A Study on the Effects of High-Intensity Interval Training (HIIT) Intervention on Physical Fitness of University Students with Obesity

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Abstract: *The population of university students with obesity faces a significant risk of declining physical fitness levels, while traditional exercise protocols often suffer from insufficient adherence due to their time-consuming nature. Characterized by high time efficiency and strong metabolic stimulation, high-intensity interval training (HIIT) presents a potential optimized choice for exercise intervention in this group. This article systematically elaborates on the physiological and metabolic adaptation mechanisms of HIIT, analyzes the multidimensional characteristics of physical fitness composition among university students with obesity, and outlines the principles for its safe application. Furthermore, it explores the integrated network through which HIIT enhances overall physical fitness via three primary pathways: regulating energy metabolism and body composition, optimizing cardiopulmonary function and autonomic nervous system balance, and improving skeletal muscle mass and insulin sensitivity. The study indicates that the interventional effects of HIIT manifest as synergistic gains across various physical fitness dimensions, yet exhibit individual variability influenced by multiple factors such as genetics, phenotype, and behavior. Future research should focus on the refined design of HIIT protocols, integrate multi-omics approaches and digital technologies to promote biomarker-based personalized interventions, and explore its value in broader health outcomes.*

Keywords: *High-Intensity Interval Training (HIIT); University Students with Obesity; Physical Fitness; Mechanism of Action; Personalized Intervention*

Introduction

The increasing prevalence of obesity among university students, coupled with its association with declining levels of physical fitness, constitutes a significant health concern for this population. Compared to traditional moderate-intensity continuous training, High-Intensity Interval Training (HIIT) demonstrates superior time efficiency in inducing similar or even greater physiological adaptations. However, a systematic theoretical explanation of its impact on the physical fitness of university students with obesity remains to be further developed. Clarifying the theoretical basis, intrinsic mechanisms, and the logic of effect integration through which HIIT acts on this specific group is essential for constructing a scientific interventional theoretical framework. This study aims to systematically analyze, from a theoretical perspective, the physiological and metabolic foundations of HIIT and its compatibility with the physical fitness characteristics of university students with obesity. It seeks to delve into the multi-pathway mechanisms underlying its intervention effects and provides an integrated discussion on the synergy, individual variability of these effects, and future directions for optimization. Consequently, it offers a theoretical basis and forward-looking insights for designing exercise prescriptions targeted at this population.

1. Theoretical Basis of High-Intensity Interval Training and Physical Fitness Characteristics of University Students with Obesity

1.1 Physiological and Metabolic Adaptation Mechanisms of High-Intensity Interval Training

The physiological effects of High-Intensity Interval Training (HIIT) stem from its alternating, deep mobilization of the body's energy supply systems. During the high-intensity exercise phases, the body primarily relies on the anaerobic glycolytic system to rapidly generate energy, accompanied by significant lactate accumulation, which induces substantial metabolic stress. In the subsequent intermittent recovery periods, energy supply shifts to the aerobic oxidative system to clear metabolic by-products, resynthesize phosphagens, and oxidize fats. This cyclical alternation imposes a significant load on the cardiopulmonary system, compelling cardiac output, stroke volume, and tissue oxygen uptake capacity to reach and maintain elevated levels within short timeframes, thereby effectively stimulating improvements in maximal oxygen uptake (VO_2max). From a metabolic adaptation perspective, HIIT can significantly enhance skeletal muscle mitochondrial density and function, increase oxidative enzyme activity, and promote fatty acid mobilization and oxidation capacity.

At a deeper molecular level, the mechanisms involve the regulation of cellular signaling pathways. A single HIIT session can activate key signaling molecules such as AMP-activated protein kinase (AMPK) and peroxisome proliferator-activated receptor gamma coactivator 1-alpha (PGC-1α). The sustained activation of these molecules amplifies a cascade of adaptive responses, including promoting mitochondrial biogenesis, optimizing the capillary network, and improving insulin signal transduction. Consequently, HIIT not only achieves caloric expenditure through acute high energy consumption but also fundamentally enhances the body's metabolic flexibility and energy utilization efficiency by inducing chronic physiological and metabolic adaptations. This provides a theoretical basis for improving metabolic disorders in individuals with obesity[1].

1.2 Composition and Assessment Dimensions of Physical Fitness in University Students with Obesity

The physical fitness status of university students with obesity exhibits multi-dimensional specific alterations. Its composition typically encompasses health-related physical fitness and skill-related physical fitness, with the former being the core focus of this study. Health-related physical fitness primarily includes cardiorespiratory endurance, body composition, muscular strength and endurance, and flexibility. For university students with obesity, abnormal body composition is a core characteristic, manifested as a significantly excessive body fat percentage, increased fat mass, and often accompanied by visceral fat accumulation and relatively insufficient lean body mass. Cardiorespiratory endurance is often impaired due to increased circulatory system load, decreased movement economy, and potential metabolic syndrome factors. This impairment is characterized by a possibly adequate absolute value of maximal oxygen uptake (VO_2max) but a significantly low relative value (per kilogram of body weight).

The assessment of physical fitness in this population requires targeted and safe standardized protocols. Cardiorespiratory endurance is typically evaluated using graded exercise tests with progressively increasing workload, such as treadmill or cycle ergometer tests, with the direct measurement or indirect estimation of maximal oxygen uptake (VO_2max) serving as the gold standard. Accurate assessment of body composition can be achieved through methods like dual-energy X-ray absorptiometry (DXA) or bioelectrical impedance analysis (BIA), while anthropometric measurements (such as waist circumference and waist-to-hip ratio) provide simple and effective field indicators for assessing fat distribution. Muscular strength and endurance can be evaluated using isokinetic or isotonic strength testing equipment, or through field-based tests like handgrip strength and sit-up tests for group screening. These assessment dimensions collectively form the baseline reference and outcome evaluation system for understanding the effects of HIIT intervention[2].

1.3 Adaptability and Safety Considerations for Applying HIIT to Obese Populations

When applying High-Intensity Interval Training (HIIT) to individuals with obesity, training protocols must be adaptively modified based on their physiological and anatomical characteristics to ensure safety and feasibility. Individuals with obesity often exhibit increased resting metabolic demands, diminished heat dissipation capacity during exercise, elevated joint loading pressure, and potential subclinical cardiovascular risks. Consequently, the initial design of HIIT protocols should emphasize "relative high-intensity" rather than "absolute high-intensity." This means that workloads should be prescribed based on the individual's peak exercise capacity (e.g., peak heart rate, peak power output), rather than applying a uniform external absolute load. The selection of exercise modalities should prioritize minimizing joint impact, favoring options such as cycle ergometers, elliptical trainers, or aquatic exercises over running.

The core considerations for ensuring safety lie in rigorous pre-participation screening, individualized intensity monitoring, and adequate recovery intervals. Pre-participation screening, involving medical questionnaires and assessment of basic physiological indicators, is necessary to exclude exercise contraindications. During training sessions, exercise intensity should be monitored in real-time by combining heart rate measurement with the use of the Rating of Perceived Exertion (RPE) scale. This ensures that the high-intensity intervals remain within a safe and effective target range. The duration of recovery intervals should allow for a significant decrease in heart rate, which safeguards the quality of subsequent high-intensity intervals and mitigates cardiovascular risk. The principle of progressive overload is crucial. In the initial phases, interval duration can be extended while the duration of high-intensity efforts is shortened. As physical fitness improves, training variables can be gradually adjusted. This approach induces positive training adaptations while maintaining controllable risks.

2. Exploration of the Mechanisms by Which HIIT Intervention Affects the Physical Fitness of University Students with Obesity

2.1 Regulatory Pathways Based on Energy Metabolism and Body Composition

The optimization of body composition in university students with obesity through HIIT intervention is first reflected in its profound remodeling of energy balance. A single HIIT session induces a sharp increase in energy expenditure within a short period due to its extreme exercise intensity, with energy consumption per unit time significantly higher than that of moderate-intensity continuous exercise. More critically, the phenomenon of excess post-exercise oxygen consumption (EPOC) is significantly induced and prolonged following such training. The EPOC phase represents various physiological and biochemical processes undertaken by the body to restore homeostasis, including phosphagen resynthesis, lactate clearance, the return of body temperature and hormone levels to baseline, and muscle fiber repair. These processes continuously consume oxygen and oxidize fat at a relatively high proportion. Therefore, HIIT constructs a robust energy expenditure window encompassing both the "during-exercise" and "post-exercise" phases, providing direct impetus for achieving a negative energy balance and fat reduction[3].

At the molecular regulatory level, HIIT induces adaptive remodeling of the skeletal muscle and systemic metabolic network through repetitive metabolic stress. The repeated stimulation of HIIT maintains AMPK in a state of sustained activation, which in turn inhibits mTORC1 activity and upregulates the expression of PGC-1α. As the master regulator of mitochondrial biogenesis, the upregulation of PGC-1α expression drives a comprehensive enhancement of mitochondrial quantity and function, including increased synthesis of electron transport chain proteins and heightened activity of fatty acid β-oxidation enzymes. This mitochondrial adaptation directly improves the cell's metabolic flexibility-that is, its ability to efficiently switch between fuel sources under different energy states. Individuals with enhanced metabolic flexibility tend to rely more on fat oxidation for energy during rest and low-intensity activities, thereby effectively reducing lipid storage. This is particularly significant for clearing ectopic fat deposits in tissues such as the liver and skeletal muscle. Furthermore, HIIT strongly stimulates the secretion of epinephrine and norepinephrine, which directly activates hormone-sensitive lipase, accelerates the breakdown of triglycerides in adipose tissue, and releases free fatty acids for energy utilization, thereby promoting improvements in body composition at its source.

2.2 Stress and Adaptation of Cardiopulmonary Function and the Autonomic Nervous System

The improvement in the cardiorespiratory system of university students with obesity through HIIT stems from the unique high-intensity intermittent loading pattern it provides, which efficiently stimulates the remodeling of cardiac structure and function. Each high-intensity sprint forces cardiac output to reach or approach its peak within a short period, imposing a powerful volume and pressure load on the myocardium. As an adaptive response, physiological cardiomyocyte hypertrophy and mild ventricular chamber dilation may occur in the left ventricle, thereby enhancing myocardial contractility and stroke volume. This constitutes the anatomical basis for the improvement in the central mechanism of maximal oxygen uptake (i.e., cardiac pumping capacity). Concurrently, coronary artery blood flow and capillary density may increase correspondingly to support the enhanced myocardial oxygen supply. Regarding pulmonary function, the high demand for ventilation during intense exercise strengthens the respiratory muscles' power and endurance, and may improve the ventilation-perfusion ratio, thereby enhancing gas exchange efficiency.

The optimization of autonomic nervous system function represents another key adaptation induced by HIIT, which is particularly significant for the cardiovascular health of individuals with obesity. The distinctive alternating pattern of exercise and recovery in HIIT essentially provides systematic "training" for both sympathetic and parasympathetic nervous system activities. Following long-term intervention, the excessive sympathetic excitation typically present at rest is often suppressed, while the high-frequency power component of heart rate variability, which reflects parasympathetic (vagal) tone, tends to increase. This shift in autonomic balance toward vagal dominance means the heart receives more adequate "rest" during resting states, heart rate reserve expands, and the regulatory capacity and stability of the cardiovascular system improve. This neural adaptation not only directly contributes to enhanced cardiopulmonary performance during exercise but is also associated with physiological changes beneficial to overall health, such as decreased resting heart rate and improved blood pressure.

2.3 Associated Impact on Skeletal Muscle Mass and Insulin Sensitivity

The positive effect of HIIT on insulin sensitivity in university students with obesity is closely linked to its multi-dimensional remodeling of skeletal muscle, which is a core insulin-sensitive tissue. Skeletal muscle is not only the primary site for glucose uptake and disposal but also a central organ for energy metabolism. HIIT effectively stimulates and helps maintain, or even increases in some individuals, skeletal muscle mass, particularly the cross-sectional area of type II muscle fibers. The maintenance or increase in lean body mass directly expands the "reservoir" capacity for insulin-mediated glucose disposal in the body. This holds protective significance against the relative or absolute loss of muscle mass associated with obesity[4].

At the cellular and molecular level, HIIT efficiently activates insulin signal transduction pathways within skeletal muscle through dual pathways of mechanical stress and metabolic stress. Each high-intensity contraction promotes the translocation of glucose transporter type 4 (GLUT4) to the cell membrane, a process that is partly independent of insulin signaling. More importantly, HIIT enhances mitochondrial oxidative capacity by activating pathways such as AMPK and PGC-1α, thereby reducing the accumulation of intramyocellular lipid intermediates like diacylglycerol (DAG) and ceramide. These lipid metabolites are recognized as key molecules that enhance serine phosphorylation of insulin receptor substrate 1 (IRS-1) and impair normal insulin signal transduction. By improving mitochondrial function and optimizing lipid metabolism, HIIT effectively clears the intracellular environment conducive to insulin resistance. Consequently, it fundamentally enhances skeletal muscle's responsiveness to insulin and improves systemic glucose homeostasis.

3. Integrated Discussion on HIIT Intervention Effects and Future Research Directions

3.1 Synergy and Interrelation of Improvements Across Physical Fitness Dimensions

The intervention effects of High-Intensity Interval Training (HIIT) on the physical fitness of university students with obesity are not isolated improvements within a single dimension; rather, enhancements across different dimensions exhibit inherent physiological connections and synergistic effects. Cardiorespiratory endurance, as a core health indicator, shows a close interconnection with improvements in body composition. The increase in maximal oxygen uptake not only reflects enhanced cardiac pumping function and muscular oxygen uptake capacity but is also directly linked to improved fat oxidation capacity during exercise. This enhancement in metabolic efficiency creates physiological conditions conducive to sustained body fat reduction. Conversely, a decrease in body fat percentage can reduce the metabolic and mechanical load during exercise, indirectly promoting further development of cardiorespiratory endurance, thereby establishing a positive reinforcing cycle.

The enhancement of muscular function plays a critical role within this synergistic network. The maintenance or slight increase in skeletal muscle mass induced by HIIT, along with neuromuscular adaptations, elevates the basal metabolic rate, providing support for sustaining long-term energy balance. Concurrently, improvements in muscular strength and endurance enhance movement economy, enabling individuals to perform exercises at a given workload with lower physiological cost, which contributes to increased training tolerance and adherence. Although the potential improvement in flexibility may not be as pronounced as the aforementioned factors, it may optimize movement patterns and reduce the risk of exercise-related injuries, thereby providing a foundation for safely implementing higher-intensity training. Consequently, the interventional effects of HIIT should be viewed as a holistic adaptation affecting multiple systems, where each dimension is interdependent, and its combined benefits surpass the simple sum of the individual effects[5].

3.2 Individual Variability in Intervention Response and Its Influencing Factors

While positive effects of HIIT are observed at the group level, the heterogeneity of responses among individuals is a scientific reality that must be acknowledged. This variability manifests as significant differences in the magnitude of improvement across various physical fitness parameters among university students with obesity following identical or similar training protocols. This heterogeneity in response is influenced by multiple interacting factors, with genetic background constituting a fundamental element. Specific gene polymorphisms, such as variations in genes related to angiotensin-converting enzyme (ACE), mitochondrial biogenesis, or lipid metabolism, may predetermine an individual's sensitivity and upper limit for physiological adaptations induced by aerobic exercise.

Apart from genetic predisposition, phenotypic characteristics and behavioral factors are equally crucial. Baseline physical fitness levels, body composition (particularly visceral fat content), hormonal status, and potential subclinical inflammation levels together constitute the initial physiological context that influences training responsiveness. Behavioral factors, including changes in daily non-exercise activity thermogenesis (NEAT), degree of nutritional intake alignment, sleep quality, and stress management, significantly modulate the net effect generated by the training. Psychological factors, such as motivation level, self-efficacy, and tolerance for exercise-induced discomfort, indirectly determine the extent to which intervention effects are achieved by influencing training effort and long-term adherence. Understanding these influencing factors helps explain heterogeneous outcomes and provides a theoretical basis for progressing towards personalized exercise prescriptions.

3.3 Theoretical and Methodological Prospects for Optimizing HIIT Protocols

Future research on optimizing HIIT protocols must shift from extensive application to refined design, with the core focus lying in a deeper exploration of the dose-response relationships of training variables. Training intensity, the duration of individual high-intensity intervals, the nature and duration of recovery intervals, weekly frequency, and the total intervention period constitute a multidimensional variable space. For the specific population of university students with obesity, there is currently no definitive conclusion regarding which combination of these variables achieves an optimal balance among safety, adherence, and effectiveness. For instance, sprint interval training with lower volume but higher intensity may differ fundamentally from HIIT variants with higher volume but slightly lower intensity, both in the pathways and the efficiency of metabolic adaptation and physical fitness improvement. This distinction requires clarification through rigorous comparative studies.

Methodological advancement is a necessary support for protocol optimization. Utilizing wearable devices and mobile health technologies for real-time monitoring and feedback of physiological data to dynamically adjust training loads represents a significant direction for enhancing personalization. Regarding outcome assessment, multi-omics approaches, such as metabolomics and proteomics, should be integrated to identify biomarkers capable of predicting training responsiveness or early training adaptations, thereby enabling more sensitive and prospective evaluation of intervention effects. Furthermore, examining HIIT within an overall framework of health behavior promotion-exploring its interactive and integrative effects with other lifestyle elements such as nutritional intervention, sleep management, and stress regulation-is key to revealing its long-term sustainable impact. Future research designs must move beyond singular fitness metrics to increasingly focus on the potential benefits of HIIT for broader health outcomes, including quality of life, cognitive function, and mental health, in order to comprehensively assess its application value.

Conclusion

Through theoretical synthesis and mechanistic analysis, this study demonstrates that the intervention effects of High-Intensity Interval Training (HIIT) on the physical fitness of university students with obesity are rooted in the extensive physiological and molecular adaptations triggered by its deep, cyclical mobilization of the body's energy supply systems. The realization of its effects occurs via multiple interconnected pathways, including the regulation of energy metabolism, the optimization of cardiopulmonary and neural functions, and the metabolic remodeling of skeletal muscle. These ultimately manifest as synergistic improvements across multidimensional physical fitness indicators such as cardiorespiratory endurance, body composition, and muscular function. However, significant individual variability in response, jointly caused by genetic background, baseline physiological status, and behavioral-psychological factors, highlights the limitations of standardized protocols. Future research should focus on exploring the refined dose-response relationships of various HIIT training variables specific to this population. It should also leverage wearable technologies and multi-omics approaches to advance intervention protocols towards dynamic personalization and predictive capability. Furthermore, placing HIIT within an integrative health behavior promotion framework to examine its long-term effects and benefits on broader indicators such as quality of life and mental health will be crucial for comprehensively assessing its application value.

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