Recently, high-intensity interval training (HIIT) has received much attention as a promising exercise option not only to improve aerobic fitness, but also to prevent and improve lifestyle-related diseases. Epidemiological studies have shown that the exercise volume, as determined by the product of exercise intensity, duration, and frequency, has been shown to be important for improvements in muscle mitochondrial activity and subsequent improvements in aerobic fitness, insulin sensitivity, and metabolic variables. Therefore, continuous moderate-intensity training has been widely recommended. On the other hand, the main contributor of HIIT to improvements in aerobic fitness and metabolic variables is its high-intensity nature, and many recent studies have shown results favoring HIIT when compared with conventional continuous training, despite its shorter exercise duration and smaller exercise volume. In this review, we aim to show the possible universal application of HIIT in a hospital setting, where athletes, sports lovers, and patients have sought medical advice and have the opportunity to undergo detailed evaluations, including an exercise stress test. For athletes, HIIT is mandatory to achieve further improvements in aerobic fitness. For patients, though higher levels of motivation and careful evaluation are required, the time constraints of HIIT are smaller and both aerobic and resistance training can be expected to yield favorable results because of the high-intensity nature of HIIT. (DOI: 10.2302/kjm.2016-0006-IR; Keio J Med 66 (2) : 19–24, June 2017)

**Keywords:** high-intensity interval training (HIIT), aerobic fitness, exercise intensity zone, polarized training

**Introduction**

Athletes tend to do too much exercise training, which can lead to overtraining-associated injuries. On the other hand, non-athletes, especially patients recommended to do more exercise by healthcare professionals, tend to do too little exercise training, partly because of time constraints.

HIIT is defined as repeated bouts of high-intensity exercise (i.e., from a maximal lactate steady state [MLSS]/respiratory compensation point [RCP] to all-out supra-maximal exercise intensity, as shown in Fig. 1), interspersed with recovery periods of low- or moderate-intensity exercise (active recovery) or complete rest (passive recovery). HIIT has been applied in competitive (endurance) sports before the beginning of the 21st century. On the other hand, because of the well-known dose (exercise volume)-response relation between physical activity and health, non-athletes who wish to improve their fitness and reduce their risk of chronic diseases have been recommended to engage in continuous moderate-intensity endurance exercise to maximize their exercise volume. However, during the last 20 years, interval training has been increasingly used by recreationally active individuals, and more recently, it has become popular among people with or at risk for cardiometabolic disorders to
Azuma K and Matsumoto H: Potential Universal Application of HIIT

3

In this review, we will discuss the characteristics and advantages of HIIT not only for athletes, but also for non-athletes who are attempting to improve their health.

Terminology

Weston et al.4 recently proposed a simple classification scheme for interval training based on exercise intensity as part of an effort to standardize terminology in future studies. In the narrow sense, the term “HIIT” is used to describe protocols in which the training stimulus is near the maximum or the target intensity is between 80% and 100% of the maximal heart rate. In contrast, “sprint interval training” (SIT) involves “all-out” or “supra-maximal” efforts, in which the target intensities correspond to workloads greater than what is required to elicit 100% of the maximal oxygen uptake (VO₂ max). In the current review, we have used HIIT in the broad sense (HIIT and SIT); however, SIT is recommended only among healthy athletes, since a safety concern exists with unchecked supra-maximal efforts.

The VO₂ max (more precisely, the VO₂ peak) is measured during an incremental exercise test using a metabolic cart, with ventilation and the expiratory concentrations of oxygen (O₂) and carbon dioxide (CO₂) being measured during the test. The VO₂ max is the value of oxygen consumption (mL/min) when the peak workload is reached during the test.

Exercise intensity

As shown in Fig. 1, the exercise (or training) intensity can be divided into 3 zones5 based on the first and second thresholds for lactate (lactate threshold [LT], and MLSS/onset of blood lactate accumulation [OBLA]) or ventilation (ventilatory threshold [VT] and RCP).6

Therefore, exercise intensity zone 1 corresponds to an intensity with minimal blood lactate accumulation and zone 2 corresponds to an intensity with blood lactate accumulation (below LT or VT), but at a rate where exercise is still sustainable with effort (below MLSS/OBLA or RCP). In contrast, zone 3 corresponds to an intensity that cannot be sustained for more than 5 minutes and should only be performed intermittently, as in HIIT. HIIT, high-intensity interval training. Reproduced and modified with permission from EMcArdle W, Katch F, Katch V: Exercise Physiology Nutrition, Energy, and Human Performance. 7th ed.7

---

**Fig. 1** Exercise training intensity zones as determined using respiratory gas analyses and blood lactate levels. During an incremental exercise test, there are two thresholds in pulmonary ventilation as well as the blood lactate level. The first ventilatory point (VT) comes from the buffering of lactic acid that begins to accumulate from increased glycolysis (anaerobic metabolism, LT) via bicarbonate, leading to excess CO₂ release and a disproportionate increase in pulmonary ventilation. When the blood lactate concentration systematically increases to 4.0 mM (OBLA), which is usually at the maximal level of steady-rate exercise and the maximal buffering rate of lactate via bicarbonate, further blood lactate accumulation causes plasma changes in pH, leading to hyperventilation (RCP). Therefore, exercise intensity zone 1 corresponds to an intensity with minimal blood lactate accumulation and zone 2 corresponds to an intensity with blood lactate accumulation, but at a rate where exercise is still sustainable with effort. In contrast, zone 3 corresponds to an intensity that cannot be sustained for more than 5 minutes and should only be performed intermittently, as in HIIT. HIIT, high-intensity interval training. Reproduced and modified with permission from EMcArdle W, Katch F, Katch V: Exercise Physiology Nutrition, Energy, and Human Performance. 7th ed.
intensity exercise in which the work volume (exercise intensity × exercise duration) is important as a training stimulus, the rationale for HIIT is to increase the training time spent near the VO_2 max (tVO_2 max), thus producing a stronger stimulus for cardiovascular and muscular adaptations, independent of the work volume. In fact, the efficacy of HIIT is suboptimal if the exercise intensity is inadequate, even among non-athletes. Boyd et al. examined the impact of low-intensity (70% peak work rate) and high-intensity (100% peak work rate) interval training (8–10 repetitions of a “1-minute on, 1-minute off” protocol, 3 times a week for 3 weeks) in overweight and obese young adults. They showed that improvements in aerobic fitness and exercise performance are intensity dependent, though changes in markers of skeletal muscle oxidative capacity are not different between the groups. This findings suggest that the additional improvements in VO_2 max are a result of a greater cardiovascular adaptation, and high-intensity training is necessary for cardiac improvement, which is a rate-limiting step in the improvement of aerobic fitness in athletes as well as healthy active individuals.

**HIIT protocols**

As shown in Fig. 2, in contrast to continuous exercise that only comprises the workload intensity and the total duration, HIIT consists of 5 main components: peak workload intensity, peak workload duration, recovery load, recovery duration, and the total exercise duration (or number of repetitions). The peak workload duration can range from a few seconds up to several minutes. The work phases are separated by periods of low- (or moderate)-intensity exercise or passive recovery with durations shorter than, equal to, or longer than the workload duration.

The accumulation of tVO_2 max is a key factor in maximizing the training stimulus to improve aerobic fitness and a variety of combinations of work duration and active/passive recovery have been reported.

For athletes, who must be able to compete while expending a supra-maximal effort during competitions, SIT (> 100% VO_2 max), rather than narrow-sense HIIT, is preferred, and the work duration tends to be short to achieve an all-out effort.

For non-athletes, Weston et al. recommended an HIIT protocol consisting of 4 sets of 4-minute work phases at > 85% of the maximal heart rate and 3-min recovery phases at 70% of the maximal heart rate in their meta-analysis. In fact, a recent report directly compared the two popular HIIT protocols, which were 4 × 4 min HIIT (4HIIT) and 10 × 1 min HIIT (1HIIT). Only 4HIIT increased VO_2 max after 6-week intervention, probably due to a longer tVO_2 max and improved estimated stroke volume. However, a shorter duration of the peak workload duration may lessen perceived exertion for individuals with a low aerobic fitness and may easily be sustained and be performed with more repetitions, resulting in a similar tVO_2 max. Matsuo et al. has proposed 3 × 3 min HIIT as a suitable protocol for Japanese as shown in his excellent review of HIIT studies among patients with obesity and metabolic syndrome.

A recent HIIT study in patients with coronary heart disease has showed that a larger increase in VO_2 max after 4 × 4 min HIIT was observed among patients who exercised with intensity in the higher end of the prescribed
85–95% of HRmax intensity zone. Again, this indicates that, from the perspective of maximizing the efficacy of HIIT, the most important point is the adequate peak workload intensity and subsequent tVO₂ max.

**Our own experience among healthy volunteers**

In our preliminary study, 12 healthy male subjects were assigned to two groups. One group performed HIIT using only a leg ergometer (LC-HIIT [N = 7]), and the other group performed HIIT using both leg and arm ergometers (LC- and AC-HIIT [N = 5]) twice weekly for 16 weeks. The training programs consisted of 8 to 12 sets of 90% VO₂ peak for 1 minute with a 1-minute very light active recovery. This protocol was originally proposed by Gibala et al. and is thought to be relatively easy to perform in real-world settings. The VO₂ peak and peak workload were measured during an LC incremental exercise test. The cross-sectional areas (CSA) of the trunk and thigh muscles were measured using magnetic resonance imaging.

The peak workload increased from the baseline in both the LC (23% ± 38%; P < 0.05) and the LC–AC groups (11% ± 9%; P < 0.05). The CSA of the quadriceps femoris muscles also increased from baseline in both the LC (11% ± 4%; P < 0.05) and the LC–AC groups (5% ± 5%; P < 0.05). Moreover, increases were also observed in the CSA of the psoas major muscle (9% ± 11%) and anterolateral abdominal muscle (7% ± 4%) in the LC–AC group. These case reports confirmed that HIIT is a time-efficient and very effective training option for simultaneously increasing aerobic fitness and muscle hypertrophy because of its high-intensity nature.

**Aerobic fitness gain by HIIT and “polarized training”**

Olympic medalists for endurance sports have used HIIT to train at velocities close to their individual competition velocities based on their own experiences, and it has now become clear that both high-intensity and high-volume training are key factors in optimizing exercise training. Traditionally, high-intensity but sustainable (intensity zone 2 in Fig. 1) endurance training (so called “threshold training”) has been recommended, since this type of training can maximize the training volume. However, recently, it has become clear that athletes, especially elite endurance athletes, endure very high training volumes (frequency, duration, and intensity); therefore, this training intensity (zone 2) is not only inadequate for improving already high aerobic fitness, but is also prone to causing incomplete recovery from frequent training and overtraining-related side effects. For example, Estevé-Lanao et al. divided 12 sub-elite runners into two separate groups that performed equal amounts of HIIT (8.4% of training with intensity zone 3). The difference between the groups in terms of their training was the amount of low- vs. moderate-intensity training that they performed. In one group, more low-intensity (zone 1) training was performed. In the other group, more moderate-intensity (zone 2) training was performed. It is interesting to note that the magnitude of the improvement in 10.4-km running performance at 5 months following the intervention was significantly greater in the group that performed more low-intensity (zone 1) training. In fact, it is becoming clear that elite athletes actually perform approximately 75% of their training at intensities clearly below LT (zone 1) and approximately 10%–20% of their training at intensities clearly above MLSS or OBLA (zone 3), which is called “polarized training.” It is assumed that high-volume, low-intensity (zone 1) training is needed for muscle adaptation and mechanical efficiency, whereas low-volume HIIT is needed for cardiac fitness gain; therefore, both of these training methods are important for athletes.

Since low aerobic fitness has been documented to be a strong predictor of risk for adverse health outcomes and is closely linked to higher all-cause mortality, HIIT might also be a promising exercise option for increasing aerobic fitness among non-athletes. In our preliminary study, an average gain of 6 mL/min.kg (1.7 Mets) of VO₂ was observed, which was mathematically associated with a 25% and a 32% lower risk of all-cause and cardiovascular disease mortality, respectively.

A recent meta-analysis for HIIT in patients with lifestyle-induced cardio-metabolic disease examined the efficacy and safety of HIIT for improving aerobic fitness compared with moderate-intensity continuous training. Ten studies with a total of 273 patients were included, and a significantly higher (almost double) increase in the VO₂ peak was observed in the HIIT group, with no apparent increase in risk.

**Body composition changes arising from HIIT**

Recent evidence has also highlighted the potential for low-volume HIIT to induce favorable changes in body composition. For example, a cycling-based SIT protocol involving 60 repetitions of 8-second all-out sprints interspersed with 12-second recovery periods and performed 3 times a week for 15 weeks was shown to be more effective than a moderate-intensity continuous training protocol involving 40 minutes of cycling at 60% of the VO₂ max for decreasing whole body and abdominal fat mass in women. The exact mechanisms responsible for mediating these changes in body composition after HIIT have not yet been clarified, though possible mechanisms include increased post-exercise oxygen consumption and changes in appetite.

Since most HIIT studies among non-athletes were performed for relatively short periods, it is less clear whether HIIT is efficacious for muscle hypertrophy. However, as in our preliminary study, because of its high-intensity
nature, HIIT can promote muscle hypertrophy in the lower legs and possibly in the trunk.24,26,27

Safety of HIIT among individuals at risk

Vigorous intensity exercise may be prone to acute but transient increases in the risk of sudden cardiac death and myocardial infarction in susceptible persons.28 This precaution is especially appropriate for individuals attempting high-intensity exercise to which they are unaccustomed, though there is no direct evidence that HIIT is equivalent to continuous vigorous exercise and, indeed, a recent retrospective risk analysis of HIIT among cardiac patients reported an event rate of only 1 non-fatal heart attack per 23,182 hours of HIIT in a supervised cardiac rehabilitation program.29 Since the incidence of heart attack is greatest among habitually least physically active individuals,28 HIIT can be safely applied after substantial warming up during each training session as well as a preceding medical check-up, stress test, and regular physical activity.

Moreover, ergometer exercise, which is usually used in HIIT, is preferable to conventional walking of 8,000–10,000 steps/day among patients with knee osteoarthritis, lumbar spinal canal stenosis, or a history of falls because of the lower impact on knees as a result of load distribution of their body by the saddle, a forward-bent posture, and no risk of falls during exercise.

Conclusion

For athletes, performing HIIT is important for aerobic fitness gains; for non-athletes who are motivated but have a “lack of time” barrier, HIIT is a very promising and time-efficient option for exercise training. Unlike conventional continuous moderate intensity exercise, the exercise intensity, not the work volume, is important. Therefore, it is also not necessary to perform longer periods of training in a gradual manner as it advances. For athletes, this is especially important for preventing unnecessary and somewhat harmful overtraining, which is often seen with high-volume, vigorous but still sustainable (zone 2) exercise. For non-athletes, because of its high-intensity nature, HIIT using an ergometer can provide a mixture of endurance and resistance exercise simultaneously without requiring difficult instructions. Moreover, HIIT using an ergometer is relatively safe when performed within an exercise intensity equal to or below the VO$_2$ peak (narrow sense HIIT, not SIT) measured during a preliminary incremental exercise test, and is relatively low impact for locomotive organs.

In hospital-based sports clinics, such as our institute, HIIT can be a very useful, universal training option for athletes and non-athletes, though the HIIT protocol needs to be more refined and individualized.

Acknowledgments

We thank the staff of the Institute for Integrated Sports Medicine for their assistance with the data collection and the maintenance of the training and evaluation equipment. We are also indebted to the staff of the Radiology Department for their support with the MRI and DXA measurements. The present study was financially supported by the Nateglinide Memorial Toyoshima Research and Education fund (2011) and a Grant-in-Aid for Young Scientists (B; no. 22700700).

References


