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Effects of High-Intensity Interval Training on Cardiorespiratory Fitness in Healthy Young Adults: A Narrative Review

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Abstract. High-intensity interval training (HIIT) is widely used to improve cardiorespiratory fitness (CRF), but improvements may vary according to training design and individual characteristics. This narrative review evaluates the effects of HIIT on CRF in healthy young adults, with a particular focus on changes in maximal oxygen uptake (VO_2max) and peak oxygen uptake (VO_2peak). Current evidence shows that HIIT can improve both VO_2max and VO_2peak, although the response may be influenced by exercise intensity, interval duration, training volume, training duration and baseline fitness. These improvements may involve central cardiovascular changes, including increases in stroke volume and maximal cardiac output, together with peripheral changes such as increased skeletal muscle capillarization and mitochondrial capacity. Autonomic and vascular changes may also occur, although their contribution to improvements in VO_2max remains less clear in healthy young adults. Overall, HIIT is an effective approach for improving CRF in this population, but differences in training protocols and participant characteristics should be considered when interpreting the response.

Keywords: High-intensity interval training, cardiorespiratory fitness, VO_2max, cardiovascualar adaptation, young adults

1. Introduction

Sedentary behavior has become increasingly common among young adults and has been associated with lower levels of physical fitness [1]. Cardiorespiratory fitness (CRF) reflects the ability of the cardiovascular and respiratory systems to supply oxygen during prolonged exercise. It is an important indicator of health, with higher CRF associated with a lower risk of cardiovascular disease and all-cause mortality [2]. Maximal oxygen uptake (VO_2max) is widely used to assess CRF and represents the highest rate at which oxygen can be taken up and used during exercise. Improving VO_2max is therefore an important aim of exercise training in both health and fitness settings. High-intensity interval training (HIIT) has received increasing attention as an effective method for improving CRF. Previous evidence has shown that HIIT can produce significant increases in VO_2max and VO_2peak in healthy adults [3, 4]. It can also produce improvements with relatively short training periods and low training volumes, making it a potentially time-efficient approach to

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aerobic training [4]. However, the size of the improvement varies between studies and individuals. Differences in training intensity, interval duration, training frequency and baseline fitness may contribute to this variation. The mechanisms that may explain these differences have also not been fully explored in healthy young adults. The effects of HIIT on CRF may also be related to changes in central cardiovascular function, skeletal muscle oxygen use, and autonomic and vascular function. This narrative review focuses on the effects of HIIT on CRF in healthy young adults. It examines changes in VO_2max and VO_2peak, as well as the physiological mechanisms that may contribute to these changes and the factors influencing the training response. The review aims to assess the effectiveness of HIIT for improving CRF and explore why its effects may vary between individuals.

2. High-intensity interval training and cardiorespiratory fitness

2.1. Definition and physiological characteristics of HIIT

HIIT is a form of interval exercise involving repeated periods of high-intensity work separated by periods of lower intensity exercise or rest. The duration and intensity of both the work and recovery periods can vary considerably between HIIT protocols. Other factors, including the number of intervals, number of sets and exercise mode, can also be adjusted to change the training session [5]. These differences mean that HIIT does not refer to a single standardized training protocol, but includes a range of training designs that vary in exercise intensity and overall training load. The definition of high intensity also varies across the literature. When HIIT is used to improve health and fitness, it generally involves repeated periods of exercise at a relatively high intensity, which can be prescribed using measures such as heart rate, oxygen uptake or perceived exertion [6]. Sprint interval training (SIT), a subcategory of interval exercise, employs maximal or near-maximal effort, differentiating it from conventional HIIT in both absolute intensity and intensity and training structure. Such protocol heterogeneity is an important source of outcome variation when interpreting cardiorespiratory fitness adaptation across studies.

2.2. Effect of HIIT on VO_2max and VO_2peak

Current evidence consistently demonstrates that HIIT is an effective strategy for improving maximal oxygen uptake (VO_2max) and peak oxygen uptake (VO_2peak) in healthy adults, which are widely used indicators of cardiovascular fitness. A meta-analysis including 28 studies and 723 healthy adults aged 18-45 years, reported a large beneficial effect of HIIT on VO_2max compared with no-exercise controls, with an average improvement of 5.5 $mL \cdot kg^{-1} \cdot min^{-1}$ [3]. Similarly, another study of 53 randomized controlled trails also found significant improvement in VO_2max and VO_2peak following HIIT across different protocols. Notably, even short intervals (≤30 s), low session volumes (≤5 min), and interventions lasting ≤4 weeks produced beneficial effects, suggesting that HIIT can provide improvements in cardiorespiratory fitness even with relatively low training volumes. Evidence also suggests that HIIT may provide greater improvements in VO_2max than traditional continuous endurance training. A study examining the effect of HIIT and endurance training on VO_2 max reported a greater improvement with HIIT, with an increase of 5.5 $mL \cdot kg^{-1} \cdot min^{-1}$ compared with 4.9 $mL \cdot kg^{-1} \cdot min^{-1}$ following endurance training [3].

However, the level of VO_2max improvement may also depend on training variables and individual fitness. Training duration may be particularly important, as longer interventions have been associated with greater improvements in VO_2max [3]. This is consistent with evidence suggesting that greater improvements in VO_2max are associated with intervals lasting at least 2 min,

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session volume of at least 15 min, and training periods of 4-12 weeks [4]. These findings suggest that sufficient exercise duration and volume may be important for maximizing improvements in VO_2max following HIIT. Initial fitness may also affect improvement in VO_2max, with greater increases observed in less-fit individuals [3]. Therefore, although HIIT consistently improves VO_2max and VO_2peak, the extent of improvement is likely to depend on both training design and initial fitness. Shorter interventions of four weeks or less can still improve VO_2max, while training lasting 4-12 weeks may produce greater improvements [4].

3. Physiological mechanisms underlying improvements in CRF

3.1. Central cardiovascular adaptations

The improvement in VO_2max following HIIT may partly result from cardiovascular adaptations that increase oxygen delivery to the working muscles. According to the Fick principle, VO_2 is determined by cardiac output (Q) and the arteriovenous oxygen difference [7]. As cardiac output is the product of heart rate (HR) and stroke volume (SV), an increase in maximal SV may increase maximal cardiac output. Evidence suggests that increased SV is an important physiological change following high-intensity interval training. One study reported that eight weeks of aerobic interval training at 90-95% HRmax increased SV by approximately 10%. VO_2max also increased by 5.5% and 7.2% in the two interval training groups [8]. The increases in both SV and VO_2max suggest that improved central cardiovascular function may have contributed to greater aerobic capacity. However, it remains unclear whether the increase in VO_2max was mainly due to greater SV, as the study did not examine changes in peripheral oxygen extraction.

More direct evidence comes from a study of active young men and women, in which maximal cardiac output increased from 20.0 to 21.7 L/min following HIIT [9]. Maximal SV also increased, while maximal HR remained unchanged. In addition, no significant change in arteriovenous oxygen difference was observed. These findings suggest that, in this study, the improvement in VO_2max was more closely related to enhanced central oxygen delivery than to greater peripheral oxygen extraction. This may not be the case to all forms of HIIT, as the relative contribution of central and peripheral factors may differ depending on participant characteristics and training protocol. One possible explanation for the increase in SV is improved ventricular filling. In previously untrained young men, six HIIT sessions over 12 days increased exercise SV and cardiac output, which were associated with an increase in end-diastolic volume [10]. Greater end-diastolic volume allows more blood to fill the ventricle before contraction, which may help increase SV during exercise. Although ventricular filling improved following HIIT, similar changes were also observed after continuous moderate intensity training, suggesting that this response may not be specific to HIIT.

3.2. Peripheral adaptations

In addition to central cardiovascular changes, improvements in VO_2max following HIIT may also involve changes within skeletal muscle. According to the Fick principle, peripheral factors influence VO_2 through the arteriovenous oxygen difference [7]. Increased muscle capillarization and mitochondrial capacity may improve oxygen utilization by the working muscles during exercise. Greater capillarization may support oxygen delivery from the blood to active muscle fibers. A study of healthy adults found that exercise training can increase skeletal muscle capillarization, with high-intensity interval training producing greater changes in the capillary-to-fiber ratio than lower-intensity training in sedentary individuals [11]. While increased capillarization may improve oxygen

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delivery within skeletal muscle, the ability of muscle fibers to use the available oxygen is also important. Mitochondrial changes may therefore contribute to improvements in aerobic capacity in response to HIIT. A recent study reported an approximately 27% increase in mitochondrial content after high-intensity training [12]. Overall, increased capillarization and mitochondrial capacity may improve the delivery and use of oxygen within skeletal muscle, supporting the increase in VO_2max after HIIT. The extent of these changes may differ between individuals, particularly with different initial fitness levels.

3.3. Vascular adaptation

HIIT may also influence cardiorespiratory fitness through changes in autonomic regulation and vascular function. These changes may support cardiovascular control and blood flow during exercise, although their direct contribution to improvements in VO_2max remains less clear.

Changes in cardiac autonomic control have been observed after HIIT. A systematic review of six studies reported improvements in parasympathetic and sympathetic regulation, measured using heart rate variability (HRV) [13]. Increased parasympathetic activity at rest may indicate improved cardiac autonomic regulation after training. However, the review included only a small number of studies with different populations and training protocols, and some HRV measures showed inconsistent responses [13]. Therefore, while HIIT appears to influence autonomic regulation, there is limited evidence that these changes directly contribute to the increase in VO_2max. Vascular function may also change in response to HIIT. A review of 36 studies found that HIIT improved flow-mediated dilation (FMD), a measure of endothelial function, by 1.59% more than moderate-intensity continuous training and 3.80% more than control [14]. However, subgroup analysis found no significant improvement in participants without cardiometabolic disease [14]. This suggests that the vascular response to HIIT may be less pronounced in healthy individuals, who may already have relatively normal vascular function.

However, the relationship between endothelial function and VO_2max is less clear in healthy young adults. In a study of 13 recreationally active young men, both FMD and VO_2max increased significantly after two four-week periods of HIIT [15]. However, FMD responses varied considerably between participants, making it difficult to directly link the improvement in endothelial function to the increase in VO_2max. The small sample, which included only men, should also be considered when interpreting these findings. Overall, autonomic and vascular changes may support cardiovascular function after HIIT, but their direct role in improving VO_2max in healthy young adults remains less certain than the central and skeletal muscle changes discussed above. Current evidence in healthy young adults is limited by small samples and short training periods, making it difficult to determine whether improvements in vascular function directly contribute to the increase in VO_2max.

4. Factors influencing the cardiorespiratory response to HIIT

4.1. Training intensity and protocol

The improvement in VO_2max with HIIT may be influenced by both exercise intensity and the interval duration. In moderately trained healthy men, interval training at 90-95% HRmax produced greater increases in VO_2max than continuous training at lower intensities, despite similar frequency and total work [8]. This suggests that exercising at a higher intensity may provide a stronger stimulus for improving aerobic capacity. The duration of each work interval may also affect the

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training response. A study found that greater improvements in VO_2max occured when HIIT intervals lasted at least two minutes [4]. Similar trends were observed for training volume, with HIIT sessions including at least 15 minutes of high-intensity work producing larger improvements than lower-volume protocols [4]. Nevertheless, short-interval, low-volume HIIT protocols still produce meaningful cardiorespiratory benefits relative to no-exercise controls. Therefore, protocols featuring longer intervals and higher total volume are preferable when maximizing VO_2max adaptation is the primary goal, whereas shorter protocols remain a viable time–efficient alternative.

4.2. Training duration and frequency

Training duration may also affect the improvement in VO_2max with HIIT. Two studies reported greater increases in VO_2max with longer training periods [3, 4]. Nevertheless, shorter training periods were still effective, suggesting that training duration may influence the size of the improvement rather than determine whether an improvement occurs. The effect of weekly training frequency is less clear. In healthy inactive adults, eight weeks of HIIT performed either two or three times per week increased VO_2peak by 10.8% and 13.6%, respectively, with similar improvements between the two groups [16]. This suggests that increasing weekly frequency does not necessarily result in a greater improvement in aerobic capacity. Overall, longer training periods appear to produce greater increases in VO_2max, whereas increasing the number of weekly sessions does not necessarily lead to greater benefits.

4.3. Baseline cardiorespiratory fitness

The improvement in VO_2max after HIIT may vary according to baseline fitness. A study of healthy adults found that participants with lower initial fitness showed greater increases in VO_2max, with an additional improvement of approximately 3.2 $mL \cdot kg^{-1} \cdot min^{-1}$ compared with those with higher baseline fitness [3]. This suggests that individuals with lower aerobic fitness may have greater capacity for improvement when starting HIIT. A similar pattern has been observed in peripheral changes. In sedentary individuals, high-intensity interval training increased skeletal muscle capillarization, whereas no further increase was observed in already trained individuals [11]. Although these findings do not show that greater capillarization directly contributes to the larger VO_2max response in less fit individuals, they suggest that initial fitness may influence several physiological responses to training. Therefore, the effect of HIIT on VO_2max should be considered in relation to baseline fitness level. Young adults with lower initial fitness may achieve greater improvements from HIIT, whereas those who are already trained may show smaller changes. This suggests that baseline fitness should be considered when evaluating the expected benefits of HIIT.

4.4. Participant characteristics (age, gender, habitual physical activity)

Participant characteristics may also affect the response to HIIT, although differences in VO_2max improvements between women and men appear to be relatively small. A review of healthy adults found similar improvements in VO_2max in women and men. This suggests that sex may not be a major factor affecting improvements in VO_2max after HIIT. Interestingly, baseline training status and training duration showed a stronger relationship with differences in VO_2max responses than sex [17]. This is consistent with earlier evidence showing that initial fitness and training design affect the VO_2max response to HIIT [3, 4]. Age may also affect the response to exercise, but it is less relevant to the present review because the population is limited to healthy young adults. In addition,

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the age analysis in the review was limited by overlapping age groups [17]. Therefore, differences between age groups are included only as supporting evidence rather than a central part of the discussion.

5. Conclusion

Overall, current evidence suggests that HIIT is an effective approach for improving cardiorespiratory fitness in healthy young adults, with consistent increases in VO_2max and VO_2peak reported across different training protocols. The size of these improvements may depend on how HIIT is performed. Higher exercise intensity, longer intervals and greater training volume may produce larger improvements, while shorter and lower volume protocols can still be effective. Baseline fitness also appears to influence the response, with greater improvements generally observed in individuals with lower initial fitness. These findings suggest that the benefits of HIIT are influenced by both training design and individual characteristics. The improvement in cardiorespiratory fitness may involve both central and peripheral changes. Increases in stroke volume and maximal cardiac output may improve oxygen delivery during exercise, while greater skeletal muscle capillarization and mitochondrial capacity may support oxygen use within the muscle. Autonomic and vascular changes may also occur after HIIT, although their direct contribution to improvements in VO_2max in healthy young adults remains less clear. Several limitations should be considered when interpreting the current evidence. HIIT protocols vary considerably between studies, and some studies include small samples or relatively short training periods. Differences in baseline fitness and participant characteristics also make direct comparisons between studies difficult. Future research should therefore use more consistent HIIT protocols, include larger samples and longer training periods, and clearly define the characteristics of healthy young adults. Future studies should examine central, peripheral and vascular changes together to better understand their contribution to improvements in cardiorespiratory fitness.

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