Narrative review

What training method to choose for achieving optimal adaptations and maximize endurance performance: a threshold, high volume, high intensity interval, or polarized training method?

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Abstract

To improve endurance performance athletes attempt to achieve optimal adaptations through training. Several training methods are well-known in the world of endurance sports, including threshold training, high volume training, high intensity interval training, and polarized training. These training methods show differences in intensity and volume, and stimulate therefore different adaptations. Over the years a lot of research has been done to indicate the effects of these training methods. Recently, more studies have included polarized training to their interest, and compared this type of training to other methods. Polarized training seems to be the most effective training method to improve endurance performance and is therefore currently a hot topic. This review explains how threshold, high volume, high intensity interval, and polarized training are performed, and what possible adaptations are achieved through these different types of training. Moreover, the underlying mechanisms behind the benefits of a polarized training distribution will be discussed.

Introduction

Endurance athletes who want to improve their exercise performance try to find the perfect training method for achieving maximal adaptations. Exercise training can alter physiological systems in such way that physical work capacity is enhanced through an improved capacity to deviate from resting homeostasis during subsequent exercise sessions (Hawley et al., 1997). The rate of these physiological changes depends to a great extent on volume and intensity. Three popular training methods among endurance athletes that differ a lot
from each other, are threshold training (THR), high volume training (HVT), and high intensity interval training (HIIT). THR is training at or close to the lactate threshold, and can improve endurance performance in untrained people (Denise et al., 1984). However, THR does not seem to improve endurance performance related variables in well-trained athletes (Stöggl & Sperlich, 2014). HVT consist of long periods of low intensity training (below the lactate threshold), whereas HIIT includes short intervals of high intensity training (above the lactate turn point). It is known that HVT improves fat and glucose utilization, which is beneficial for long lasting endurance performance (Romijn et al., 1993). HIIT, on the contrary, induces several central and peripheral adaptations, including increased stroke (Hergerud et al., 2007) and blood volume (Shepley et al., 1992), \(O_2\) extraction (Daussin et al., 2007) and improvements in aerobic and anaerobic metabolism (MacDougall et al., 1998). Despite both HVT and HIIT show important adaptations to endurance performance, recent studies have indicated that the combination of these two training methods provides the greatest physiological and performance adaptations in endurance athletes (Stöggl & Sperlich, 2014; Neal et al., 2012; Esteve-Lanao et al., 2007; Seiler & Kjerland, 2006; Muñoz et al., 2006). This combination of HVT and HIIT is known as polarized training (POL) and consists of a high percentage (±80%) of training sessions at low intensity (below the lactate threshold) and a low percentage of training sessions (±20%) at high intensity (above the lactate turn point) (Seiler, 2010). POL seems to be the perfect mix between training volume and training intensity for endurance athletes to achieve optimal adaptations, and is therefore currently a hot topic within the world of endurance sports.

POL shows greater improvements in most endurance variables, for example VO2max, than HVT and HIIT (Stöggl & Sperlich, 2014). Also, a polarized training distribution may prevent overtraining or diminishing returns in performance (Muñoz et al., 2013) and leads to an enhanced recovery compared to other training models (Neal, 2012). Next to these physiological benefits, POL is not only effective for elite athletes, but also for people who perform endurance sports at a lower level. These people, who train less often, form the biggest group of athletes and deserve therefore more attention. This review will focus on the effects of POL in well-trained athletes who train regularly, but do not perform sports at top level. The adaptations and underlying mechanisms behind POL will be further discussed.

The purpose of this review is to: 1) explain which physiological adaptations can occur after training 2) present to what adaptations THR, HVT, HIIT, and POL may lead in well-trained endurance athletes, and 3) discuss why POL shows greater adaptations to endurance performance than THR, HIIT and HVT.

**Methods**

Scientific literature studies focused on training methods and adaptations have been used to write this review. The knowledge with regard to training methods and endurance performance develops rapidly. Articles that have been written a long time ago (more than 20 years), are likely not up-to-date anymore and therefore barely used in this review. Most included studies, especially those about POL, were very recent (not older than 5 years). Also, this review focusses specifically on well-trained athletes, who train between 5-20 hours a week or have at least 5 years of training experience, but do not perform sports at top level. All the articles that did not include athletes who met these criteria were therefore excluded for further use. In the next part, it is explained how different training intensities can be scaled, and which training intensity zones are involved in the four training methods used in this review (THR, HVT, HIIT, POL).

**Different training zones**

Different intensity scales to measure endurance intensity in athletes exist. In this review, a three-intensity zone scale is used. These three intensity zones are based on the first and second ventilatory/lactate thresholds (figure 1). In zone 1, below VT1, the exercise
intensity is low, and therefore %VO2max and blood lactate levels as well (<2 mmol/L blood lactate). In zone 2, which reflects a moderate exercise intensity, breathing rates and blood lactate levels increase to a maximal steady state (2-4 mmol/L blood lactate). Zone 3 includes exercising at a high intensity. The blood lactate production and minute ventilation rises quickly during zone 3 towards the point of fatigue (>4 mmol/L blood lactate) (Seiler, 2010).

**Threshold training (THR)**

THR involves training near or at the lactate threshold. Using this training method, most of the training sessions are performed between the first and second ventilatory/lactate threshold (zone 2). Just a small percentage of training sessions will be in either zone 1 or zone 3 (figure 2). The exercise intensity is moderate and blood lactate is 2-4 mmol/L (Seiler & Kjerland, 2006).

**High volume training (HVT)**

HVT consists of long periods of training below the first ventilatory/lactate threshold (zone 1). The exercise intensity is low, and blood lactate is <2 mmol/L (Laursen & Jenkins, 2002).

**High intensity interval training (HIIT)**

HIIT refers to short-duration training above the second ventilatory/lactate threshold. HIIT consists of repeated bouts of high-intensity exercise (zone 3, lactate ≥4 mmol/L), interrupted with recovery periods of low-intensity exercise (zone 1) or complete rest (Hawley et al., 1997).

**Polarized training (POL)**

POL is a combination of HVT and HIIT. It consists a high percentage of training sessions (~80%) of HVT (low intensity, zone 1) and a low percentage of training sessions (~20%) of HIIT (high intensity, zone 3) (Seiler, 2010). Only a very little percentage of the total exercise sessions will be spent between the two ventilatory/lactate thresholds (figure 3). Essentially, the goal of POL is to stay away from zone 2, and train in either zone 1 or zone 3, but much more in zone 1.
Figure 3: Polarized training model. Large training frequency is below VT1, combined with significant doses of training above VT2 (Seiler & Kjerland, 2006).

Possible adaptations to training in endurance athletes

Endurance training can lead to many physiological adaptations. Especially adaptations that occur within the heart and muscles could significantly improve endurance performances. Training can lead to an increase in heart size, stroke volume, cardiac output, blood flow and blood volume, and a decrease in heart rate at rest and during submaximal exercise (Kenney, Wilmore & Costill, 2015). Because of these cardiovascular adaptations, the blood supply towards activated muscles during exercise increases, and therefore the muscles receive more oxygen that can be used for aerobic oxidation.

These benefits from adaptations in the heart are strengthened by adaptations that occur in the muscle itself. First, aerobic activities rely mostly on type I fibers (slow twitch). In response to aerobic training, these type I fibers become larger. Also, other evidence suggests that there can be a transition of type IIx to type IIa fibers, and a transition of type II to type I fibers (Rico-Sanz et al., 2003). Another important adaptation reflects an increase in the number of capillaries surrounding each muscle fiber. More capillaries allows for greater exchange of gases (CO₂ and O₂), heat, nutrients, and metabolic by-products between the blood and the contracting muscle fibers. This increase in capillary density is an important adaptation to cause an increase in VO2max, which is one of the key components of endurance training (Bassett & Howley, 2000). Moreover, endurance training has been shown to increase muscle myoglobin content, which is important for transferring oxygen from the cell membrane to the mitochondria within active muscle fibers. Oxidative energy production, which is highly important during endurance exercise, takes place in these mitochondria. Training can increase both the numbers and size of muscle mitochondria, so that the muscle fibers’ capacity to produce ATP aerobically improves. These changes are further enhanced by an increase in the activity of mitochondrial oxidative enzymes (Kenney, Wilmore & Costill, 2015).

Athletes who try to improve their endurance performance, want these adaptations to be as large as possible. Training distribution (volume and intensity) is therefore very important. The four training models described earlier (THR, HVT, HIIT, POL) all include different training distributions, and thus different physiological effects.

Adaptations to THR

Training around the lactate threshold improves VO2max, lactate/ventilatory thresholds, and endurance performance in untrained people. However, endurance improvements to THR in already trained subjects were found to be clearly smaller and not statistically significant (Londeree, 1997), and other findings even suggest that THR in well-trained athletes may be counterproductive (Esteve-Lanao et al., 2007; Guellich and Seiler, 2010). In contrast, improvements in running speed after THR were found in elite cross-country skiers (Everts et al., 2001). The findings with regard to adaptations in well-trained athletes after THR are somewhat contradicting, but it is clear that several studies showed that POL and HIIT are more effective training methods to improve endurance performance than THR (Stöggl & Sperlich, 2014; Neal et al., 2012; Muñoz et al., 2013).
THR could generate sympathetic stress (Chwalbinska-Moneta et al., 1998), while offering no further stimulus for performance enhancement (Londeree, 1997). It has been reported that recovery from a training session in zone 1 is faster than a training session in zone 2, yet the recovery following a training session in zone 3 is no different than following a session in zone 2 (Seiler, Haugen & Kuffel, 2007). At the same time, greater cardiovascular and muscular adaptations have been found after training in zone 3 compared to zone 2. This includes larger increases in buffering capacity, improved capillarity, and greater recruitment of fast-twitch muscle fibers (Iaia et al., 2009; Iaia et al., 2011). Thus, THR increases the risk of overtraining compared to HVT, while causing less physiological adaptations than HIIT. Therefore, THR may not be an effective training strategy to improve endurance performance in well-trained athletes.

**Adaptations to HVT**

In moderately trained persons, HVT improves metabolic and hemodynamic adaptations (Laursen, 2010). Important adaptations include improved fat and glucose utilization, which is beneficial for long lasting endurance events, as glycogen can be spared. A slower rate of utilization of muscle glycogen and enhanced reliance on fat as a fuel source, improves the ability to sustain a higher exercise intensity (Kenney, Wilmore & Costill, 2015). The high mitochondrial oxidative capacity, improved fat oxidation and increased glucose transport capacity within the skeletal muscle after HVT are achieved through the calcium-calmodulin kinases (CaMK), which are mitochondrial biogenesis messengers (Rose et al., 2007). Because of a prolonged rise in intramuscular calcium during HVT, CaMK activity rises, which stimulates the activation of PGC-1α and eventually mitochondrial biogenesis (figure 4).

**Adaptations to HIIT**

HIIT can serve as an effective training method to traditional endurance training, inducing similar or even superior changes in a range of physiological, performance and health-related markers (Wisloff et al., 2007; Tjonna et al., 2009; Hwang et al., 2011). One of these important adaptations is an increased skeletal muscle oxidative capacity, due to cardiovascular and skeletal muscle adaptations. Other adaptations that have been documented after HIIT include an increased resting glycogen content, a reduced rate of glycogen utilization and lactate production during exercise, an increased capacity for whole-body and skeletal muscle lipid oxidation, enhanced peripheral vascular structure and function (including stroke volume, blood volume and O2 extraction), improved exercise performance (measured by time-to-exhaustion tests or time trials),
increased maximal oxygen uptake, and improvements in aerobic and anaerobic metabolism (Gibala et al., 2006; Rakobowchuk et al., 2008). Similar to HVT, HIIT can also increase mitochondrial capacity, as it can activate PGC-1α, which is regarded the master regulator of mitochondrial biogenesis in the muscle (Wu et al., 1999). However, the manner in which PGC-1α is stimulated, differs from HVT. The altered energy status in muscle associated with small reductions in ATP concentrations, as seen in HIIT, elicits a rise in adenosine monophosphate (AMP), which activates the AMP-activated protein kinase (AMPK) (Gibala et al., 2009). These AMPK’s stimulate the activation of PGC-1α, which eventually leads to mitochondrial biogenesis (figure 5) and therefore an increased capacity to generate ATP aerobically.

Due to these adaptations, HIIT can increase endurance variables as time to exhaustion (TTE), time trial performance, lactate and ventilatory thresholds and VO2max (Stöggl & Sperlich, 2014).

**Disadvantages of HVT and HIIT**

As explained above, both HVT and HIIT can induce multiple adaptations to endurance performance. Some of these adaptations are similar, for example the increase in mitochondrial biogenesis, but achieved through different pathways. However, both HVT and HIIT have their disadvantages. HVT can stagnate improvements in VO2max and performance when it becomes the major component of training and HIIT sessions are neglected (Stöggl & Sperlich, 2014). Whenever HIIT is the only training method, overtraining can be the result. HIIT is extremely demanding and if adequate recovery is ignored, autonomic balance is continually disturbed which leads to overtraining (Billat et al., 1999). For this reason HIIT may not be safe, tolerable or appealing for some individuals. Polarized training seems to be the solution for these disadvantages of HVT and HIIT. In the next part, results of several studies regarding the large benefits of POL are illustrated.

**Adaptations to POL, compared to THR, HVT, and HIIT**

Although THR, HVT, and HIIT may all lead to several adaptations that improve endurance performance, different recent studies have indicated that a POL distribution leads to the greatest physiological adaptations in well-trained endurance athletes.

Stöggl and Sperlich (2014) included both THR, HVT, HIIT and POL in their study. Forty-eight runners, cyclists, triathletes, and cross-country skiers were randomly assigned to one of four groups (POL, THR, HVT, or HIIT) performing training over 9 weeks. Before and after the intervention, an incremental test, a work economy test and VO2max tests were performed. With these tests, key components of endurance training could be measured. POL demonstrated the greatest increase in VO2max, time to exhaustion, and peak velocity/power (table 1). Velocity/power at 4 mmol/L increased after POL and HIIT, but not after THR and HVT. No differences in pre- to post-changes of work economy were found between the groups. Body mass was most reduced following HIIT. These results show that POL resulted in the greatest improvements in most key variables of endurance performance in well-trained endurance athletes.
Table 1: Changes (%) in some key variables of endurance training following POL, HIIT, THR, and HVT (Stöggl & Sperlich, 2014)

<table>
<thead>
<tr>
<th></th>
<th>POL</th>
<th>HIIT</th>
<th>THR</th>
<th>HVT</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTE</td>
<td>17.4 ± 16.1***</td>
<td>8.8 ± 8.6**</td>
<td>6.2 ± 9.0</td>
<td>8.0 ± 10.3</td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>V/P2</td>
<td>9.3 ± 12.4</td>
<td>12.1 ± 8.8**</td>
<td>2.0 ± 13.8</td>
<td>0.8 ± 13.3</td>
<td>F3, 57 = 1.9</td>
<td>NS</td>
</tr>
<tr>
<td>V/Pd</td>
<td>8.1 ± 4.6**</td>
<td>5.6 ± 4.8*</td>
<td>1.4 ± 4.3†</td>
<td>1.2 ± 6.6†</td>
<td>F3, 57 = 4.5</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>V/Ppeak</td>
<td>5.1 ± 3.0**</td>
<td>4.4 ± 2.8**</td>
<td>1.8 ± 4.8</td>
<td>-1.5 ± 4.9***</td>
<td>F3, 57 = 4.6</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Another study by Neal et al. (2012) found that six weeks of a polarized training-intensity distribution led to greater physiological and performance adaptations than a threshold model in trained cyclists. During this randomized crossover study, twelve well-trained male cyclists (7-8 h/wk) were divided into two groups of six participants. The first group (n=6) completed six weeks of POL (80% low intensity, 0% moderate intensity, 20% high intensity) first, whereas the second group (n=6) completed six weeks of THR (57% low intensity, 43% moderate intensity, 0% high intensity) first. After these six weeks, a post-training intervention testing week followed. The participants then completed six weeks of training following the alternate training-intensity distribution, again followed by a post-training testing week. Although the total training volume of the THR training model was higher, the results of the tests show that the lactate threshold (LT), peak power output (PPO), and exercise capacity at 95% all improved to a greater extent following POL compared to THR (table 2). Although there was no statistically significant difference between POL and THR for the improvement in 40-km TT mean power output, the effect size was larger for POL, and the magnitude of change was twice as large as observed following THR. The greater effect sizes for all of the key performance and adaptation markers with

Table 2: Mean percentage change and effect sizes for key performance and adaptation measures after 6 wk of POL and THR (Neal et al., 2012)

<table>
<thead>
<tr>
<th>Training Model</th>
<th>Measure</th>
<th>Δ, %</th>
<th>Effect Size</th>
<th>Descriptor*</th>
</tr>
</thead>
<tbody>
<tr>
<td>POL</td>
<td>40-km TT</td>
<td>8 (±8)</td>
<td>0.57</td>
<td>Moderate</td>
</tr>
<tr>
<td>THR</td>
<td>40-km TT</td>
<td>8 (±8)</td>
<td>0.57</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

Esteve-Lanao et al. (2007) studied the impact of different intensity distributions on performance in endurance athletes. Two groups of well-trained runners were subjected to a 5-month training program that differed only in the distribution of training intensity, but not in total training load. The first group of athletes performed a relatively higher percentage of their total training time in zone 1, with a total percentage distribution in zones 1, 2, and 3 of 80/10/10. The second group trained relatively more in zone 2 and less in zone 1, with a total percentage distribution of 65/25/10. All the participants performed a simulated 10.4 km cross-
country race before and after the training period. The key finding of this study was that the training distribution of 80/10/10 elicited in a greater running performance improvement (36 seconds faster) than the distribution of 62/25/10. These results provide more evidence that a large percentage of training in zone 1 (±80%), as is included in a polarized training model, is important for optimizing performance gains. These findings are supported by a study from Seiler and Kjerland (2006). This study quantified the daily training distribution of twelve well-trained junior cross country skiers. These young well-trained athletes were national competitive skiers in their age group (17-18 jr). The athletes performed a treadmill test to exhaustion to determine VT1, VT2, VO2max and the maximal heart rate. The VT1 and VT2 were used to delineate the three intensity zones (figure 1). During the same time, all the training sessions performed over 32 consecutive days were quantified using heart rate registration, rating of perceived exertion, and blood lactate measurements. The key finding of this study was that these successful well-trained junior cross-country skiers adopted a polarized model of intensity distribution. About 75% of their training sessions were performed below VT1, while 15-20% of training sessions were performed above VT2. Only 5-10% of training sessions were performed between VT1 and VT2. Again it is showed that athletes who want to adapt to training as much as possible train very little at the lactate threshold intensity, whereas a lot of training is done in zone 1. This polarized way of training seems to be successful in both elite athletes and well-trained endurance athletes. The last study that was included for this review (Muñoz et al., 2013) randomly assigned thirty-two Spaniard runners (mean competition experience ≥5.5 y) to two different training groups (each n=16) for ten weeks. The first group increased the contribution of zone 1 in their training sessions (as in POL), whereas the second group decreased contribution of zone 1 and increased the contribution of zone 2 (as in THR). The total training percentage distribution in zones 1, 2 and 3 in group 1 was ~75/5/20, and in group 2 ~45/35/20. Before the intervention started, the subjects performed a maximal exercise test to determine VT1 and VT2, as well as a 10-km race. After the intervention, the subjects performed the same 10 km race. The key finding of this study was that both THR and POL over ten weeks resulted in a significant improvement in a 10K performance test. However, the mean improvements after POL were greater compared to THR (119 sec improvement versus 84 sec improvement) (figure 6). This study thus concludes as well that POL stimulates greater training effects than THR in well-trained runners.

As described in the studies above, POL results in great adaptations and improvements to endurance performance. In the next paragraph, the possible underlying mechanisms why POL results in greater adaptations and improvements than THR, HVT, and HIIT are examined.

Why does POL result in greater adaptations than THR, HVT, and HIIT?

As explained before, HVT improves metabolic and hemodynamic adaptations, as well as fat and glucose utilization. HIIT leads to adaptations in stroke and blood volume, O2 extraction, and improvements in aerobic and anaerobic metabolism. However, HVT and HIIT also cause similar adaptations as they both stimulate the activation of PGC-1α through different pathways (figure 7).
Despite some similar adaptations to HVT and HIIT, it is likely that the combination of these two training methods, as demonstrated in POL, is the most effective way to achieve the greatest adaptations. Improvements in VO2max will stagnate when HVT is the only training component. For this improvement in VO2max, HIIT is needed. At the same time, the large amount of HVT (±80% of training sessions) decreases the risk of disturbing autonomic balance that could lead to overtraining, fatigue and staleness, which is likely to happen when HIIT is the only training method. As explained, HIIT and THR can easily induce overtraining, as the training intensity is high. In POL, however, overtraining is not likely given the greater recovery time and reduced fatigue. The acute recovery from a training session in zone 1 is faster than from zone 2, but the recovery time following a training session in zone 3 is equal to the recovery time following training in zone 2. If zone 3 training leads to larger physiological adaptations compared to zone 2, but with similar recovery periods, then this could be considered a more effective training strategy. Moreover, since recovery is greater from zone 1 than zone 2, it has been recommended to combine zone 3 training with zone 1 training (Seiler, Haugen & Kuffel, 2007). The effectiveness of POL may therefore be the result of great intensity-specific adaptations and an enhanced recovery. POL seems to benefit from optimal adaptations to both HVT and HIIT, without experiencing the disadvantages of these training methods, and therefore the greatest adaptations can be achieved.

**Discussion**

The main aim of this review was to explain which adaptations can occur after THR, HVT, HIIT and POL, and discuss what possible underlying mechanisms behind POL make this training method so effective to improve endurance performance in well-trained athletes.

Although several scientific studies have researched the adaptations to POL, the precise mechanisms behind the beneficial effects of POL in well-trained athletes are not yet fully understood. However, it is clarified by different studies that exercise intensity is a key driver to optimally improve endurance performance (Neal et al., 2012). It is likely that a polarized approach to training...
may be optimal, where periods of both HVT and HIIT are performed. The addition of HIIT to HVT in well-trained athletes can elicit further enhancements in endurance performance, probably due to an improved ability of skeletal muscles to generate ATP aerobically. Therefore, HIIT is an important component of POL. Moreover, the large contribution of HVT (~80% of training sessions) within a polarized training distribution is likely to facilitate for aerobic adaptions as well, yet the intensity may be low enough to promote autonomic balance, recovery and athlete health (Laursen, 2010). These suggestion, however, need further research.

Different articles have reported that 80% of the training sessions in POL should consist of HVT, while 20% of the training session should include HIIT. A study by Tønnessen et al. (2014) monitored the training sessions of eleven Olympic and world champion XC skiers and biathletes previous to a competition. These elite athletes clearly adopted a polarized intensity distribution model, but the endurance training time ratio between HVT and HIIT for these top athletes was ~90-10. This finding is in contrast with other studies that reported the ~80-20 distribution as the optimal one (Esteve-Lanao et al., 2005; Seiler & Kjerland, 2006; Esteve-Lanao et al., 2007). However, these studies did not do any research to alternative training distributions. Training adaptations differ per person and per sport, which makes it hard to find the optimal polarized training distribution. This aspect requires therefore further research in the future.

Most studies to POL reflect either well-trained or elite athletes. For these type of athletes, POL seems to be the most effective training method. However, not much information is known about the effects of POL in untrained people with no or little training experience. It is likely that POL also has beneficial effects in these recreational people, as the HIIT sessions might maximize adaptive signaling given the limited total stimulus, and the knowledge that overtraining is not likely given the greater recovery time when training is much less frequent. At the same time, a polarized training approach may also be beneficial for recreational athletes by emphasizing the avoidance of a monotone intensity distribution and keeping “easy training easy and hard training hard” (Muñoz et al., 2014). However, it is not easy to imply POL in recreational athletes, as it is hard to keep recreational people training 45-60 min a day 3-5 days a week, without accumulating a lot of training time at their lactate threshold (Seiler & Tønnessen, 2009). Low-intensity sessions are often performed harder than prescribed, while high-intensity sessions are rather performed at a lower intensity than recommended. This is also a likely scenario for time-limited recreational people (Foster et al., 2001). The opportunities and effects of POL with regard to recreational athletes need therefore more research.

Recent results from different studies show that endurance athletes who train polarized, gain the greatest adaptations. A further understanding of the underlying physiological mechanisms behind POL is however desired, so that future training programs for endurance athletes can even be better organized and manipulated to achieve optimal adaptations.

References


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