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Constant and Variable-Intensity Distribution High-Intensity Interval Training Approaches: Which Is More Effective in Increasing Time Spent at Maximal Oxygen Uptake? A Narrative Review

Sabit ve Değişken Şiddet Dağılımlı Yüksek Şiddetli İnterval Antrenman Yaklaşımları: Hangisi Maksimal Oksijen Tüketim Düzeyinde Geçirilen Zamanı Artırmada Daha Etkilidir? Anlatımsal Bir Derleme

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CONSTANT AND VARIABLE-INTENSITY DISTRIBUTION HIGH-INTENSITY INTERVAL TRAINING APPROACHES: WHICH IS MORE EFFECTIVE IN INCREASING TIME SPENT AT MAXIMAL OXYGEN UPTAKE? A NARRATIVE REVIEW

ABSTRACT

The total time spent at high percentages of maximal oxygen uptake ($\dot{V}O_{2max}$) during a high-intensity interval training (HIIT) session is considered one of the key acute responses for inducing long-term improvements in $\dot{V}O_{2max}$. Therefore, over the past 15 years, many studies have focused on maximizing the time spent near $\dot{V}O_{2max}$ in constant-intensity HIIT protocols by manipulating variables such as work duration, number of repetitions, recovery duration, and recovery intensity. More recently, however, a limited number of studies have employed strategies that modify the intensity distribution within work bouts in order to increase this time. This narrative review aimed to examine the potential of HIIT strategies with variable intensity distributions to maximize the time spent near $\dot{V}O_{2max}$ compared with constant-intensity HIIT protocols. Accordingly, fast-start, varied-intensity, linearly varying, and stepwise decreasing-intensity protocols were addressed. The findings indicate that, when sufficiently long work bouts are applied to allow $\dot{V}O_2$ to reach maximal levels, variable intensity-distribution HIIT approaches can increase the time spent at $\dot{V}O_{2max}$ compared with traditional constant-intensity protocols. Furthermore, these strategies were found to elicit greater total $\dot{V}O_2$ consumption despite producing similar blood lactate responses and ratings of perceived exertion. These results suggest that HIIT approaches incorporating variable intensity distributions may impose higher aerobic demands.

Keywords: Fast-Start, High-Intensity Interval Training, Linearly Varying, Maximal Oxygen Uptake, Varied-Intensity.

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SABİT VE DEĞİŞKEN ŞİDDET DAĞILIMLI YÜKSEK ŞİDDETLİ İNTERVAL ANTRENMAN YAKLAŞIMLARI: HANGİSİ MAKSİMAL OKSİJEN TÜKETİM DÜZEYİNDE GEÇİRİLEN ZAMANI ARTIRMADA DAHA ETKİLİDİR? ANLATIMSAL BİR DERLEME

ÖZ

Bir yüksek şiddetli interval antrenman (HIIT) seansı sırasında maksimal oksijen tüketiminin ($\dot{V}O_{2maks}$) yüksek yüzdelerinde geçirilen toplam süre, $\dot{V}O$-

$_{2maks}$'ı uzun vadede geliştiren temel akut yanıtlardan biri olarak kabul edilmektedir. Bu nedenle, son 15 yılda yapılan birçok çalışma, yüklenme süresi, tekrar sayısı, dinlenme süresi ve dinlenme yoğunluğu gibi değişkenleri manipüle ederek sabit şiddetli HIIT protokollerinde $\dot{V}O_{2maks}$'a yakın geçirilen zamanı maksimize etmeye odaklanmıştır. Ancak son dönemde sınırlı sayıda çalışma, bu süreyi artırabilmek amacıyla yüklenme periyotları içindeki şiddet dağılımını değiştiren stratejiler kullanmıştır. Bu anlatımsal derleme, sabit şiddetli HIIT protokollerine kıyasla, değişken şiddet dağılımına sahip HIIT stratejilerinin $\dot{V}O_{2maks}$'a yakın geçirilen süreyi maksimize etme potansiyelini incelemeyi amaçlamıştır. Bu bağlamda hızlı başlangıçlı, çeşitlendirilmiş şiddetli, doğrusal olarak değişen ve basamaklı azalan şiddetli protokoller ele alınmıştır. Bulgular, $\dot{V}O_2$'nin maksimale ulaşmasına izin verecek kadar yeterli uzunluktaki yüklenme periyotları uygulandığında, değişken şiddet dağılımlı HIIT yaklaşımlarının geleneksel sabit şiddetli protokollere kıyasla $\dot{V}O_{2maks}$ düzeyinde geçirilen süreyi artırabildiğini göstermektedir. Ayrıca, bu stratejilerin benzer kan laktat yanıtları ve algılanan efor derecesine rağmen daha yüksek toplam $\dot{V}O_2$ tüketimi sağladığı bulunmuştur. Bu sonuçlar, değişken şiddet dağılımlarını içeren HIIT yaklaşımlarının daha yüksek aerobik talepler oluşturabileceğini ortaya koymaktadır.

Anahtar Kelimeler: Değişken Şiddetli, Doğrusal Değişen, Hızlı Başlangıç, Maksimal Oksijen Tüketimi, Yüksek Şiddetli İnterval Antrenman.

INTRODUCTION

Exercising within the severe-intensity domain or at an intensity close to maximal oxygen uptake ($\dot{V}O_{2max}$) imposes substantial stress on the body's oxygen transport and utilization systems, which plays a critical role in improving endurance performance (Midgley & McNaughton, 2006; Buchheit & Laursen, 2013). There are various training modalities that aim to enhance $\dot{V}O_{2max}$ and endurance performance (Buchheit & Laursen, 2013; Norouzi et al., 2023). One such method that enables athletes to extend their time at high intensities is high-intensity interval training (HIIT) (Midgley & McNaughton, 2006; Buchheit & Laursen, 2013). HIIT is performed as repeated work bouts at a constant intensity above the lower boundary of the severe domain, interspersed with short recovery periods that do not permit full recovery (Figure 1).

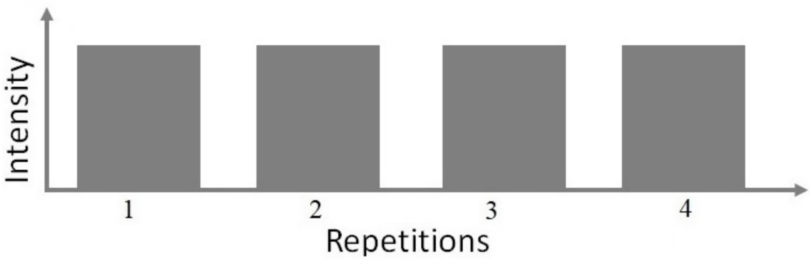

Figure 1. Constant-intensity HIIT protocol.

Each work bout is performed at a constant high intensity, separated by recovery periods. Gray bars denote work; white gaps denote recovery.

During a HIIT session, attaining a near-maximal $\dot{V}O_2$ level (high %$\dot{V}O_{2max}$) and accumulating time at ≥ 90% $\dot{V}O_{2max}$ are considered key factors for enhancing the central and peripheral adaptations that improve $\dot{V}O_{2max}$ and endurance performance (Laursen & Jenkins, 2002; Buchheit & Laursen, 2013). Accordingly, these two acute responses are considered as critical stimuli for evaluating the effectiveness of HIIT (Thevenet et al. 2007; Norouzi et al., 2023; Odden et al., 2024). Based on this premise, numerous studies over the past 15 years have focused on maximizing the time spent near $\dot{V}O_{2max}$ in HIIT sessions by manipulating variables such as intensity, work-bout duration, number of repetitions, recovery duration, and recovery intensity (Buchheit and Laursen, 2013; Turnes et al. 2016; Norouzi et al. 2023). Constant-intensity HIIT protocols rely on an equal workload distribution, with constant intensity maintained throughout the work periods (Buchheit and Laursen, 2013; Thron et al., 2024). Indeed, with appropriate selection of work rate and optimization of work and recovery durations, constant-intensity HIIT protocols have enabled athletes to reach and to successfully extend the time accumulated near $\dot{V}O_{2max}$ (Norouzi et al. 2023; Odden et al. 2024). In addition to these well-established approaches, the literature also presents several alternative methods (e.g., fast-start, varied-intensity, linearly varying, and stepwise decreasing-intensity protocols). However, many of these have received limited attention. One such underexplored strategy involves manipulating the intensity distribution within the work intervals (Mølmen and Rønnestad, 2024). Although relatively neglected, this method has shown promising results.

Including a higher-intensity segment at the onset of exercise accelerates $\dot{V}O_2$ kinetics and allows maximal values to be reached more quickly (Bailey et al., 2011). Recent evidence indicates that this approach has the potential to increase the time spent near $\dot{V}O_{2max}$ compared with constant-intensity protocols (Bossi et al., 2020;

Rønnestad et al., 2022). Continuing the work at a lower intensity within the severe domain thereafter helps maintain the elevated $\dot{V}O_2$ level. The basis of this strategy is the physiological relationship between phosphocreatine (PCr) depletion and the rise in $\dot{V}O_2$ (Chance and Williams, 1955; Whipp and Mahler, 1980; Rossiter et al., 2002). As is well known, the faster [PCr] declines, the faster $\dot{V}O_2$ increases (Wilson, 2015). Therefore, HIIT protocols that aim to stimulate $\dot{V}O_{2max}$ often begin the work period at a higher intensity and then lower the intensity after a certain duration (Lisbôa et al. 2015; Lisbôa et al., 2019; Bossi et al. 2020; Rønnestad et al., 2022). Moreover, the rapid initial intensity increase is likely to heighten motor unit recruitment and muscle activation, with particular emphasis on the quadriceps (Hodson-Tole and Wakeling, 2009; Heinonen et al., 2012). In fast-start, varied-intensity, and stepwise decreasing-intensity HIIT approaches that incorporate workload distribution, the presence of multiple high-intensity surges within a work period may promote more homogeneous activation across the quadriceps and recruit a larger pool of motor units (Rønnestad et al., 2021). This can increase the contribution of low-efficiency, fast-fatiguing motor units, elevate adenosine diphosphate concentrations (Vanhatalo et al., 2011), promote stronger activation of oxidative phosphorylation, and thereby contribute to higher $\dot{V}O_2$. As a result, these physiological processes may allow a longer time at ≥ 90% $\dot{V}O_{2max}$.

The purpose of this narrative review is to summarize current findings on HIIT approaches that aim to maximize the time spent near $\dot{V}O_{2max}$ and to underscore the significance of exploring intensity distribution strategies within work intervals. As the existing evidence suggests, there remains a need for methodologically rigorous and long-term investigations comparing different intensity profiles in this line of research.

Fast-Start HIIT

In the fast-start HIIT approach, the initial work repetitions are performed at a higher exercise intensity, after which the intensity during subsequent repetitions is held lower (Figure 2A) (de Aguiar et al., 2013). This strategy is intended to accelerate the $\dot{V}O_2$ response and reduce the time required to reach $\dot{V}O_{2max}$, thereby enhancing exercise tolerance during later intervals and increasing the overall time spent near $\dot{V}O_{2max}$.

De Aguiar et al. (2013) implemented a protocol consisting of 30-second work intervals interspersed with 15 seconds of passive recovery. Three HIIT conditions were compared: two constant-intensity protocols, in which participants performed all repetitions at a constant running speed of either 105% or 125% critical speed, and a fast-start protocol, where the initial repetitions were performed at 125% critical speed before the speed was reduced to 105% in the remaining intervals. The transition from high to lower intensity in the fast-start condition was individualized, occurring when 50% of each participant's anaerobic running capacity had been expended. All protocols were performed to exhaustion. Despite the longer total exercise duration in the 105% critical speed protocol, the time spent at or above 95% $\dot{V}O_{2max}$ was highest in the fast-start condition, reaching 286 seconds, compared to 106 and 116 seconds in the constant-intensity HIIT protocols at 105% and 125% critical speed, respectively. These findings indicate that the fast-start strategy may accelerate $\dot{V}O_2$ kinetics and increase the time spent near $\dot{V}O_{2max}$.

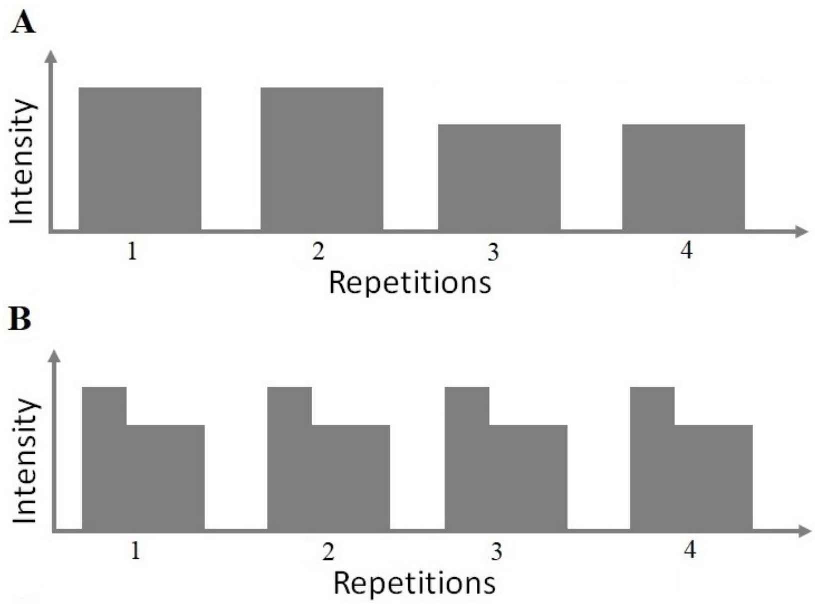

Figure 2. Fast-Start HIIT approach

A) Single-step, repetition-wise decreasing intensity: Each work bout is maintained at a constant high intensity; however, subsequent repetitions are performed at a lower intensity (1–2 high, 3–4 lower). B) Two-step within-bout (fast-start): Each work bout begins at a higher intensity and then continues at a lower, constant intensity.

Another fast-start implementation involves beginning the initial portion of each work period at a higher intensity, followed by a reduction in intensity within the same work period (Figure 2B). Rønnestad et al. (2019) applied this modified fast-start strategy, originally used by de Aguiar et al. (2013), to a group of well-trained cross-country skiers with the aim of enhancing oxygen uptake, and compared it against a constant-intensity HIIT protocol. Unlike the original design where speed adjustments occurred after completing repetitions, their protocol implemented speed changes based on a predefined elapsed time within each work period. Both HIIT protocols consisted of five 5-minute work bouts, each separated by 3-minute recovery intervals. In the fast-start protocol, each 5-minute work bout commenced with 1.5 minutes at 100% $\dot{V}O_{2max}$ velocity ($v\dot{V}O_{2max}$), followed by 3.5 minutes at 85% $v\dot{V}O_{2max}$.

In the constant-intensity HIIT protocol, participants maintained a constant speed corresponding to 90% $v\dot{V}O_{2max}$ throughout the work periods. All HIIT protocols were performed by roller-skiing on a motorized treadmill set at a 9% incline. During the 3-minute recovery periods, the first 2 minutes were passive, and the final minute consisted of active recovery at 7 $km{\cdot}h^{-1}$ on a 9% incline. The time spent above 90% $\dot{V}O_{2max}$ was 12.0 minutes in the fast-start HIIT protocol and 10.8 minutes in the constant-intensity HIIT protocol. Although, on average, the fast-start protocol provided approximately 70 seconds more time than the constant-intensity protocol, this difference was not statistically significant. Even so, because the smallest worthwhile improvements in elite athletes are quite small (about 1–2%), this 70-second difference may still offer a meaningful advantage as a training stimulus. Indeed, even in recreational cyclists, accumulating roughly 100 seconds more time above 90% $\dot{V}O_{2max}$ per session has been associated with the greatest improvements in $\dot{V}O_{2max}$ and intensity at the lactate threshold (LT) (Turnes et al., 2016).

To further explore the effects of pacing strategies on time spent at $\dot{V}O_{2max}$, Miller et al. (2023) aimed to compare the time spent at $\dot{V}O_{2max}$ during fast-start HIIT and constant-intensity HIIT in trained cyclists. The two protocols were matched so that anaerobic work capacity (W′) would be expended to a similar extent. This approach allowed the researchers to isolate the effects of intensity distribution on time spent at $\dot{V}O_{2max}$, without the results being influenced by differences in total exercise load. In both protocols, four 3-minute work bouts were performed, with 3 minutes of active recovery at 50 W between bouts. During the work bouts, intensity was adjusted in each repetition to allow the expenditure of 60% W′ (target W′). However, the within-bout distribution of W′ expenditure differed between protocols. In the fast-start protocol, 50% of the target W′ was consumed in the first minute, and the remaining 50% was consumed evenly across the second and third minutes (25% each), with this pattern repeated across all four intervals. In the constant-intensity protocol, the target W′ was distributed evenly across the 3-minute duration, at approximately 33.33% per minute. Total W′ expenditure was identical in both protocols. Nevertheless, in fast-start HIIT the power output was set higher in the first minute and lower in the subsequent two minutes, whereas in constant-intensity HIIT was kept constant across the entire work bout. The findings showed no significant difference between protocols in the total time spent at or above 90% $\dot{V}O_{2max}$ when W′ expenditure was matched. Theoretically, equating W′ may yield similar metabolic loading despite different pacing strategies. In addition, because participants exercised to exhaustion, both protocols may have produced comparable durations at or above 90% $\dot{V}O_{2max}$. Such practice may facilitate more rapid adaptation to severe-intensity exercise and help sustain performance during work bouts. However, when total anaerobic work is equalized, any superiority in time at or above 90% $\dot{V}O_{2max}$ may diminish, although small gains can still be valuable from a training perspective.

Varied-intensity HIIT

Varied-intensity HIIT is a strategy similar to the fast-start approach but involves more frequent and systematic changes in intensity within each work period (Figure 3) (Bossi et al., 2020; Rønnestad et al., 2022). The key difference from fast-start is the greater frequency of intensity shifts within the work bout (Bossi et al., 2020; Rønnestad et al., 2021 and 2022). The effect of this approach on increasing the time spent at ≥ 90% $\dot{V}O_{2max}$ is attributed to a faster $\dot{V}O_2$ response.

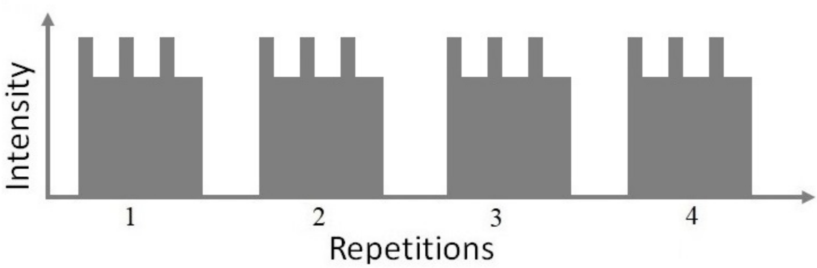

Figure 3. Varied-intensity HIIT approach

Each work bout is performed at a high base intensity, with several brief surges to a higher intensity inserted within the bout (illustrated as spikes). Gray shapes indicate the work bouts; the gaps between bouts indicate the recovery periods.

Bossi et al. (2020) compared varied-intensity HIIT with a constant-intensity HIIT. Both protocols comprised six 5-minute work bouts, separated by 2.5-minute active recovery periods at 30% peak power output (PPO). Although the distribution of power output within the work bouts differed, mean power output and total session duration were matched between protocols. In the varied-intensity HIIT protocol, each work bout consisted of three 30-second surges at 100% PPO, two intervening 1-minute blocks, and a final 1.5-minute segment at 77% PPO. In contrast, the constant-intensity HIIT protocol comprised steady 5-minute bouts at 84% PPO. Despite similar ratings of perceived exertion between protocols, the varied-intensity HIIT protocol produced a 43% greater time at ≥ 90% $\dot{V}O_2$max compared with the constant-intensity protocol (varied-intensity: 410 seconds; constant-intensity: 286 seconds). Moreover, the varied-intensity protocol elicited a higher total $\dot{V}O_2$ and an average oxygen uptake closer to $\dot{V}O_{2max}$, indicating a greater aerobic load. Notably, despite the increased aerobic demand, physiological and perceptual responses such as breathing frequency, heart rate, blood lactate concentration, rate of perceived exertion, and cadence did not increase significantly relative to the constant-intensity HIIT protocol.

Following these results, Rønnestad et al. (2021) compared a constant-intensity HIIT approach with fast-start HIIT and varied-intensity HIIT in trained male cross-country skiers. Each of the three HIIT approaches consisted of five 5-minute work bouts, separated by 3-minute recovery periods that included passive and active components. The protocols were matched for mean speed and total duration. In the fast-start HIIT protocol, the first 2 minutes of each 5-minute work bout were performed at 100% $v\dot{V}O_{2max}$, and the subsequent 3 minutes were performed at a speed calculated as LT + 0.20 × ($v\dot{V}O_{2max}$ – LT). In the varied-intensity HIIT approach, each work bout comprised three 40-second surges at 100% $v\dot{V}O_{2max}$ interspersed with three 1-minute blocks at LT + 0.20 × ($v\dot{V}O_{2max}$ – LT).

According to the findings, despite similar ratings of perceived exertion and pain score across the three protocols, the fast-start and varied-intensity HIIT protocols increased the time spent at ≥ 90% $\dot{V}O_{2max}$ by 10% and 14%, respectively, compared with constant-intensity HIIT. Consistent with the results of Bossi et al. (2020), Rønnestad et al. (2021) also reported that, despite the higher aerobic demand, physiological and perceptual responses such as breathing frequency, ventilation, heart rate, blood lactate concentration, ratings of perceived exertion, and pain did not increase significantly relative to the constant-intensity HIIT protocol. They also analyzed VO_{2max} responses by averaging %$\dot{V}O_{2max}$ across the first two minutes, the third minute, and the final two minutes of each work bout. For both the fast-start and varied-intensity conditions, $\dot{V}O_{2max}$ in the first two minutes and in the third minute was higher than in the constant-intensity protocol. In the final two minutes of the work bout, the varied-intensity condition produced a higher %$\dot{V}O_{2max}$ than the fast-start condition. These findings point to important physiological mechanisms. It is well established that high-intensity exercise is known to increase quadriceps muscle activation and motor unit recruitment. The presence of multiple high-intensity surges within a work bout may have recruited a larger pool of motor units in the quadriceps (Rønnestad et al., 2021). This could increase the contribution of low-efficiency, fast-fatiguing motor units, elevate oxygen consumption, and thereby extend the time spent at ≥ 90% $\dot{V}O_{2max}$ (Rønnestad et al., 2021). Although the fast-start HIIT approach can also enhance quadriceps activation, in HIIT models that employ relatively long work bouts such as 5 minutes, incorporating multiple high-intensity surges within the bout may provide a stronger stimulus to raise $\dot{V}O_2$ and prolong the time at or near $\dot{V}O_{2max}$. Because this approach includes both short and long efforts within the work period, it has the potential to confer physiological adaptations typical of both short and long HIIT models. Moreover, varied-intensity HIIT may be highly practical for endurance sports because it can simulate race-pace fluctuations at the start, middle, and end of an event.

Linearly Varying Intensity

Another variable intensity-distribution strategy is a linear varying-intensity HIIT in which the workload within each work bout changes linearly over time, either decreasing (Figure 4A) or increasing (Figure 4B). Wommer et al. (2022) compared three HIIT protocols: two linearly varying intensity approaches (linearly decreasing intensity and linearly increasing intensity) and a constant-intensity HIIT protocol. All three protocols consisted of 8 × 60-second work bouts interspersed with 60-second active recovery at 80% LT. Work was matched across protocols and the work-to-recovery ratio was 1:1. In the constant-intensity protocol, work bouts were performed at 100% PPO. In the linearly decreasing-intensity protocol, power output declined linearly from 110% PPO to 90% PPO across each repetition. In the linearly increasing-intensity protocol, it rose linearly from 90% PPO to 110% PPO. Their findings showed no significant differences among protocols in time spent at ≥ 90% $\dot{V}O_{2max}$ (constant: 274 seconds; decreasing: 313 seconds; increasing: 310 seconds). Similarly, mean $\dot{V}O_2$, the proportion of time ≥ 90% $\dot{V}O_{2max}$ relative to total work duration (57–65%), maximal heart rate, blood lactate concentration, and ratings of perceived exertion were comparable across protocols. Although not statistically significant, the proportion of time ≥ 90% $\dot{V}O_{2max}$ was 65% in both the decreasing and increasing HIIT conditions, versus 57% in the constant-intensity condition. This small yet potentially practical difference may have arisen from higher $\dot{V}O_{2max}$ responses observed in the early repetitions, particularly the 2nd, 3rd, and 4th, with a nonsignificant increase in the decreasing condition and a significant increase in the increasing condition. While these results did not translate into a clear advantage for time at $\dot{V}O_{2max}$, they suggest a limited effect in favor of the linear variable-intensity approaches. Possible reasons for the inconsistency with studies using varied-intensity HIIT that reported larger benefits (Bossi et al., 2020; Rønnestad et al., 2022) include the absence of exercise to exhaustion and the relatively short work-bout duration (60 seconds), which may have constrained the contribution of accelerated $\dot{V}O_2$ kinetics to time spent near $\dot{V}O_{2max}$.

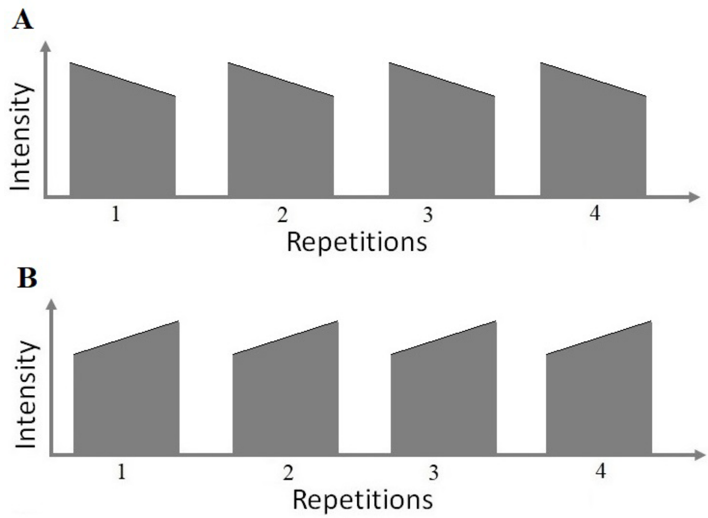

Figure 4. Linearly varying intensity HIIT approach

A) Linearly decreasing-intensity HIIT: each work bout starts at a higher intensity and decreases linearly over time. B) Linearly increasing-intensity HIIT: each work bout starts at a lower intensity and increases linearly over time. Gray shapes indicate the work bouts; the gaps between bouts indicate the recovery periods.

Stepwise Decreasing-Intensity HIIT approach

The stepwise decreasing-intensity HIIT approach is based on progressively lowering exercise intensity within each work period (Figure 5) (Lisbôa et al., 2015; Lisbôa et al., 2019). While it resembles fast-start and varied-intensity HIIT in terms of within-bout intensity variability, it differs by starting near the upper boundary of the severe-intensity domain and then reducing intensity gradually toward the lower boundary of the severe domain (Lisbôa et al., 2015; Lisbôa et al., 2019).

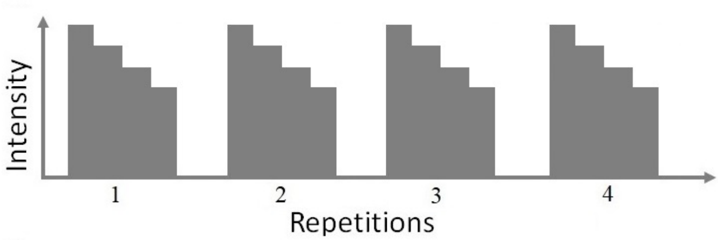

Figure 5. Stepwise Decreasing-Intensity HIIT approach

Each work bout starts at a high intensity and decreases stepwise across the bout. Gray shapes indicate the work bouts; the gaps between bouts indicate the recovery periods.

The rationale is that training at either the lower or the upper edge of the severe domain can be highly potent, yet each has drawbacks: at the lower edge, time to reach $\dot{V}O_{2max}$ is prolonged, whereas at the upper edge, time to exhaustion is very short (Lisbôa et al., 2015). Therefore, beginning each work bout at an intensity corresponding to the upper boundary of the severe domain and then tapering toward its lower boundary may accelerate $\dot{V}O_2$ kinetics and extend the time spent near $\dot{V}O_{2max}$. In the first study to examine this approach, Lisbôa et al. (2015) tested recreationally active men by dividing each work bout into four equal segments, each performed at a different intensity. The highest and lowest intensities were set at the highest workload that elicited $\dot{V}O_{2max}$ (I_{HIGH}, approximately 130% PPO) and at 110% critical power, respectively. The two middle intensities were individualized so that the total work performed above critical power would match that of a constant-intensity HIIT protocol. The duration of each work bout was determined from the time to exhaustion at I_{HIGH}. In the constant-intensity HIIT protocol, work was performed at I_{HIGH} for a duration equal to 60% of the time to exhaustion at I_{HIGH}. Both HIIT protocols used 1:1 active recovery at 30% PPO from the incremental test, and in both approaches participants exercised to volitional exhaustion. Compared with constant-intensity HIIT, the stepwise decreasing-intensity approach allowed participants to sustain the protocol longer (371 seconds vs 225 seconds). Time spent at ≥ 90% $\dot{V}O_{2max}$ (259 seconds vs 123 seconds) and at ≥ 95% $\dot{V}O_{2max}$ (186 seconds vs 76 seconds) was also significantly greater (Lisbôa et al., 2015). When expressed relative to total exercise time, the proportions of time ≥ 90% and ≥ 95% $\dot{V}O_{2max}$ were higher in the stepwise decreasing-intensity condition as well. Lisbôa et al. (2019) later employed a very similar design in well-trained cyclists and reported results consistent with those observed in recreational participants. These findings suggest that the increased time near $\dot{V}O_{2max}$ in this approach is not solely attributable to a longer time to exhaustion during HIIT, but may also be related to accelerated oxygen kinetics. Allowing work at multiple intensities within the severe domain, from the highest workload that elicits $\dot{V}O_{2max}$ down to lower workloads, may broaden the spectrum of potential adaptations.

Methodological Considerations

Fast-start strategies can accelerate the rise in $\dot{V}O_2$, particularly during longer work bouts, by reducing the time constant of pulmonary $\dot{V}O_2$ kinetics and delaying the onset of fatigue (Bailey et al., 2011; de Aguiar et al., 2013; Rønnestad et al., 2020). However, variable-intensity protocols that incorporate multiple high-intensity surges within the work interval appear more effective at sustaining elevated

$\dot{V}O_2$, since workload fluctuations enhance motor unit recruitment and oxidative phosphorylation activation (Hodson-Tole and Wakeling, 2009; Bossi et al., 2020; Rønnestad et al., 2021). When work intervals are short (e.g., one minute), achieving $\dot{V}O_{2max}$ is more challenging because of the delayed oxygen kinetics and limited time for the slow component to manifest (Hill et al., 2002; Caputo and Denadai, 2008). In such cases, protocols to exhaustion can compensate, as exercising to task failure extends time spent near or at $\dot{V}O_{2max}$ (Chidnok et al., 2013; De Lucas et al., 2013). The magnitude of these benefits is highly sensitive to methodological variables, including the duration of work bouts, the type of recovery (active vs. passive), the criteria used for exhaustion, and the basis of workload prescription, whether anchored to critical power/velocity, W′ and its reconstitution, or performance indices such as $v\dot{V}O_{2max}$ (Thevenet et al., 2007; Ferguson et al., 2010; Jones and Vanhatalo, 2017). In protocols that use only short intervals or omit task failure, the stimulus may be insufficient to maximize oxidative stress and cardiopulmonary engagement, thereby limiting adaptations (Midgley and McNaughton, 2006; Wommer et al., 2022).

Overall, HIIT models that strategically distribute workload within the work period, such as fast-start, varied-intensity, linearly varying, and stepwise decreasing-intensity approaches, show strong potential to increase the accumulated time at high $\dot{V}O_2$ during both short and long intervals. Yet, long-term and methodologically rigorous studies are still required to clarify whether these acute physiological responses translate into meaningful chronic adaptations and real-world performance improvements (Laursen and Jenkins, 2002; Odden et al., 2024).

CONCLUSIONS AND RECOMMENDATIONS

This narrative review suggests that HIIT approaches that deliberately alter the within-bout intensity distribution can, by accelerating $\dot{V}O_2$ kinetics, maximize the time spent at $\dot{V}O_{2max}$ compared with constant-intensity HIIT protocols. Stepwise decreasing-intensity, fast-start, and varied-intensity HIIT approaches create a higher early metabolic demand, rapidly engage oxidative phosphorylation, and facilitate the maintenance of high $\dot{V}O_2$ levels in the ensuing minutes. Athletes and coaches aiming to reach $\dot{V}O_{2max}$ and extend the time maintained at that level should look beyond constant-intensity HIIT and integrate fast-start, stepwise decreasing-intensity, or varied-intensity strategies into their planning. Because race pace in endurance disciplines is inherently variable, these protocols are better suited to reflecting race-specific demands and transferring to performance. In sum, HIIT protocols that incorporate variable workload distributions stand out as an effective tool for simulating race-specific physiological demands and provide a valuable training stimulus for performance development.

Conflict of Interest Statement

The authors declare that they have no personal or financial conflicts of interest related to this study.

Author Contribution Rates

Design of Study: RÇ(%90), EA(%10)

Data Acquisition: RÇ(%60), EA(%40)

Data Analysis: RÇ(%60), EA(%40)

Writing Up: RÇ(%60), EA(%40)

Submission and Revision: RÇ(%60), EA(%40)

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