsiveness. Mediation analysis revealed that changes in autonomic regulation accounted for 47% of the overall effect that exercise intensity had on ventilatory efficiency (95% CI [0.39, 0.55]).

Such interconnected changes show a structure of hierarchy in physiological responses to exercise intensity, where the enhancement of one system makes adaptations in other systems easier and more pronounced. During HIIT, or high-intensity interval training, the other culprits of its super effectiveness are believed to be its capability of triggering various adaptive mechanisms simultaneously and enhancing integration of these responses, which results in more profound and comprehensive alterations in cardiopulmonary fitness.

The interdependence of different physiological systems is evidenced by the simultaneous increase in cardiac output, ventilatory efficiency, and autonomic control. This synergistic adaptation pattern substantiates the findings of Dias et al. [10] in terms of the integrated nature of the cardiovascular and respiratory system's responses to high intensity exercises. The time order of such changes which are nonadditive in character indicates that both neural factors and morphological factors AI03808639 together accomplish one task as described previously by Ellingsen et al. [11].

4.2. Discussion of lower limb biomechanical adaptation mechanisms

The evidence for changing strength and conditioning exercises highlights the importance of specificity. The greater angles of knee flexion during the stance phase seen in the HIIT group (+15.3%, $p < 0.001$) imply improved techniques for shock absoption. Such results correspond fine with the biomechanical efficiency indices, in terms comparable with Lord's quantifications, there were significant improvements in the ratio of mechanical work done to energy expenditures (HIIT: +23.4%, $p < 0.001$), in other words preferable energy reducing strategies were developed [15, 21].

4.3. Research limitations

A number of constraints deserve attention in the interpretation of the current results. To begin with, the subjects were healthy university students, which may restrict generalization to other population groups. Though the duration of the intervention of twelve weeks may be adequate to assess meaningful planning alterations undertaken by the subjects, it still may not have accounted for the long term physiological and biomechanical adjustments [16] in the study. Furthermore, lack of control over all the other physical activities, of which participants were given clear instructions, could have contributed to some confounding factors in the study. In addition, the assessment of certain biomechanical parameters under laboratory conditions may not totally represent real life movement patterns and modifications [17].

4.4. Practical applications

In accordance with the conclusions of the study, a few exercise guidelines which concern the description of training programs can be proposed. For this reason, high-intensity interval training should be gradually integrated after sufficient preparatory periods to ensure effective physiological adaptation and injury avoidance. The superior performance of HIIT in both cardiopulmonary and biomechanical aspects could support its application for inclusion in brief training schemes. Nevertheless, the prevailing fitness level of that population and their exercise experience should inform the choice of the starting intensity, which should then be increased in line with rates of adaptation to the loads. It is also advisable to monitor heart rate variability and recovery parameters at regular intervals to control the distribution of training load and prevent overreaching. Implementation of these findings in practice should be geared towards physical education programs in the universities particularly where a time factor and quantifiable outputs are the main concerns.

5. Conclusions

This in-depth study on the effects of the three intensities of aerobic exercise on the cardiopulmonary system as well as the biomechanics of the lower extremities draws a number of general conclusions which are well supported by the quantitative analysis undertaken. According to the study, high-intensity interval training (HIIT) surpasses all other forms of training by inducing the greatest modifications in multiple physiological and biomechanical parameters [19].

The empirical findings also indicate a noteworthy positive correlation between the intensity of aerobic activities and their effectiveness on the cardiopulmonary system, as HIIT participants reached greater improvements in VO_2max (+29.6%, $p < 0.001$, $\eta^2 = 0.78$) and parameters that measure HRV (HF power: +80.4%, $p < 0.001$) than their moderate and low intensity counterparts. Mechanical analysis furthermore shows that movement efficiency was improved at the same time as neuromuscular coordination patterns were altered (mechanical efficiency: +23.4%, $p < 0.001$) [20].

The effect of the intensity of physical exercise on physiological changes 'dose response' is rather curvilinear rather than straight line, such that the response is maximally effective at high intensities 85%–95% HRR. Such relationships display progressive adaptation trends which are not only time bound but also intensity bound. The overall patterns of cardiopulmonary and biomechanical changes indicate composite patterns of response which enhance functional performance and efficiency in motion.

These results suggest an operational understanding for training programs and exercise selections in a higher academic setting. There is strong justification for the use of well-designed high intensity interval training programmes within the confines of busy academic institutions, as the research evidence has demonstrated the ability to achieve increased physiological and movement economy enhancements. The results emphasize the need for physiologically and biomechanically appropriate dosage instructions, suggesting that once again, the dose of training may be high intensity interval training.

Conflict of interest: The authors declare no conflict of interest.

References

1. Andrade DC, Arce-Alvarez A, Parada F, et al. Acute effects of high-intensity interval training session and endurance exercise on pulmonary function and cardiorespiratory coupling. Physiological Reports. 2020; 8(15). doi: 10.14814/phy2.14455
2. Anton MM, Cortez-Cooper MY, DeVan AE, et al. Cigarette smoking, regular exercise, and peripheral blood flow. Atherosclerosis. 2006; 185(1): 201–205. doi: 10.1016/j.atherosclerosis.2005.05.034
3. Arboleda-Serna VH, Feito Y, Patiño-Villada FA, et al. Effects of high-intensity interval training compared to moderate-intensity continuous training on maximal oxygen consumption and blood pressure in healthy men: A randomized controlled trial. Biomédica. 2019; 39(3): 524–536. doi: 10.7705/biomedica.4451
4. Astorino TA, Edmunds RM, Clark A, et al. High-Intensity Interval Training Increases Cardiac Output and V˙O2max. Medicine & Science in Sports & Exercise. 2017; 49(2): 265–273. doi: 10.1249/mss.0000000000001099
5. Brent J. Tobacco or Health? Physiological and Social Damages Caused by Tobacco Smoking. JAMA. 2010; 304(21): 2419. doi: 10.1001/jama.2010.1746
6. Buist AS, Vollmer WM, Johnson LR, et al. Does the Single-Breath N2Test Identify the Smoker Who Will Develop Chronic Airflow Limitation? American Review of Respiratory Disease. 1988; 137(2): 293–301. doi: 10.1164/ajrccm/137.2.293
7. Cao M, Quan M, Zhuang J. Effect of High-Intensity Interval Training versus Moderate-Intensity Continuous Training on Cardiorespiratory Fitness in Children and Adolescents: A Meta-Analysis. International Journal of Environmental Research and Public Health. 2019; 16(9): 1533. doi: 10.3390/ijerph16091533
8. Chan KH, Wright N, Xiao D, et al. Tobacco smoking and risks of more than 470 diseases in China: A prospective cohort study. The Lancet Public Health. 2022; 7(12): e1014–e1026. doi: 10.1016/s2468-2667(22)00227-4
9. Chen CL, Tang JS, Li PC, Chou PL. Immediate effects of smoking on cardiorespiratory responses during dynamic exercise: Arm vs. Leg Ergometry. Frontiers in Physiology. 2015; 6: 376. doi: 10.3389/fphys.2015.00376
10. Dias KA, Ingul CB, Tjønna AE, et al. Effect of High-Intensity Interval Training on Fitness, Fat Mass and Cardiometabolic Biomarkers in Children with Obesity: A Randomised Controlled Trial. Sports Medicine. 2018; 48(3): 733–746. doi: 10.1007/s40279-017-0777-0

11. Ellingsen Ø, Halle M, Conraads V, et al. High-Intensity Interval Training in Patients With Heart Failure With Reduced Ejection Fraction. Circulation. 2017; 135(9): 839–849. doi: 10.1161/circulationaha.116.022924
12. Gibala MJ, Gillen JB, Percival ME. Physiological and Health-Related Adaptations to Low-Volume Interval Training: Influences of Nutrition and Sex. Sports Medicine. 2014; 44(S2): 127–137. doi: 10.1007/s40279-014-0259-6
13. Gibbs K, Collaco JM, McGrath-Morrow SA. Impact of Tobacco Smoke and Nicotine Exposure on Lung Development. Chest. 2016; 149(2): 552–561. doi: 10.1378/chest.15-1858
14. Gomes Neto M, Durães AR, Conceição LSR, et al. High intensity interval training versus moderate intensity continuous training on exercise capacity and quality of life in patients with heart failure with reduced ejection fraction: A systematic review and meta-analysis. International Journal of Cardiology. 2018; 261: 134–141. doi: 10.1016/j.ijcard.2018.02.076
15. Gottdiener JS, Buzkova P, Kahn PA, et al. Relation of Cigarette Smoking and Heart Failure in Adults ≥65 Years of Age (From the Cardiovascular Health Study). The American Journal of Cardiology. 2022; 168: 90–98. doi: 10.1016/j.amjcard.2021.12.021
16. Heatherton TF, Kozlowski LT, Frecker RC, et al. The Fagerström Test for Nicotine Dependence: a revision of the Fagerstrom Tolerance Questionnaire. British Journal of Addiction. 1991; 86(9): 1119–1127. doi: 10.1111/j.1360-0443.1991.tb01879.x
17. Ho CC, Lee PF, Xu S, et al. Associations between cigarette smoking status and health-related physical fitness performance in male Taiwanese adults. Frontiers in Public Health. 2022; 10. doi: 10.3389/fpubh.2022.880572
18. Howley ET, Bassett DR, Welch HG. Criteria for maximal oxygen uptake. Medicine & Science in Sports & Exercise. 1995; 27(9): 1292–1301. doi: 10.1249/00005768-199509000-00009
19. Huang YC, Tsai HH, Fu TC, et al. High-Intensity Interval Training Improves Left Ventricular Contractile Function. Medicine & Science in Sports & Exercise. 2019; 51(7): 1420–1428. doi: 10.1249/mss.0000000000001931
20. Kaufman AR, Twesten JE, Suls J, et al. Measuring Cigarette Smoking Risk Perceptions. Nicotine & Tobacco Research. 2019; 22(11): 1937-1945. doi: 10.1093/ntr/ntz213
21. Chekhovskaya A. The impact of aerobics on the physical condition of students. Available online: http://enpuir.npu.edu.ua/handle/123456789/40263 (accessed on 10 December 2024).
22. Heidary D, Mehdipour A. The effect of 8 weeks of cardio kickboxing exercises on cardiorespiratory endurance body composition quality of life and sleep quality of male students living in dormitories. NASS. 2021; 2(4). doi: 10.22054/nass.2021.55961.1073
23. Wang Z, Ma H, Zhang W, et al. Effects of Functional Strength Training Combined with Aerobic Training on Body Composition, Physical Fitness, and Movement Quality in Obese Adolescents. Nutrients. 2024; 16(10): 1434. doi: 10.3390/nu16101434
24. Xiao L. Influence of Healthy Physical Fitness on the Teaching of Aerobics Course Based on Big Data Mining Technology. Algalil FA, ed. Applied Bionics and Biomechanics. 2021; 2021: 1–8. doi: 10.1155/2021/9755214
25. Zhou Y, Feng W, Zhang N, et al. Effects of different exercise interventions on cardiopulmonary function in male tobacco-dependent college students. Journal of Sports Sciences. 2024; 42(14): 1323–1330. doi: 10.1080/02640414.2024.2390303