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A Comparative Investigation into Training Intensity Distribution for Elite Athletes: Systematic Review

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ABSTRACT

Background: Endurance sports demand a finely-tuned balance between training intensity and volume to optimize athletic performance. Training Intensity Distribution has become a critical training parameter in endurance sports, potentially eliciting superior physiological adaptations and improving overall performance outcomes. Training intensity distribution influences the body's aerobic and anaerobic energy systems, enhancing endurance performance. So, the study aims to explore the best training intensity distribution for elite athletes.

Methods: We searched three electronic databases for original research articles. After analyzing the resultant original articles, studies were included if they met the following criteria: a) participants were endurance sport athletes; b) studies analyzed training intensity distribution in the form of interventions only; c) studies were published in peer-reviewed journals and d) studies analyzed training programs with a duration of 4 weeks or longer. The selected studies were then assessed using the PEDro scale.

Results: During the search of the three electronic databases, we found 10 articles. Six favored polarized training, whereas one favored pyramidal training. Two showed that low-intensity dominant training is better, and one said that a transition from pyramidal to polarized training as the competition approaches is better. The mean PEDro scale rating is 4.9.

Conclusion: Based on the research, both pyramidal and polarized training intensity distributions have merits and can be effective in different contexts. Ultimately, the choice between pyramidal and polarized training intensity distribution should consider individual athlete characteristics, sport-specific requirements, training phase, and other contextual factors.

Keywords: Training intensity distribution, polarised training, pyramidal training, and endurance athletes.

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INTRODUCTION

Training intensity distribution (TID) is a fundamental concept in sports science that is pivotal in optimizing athletic performance. It refers to the distribution of training volume across various intensity zones over a designated period. This methodology aims to achieve specific physiological adaptations while minimizing the risk of overtraining and injury. Understanding TID is crucial for coaches, athletes, and sports scientists seeking to design effective training programs tailored to individual needs and goals [1].

The concept of TID gained prominence through the pioneering work of sports physiologists and coaches who recognized the importance of balancing training loads to maximize performance gains [2]. Traditional approaches to training often emphasized high-intensity workouts, assuming that more significant effort would inevitably lead to better results. However, this one-dimensional approach neglected the significance of varying intensity levels and their distinct physiological effects on the body [3].

TID advocates a more nuanced approach by categorizing training intensity into three primary zones: low, moderate, and high. Each zone corresponds to specific physiological responses, including aerobic endurance, lactate threshold, and maximal effort. By strategically distributing training volume across these zones, coaches can elicit targeted adaptations in energy systems, muscle fibers, and metabolic pathways [2-4].

Zone 1 training, also known as low-intensity training, is fundamental to endurance training programs. It is characterized by exercising at a low intensity, typically under 80 % of an athlete's maximum heart rate or at a blood lactate level of under 2mmol/L or a score of up to 4 out of 10 on rating of perceived exertion (RPE). This training is crucial for building a solid aerobic base, enhancing recovery, and promoting cardiovascular health. Zone 1 training primarily targets the aerobic energy system, essential for endurance activities. By training at a low intensity, athletes can increase the efficiency of their cardiovascular system, enhance mitochondrial density, and improve oxygen delivery and utilization in muscles. The body relies more on fat at lower intensities as a fuel source. This adaptation not only helps improve endurance performance but also aids in reducing body fat. Low-intensity workouts facilitate active recovery, allowing athletes to maintain regular training volumes without the risk of overtraining. This form of training helps flush out metabolic waste products, reduce muscle soreness, and prevent injuries associated with high-intensity workouts [5-9].

Zone 2 training, often referred to as threshold intensity or the aerobic threshold, represents a moderate-intensity level that plays a pivotal role in endurance training. It typically involves exercising at 80-85% of an athlete's maximum heart rate or a blood lactate level between 2-4 mmol/L or a score of 5-6 out of 10 on RPE. This intensity zone is crucial for improving aerobic capacity, enhancing metabolic efficiency, and boosting endurance performance. Training in Zone 2 significantly improves aerobic capacity by increasing the volume of oxygen the body can utilize during prolonged exercise. This adaptation results from enhanced mitochondrial density and function and improved capillary density, which facilitates better oxygen delivery to muscles. At this intensity, the body becomes more efficient at utilizing fat as a primary fuel source, sparing glycogen stores for higher-intensity efforts. This shift in substrate utilization is vital for endurance athletes, allowing them to sustain more extended periods of exercise without fatigue. Zone 2 training enhances the body's ability to clear lactate from the bloodstream, which delays the onset of muscle fatigue and improves overall exercise tolerance. This adaptation is essential for maintaining performance during extended efforts and high-intensity workouts. Consistent training at this intensity strengthens the heart muscle, improving stroke volume and cardiac output. These cardiovascular adaptations contribute to more efficient blood circulation and oxygen delivery during exercise and rest [5-9].

Zone 3 training, characterized by high-intensity efforts, is critical for athletes seeking to enhance their performance. This training zone typically involves exercising at over 85 % of the maximum heart rate, a blood lactate level of over 4 mmol/L, or a score above 6 out of 10 on RPE. Zone 3 is often called the "tempo" zone, where the intensity is higher than moderate but sustainable over more extended periods than very high-intensity intervals. Zone 3 training significantly improves cardiovascular fitness. The sustained high intensity strengthens the heart, increasing stroke volume and cardiac output. This enhances the heart's efficiency in pumping blood, which is crucial for endurance and performance. Exercising in this zone helps increase the lactate threshold, the point at which lactate accumulates in the blood. A higher lactate threshold means an athlete can sustain higher intensities for longer before fatigue sets in. Zone 3 strikes a balance between aerobic and anaerobic training. It promotes the development of both energy systems, improving the body's ability to utilize oxygen efficiently and enhancing the capacity to handle and clear lactate. Regular training in Zone 3 boosts muscular endurance. It helps develop slow-twitch muscle fibers crucial for long-duration activities, enabling athletes to maintain a steady, hard pace over extended periods [5-9].

One of the key principles underlying TID is the polarized model, which suggests that a significant portion of training volume should be concentrated in the low-intensity zone, with a smaller proportion allocated to high-intensity efforts. This approach aims to capitalize on the benefits of aerobic development and high-intensity training while minimizing the risk of overtraining and burnout. Studies across various sports disciplines have consistently demonstrated the effectiveness of polarized/ pyramidal TID in enhancing endurance performance and overall athletic capacity [10].

Polarized TID emphasizes a two-tiered distribution of training intensity. This model allocates a substantial portion of training volume (typically around 80%) to low-intensity activities, such as steady-state endurance workouts or recovery sessions. The remaining volume (approximately 20%) is dedicated to high-intensity efforts characterized by near-maximal or maximal exertion, such as interval training or high-intensity intervals. Pyramidal TID is a dynamic and adaptable approach to structuring training volume across various intensity zones in sports. This methodology is characterized by a gradual increase and subsequent decrease in training intensity, forming a pyramid-shaped distribution [11].

The rationale behind Polarized TID stems from the observation that polarized training elicits superior physiological adaptations compared to more evenly distributed intensity models. Research across various endurance sports, including running, cycling, and rowing, has consistently demonstrated that athletes following a polarized training regimen exhibit more significant improvements in aerobic capacity, lactate threshold, and overall performance metrics than those adhering to other intensity distributions. One of the key mechanisms driving the positive effects of Polarized TID is its ability to stimulate concurrent adaptations in multiple physiological systems. Low-intensity training promotes mitochondrial biogenesis, enhances fat oxidation, and improves aerobic efficiency, laying a foundation for endurance performance. Meanwhile, high-intensity efforts stimulate neuromuscular adaptations, enhance anaerobic capacity, and elevate VO2 max, which is crucial for sustaining high-intensity efforts and surges during competition.

The foundation of Pyramidal TID lies in its balanced allocation of training volume across three intensity zones: low, moderate, and high. Unlike polarized training, which emphasizes extremes of low and high-intensity efforts, Pyramidal TID employs a more nuanced approach by incorporating a wider range of intensities within the training spectrum. One of the primary advantages of Pyramidal TID is its ability to promote a balanced development of aerobic and anaerobic energy systems, which is crucial for success in many sports. By incorporating a moderate volume of moderate-intensity training, Pyramidal TID also stimulates adaptations in lactate threshold, oxygen utilization, and muscular endurance, complementing the physiological benefits of low and high-intensity efforts. This balanced approach fosters well-rounded athleticism and resilience across various competitive scenarios.

Other TID frameworks, such as threshold models, offer alternative strategies for structuring training programs based on individual needs and performance objectives. These models allow flexibility in adjusting the balance between low, moderate, and high-intensity training according to athlete experience, event specificity, and seasonal variations.

Implementing TID effectively requires careful planning, monitoring, and adaptation based on ongoing assessment of athlete responses and performance outcomes. Advances in technology, such as heart rate monitors, GPS tracking devices, and metabolic analyzers, provide valuable tools for quantifying training loads and fine-tuning intensity distribution to optimize results. This study aims to determine the best TID strategy for elite athletes.

METHODOLOGY

A literature search was conducted on January 25, 2024, in the following databases: PubMed, Scopus, and Web of Science. These databases were searched with no language limitation. Citations from scientific conferences were not included. In these databases, the following keywords were searched with Boolean operators (and/ or): Training intensity distribution, periodization training, polarised training, pyramidal training, threshold training, training intensity distribution endurance, and training by elite athletes.

Studies were included based on the following criteria: a) participants were elite or national level athletes; b) studies analyzed training intensity distribution in the form of observational reports or interventions; c) studies comparing two or more types of training intensity distributions; d) studies were published in peer-reviewed journals and e) studies analyzed training programs with a duration of 4 weeks or longer. A flow chart of the search and study selection is shown in Figure 1. The studies are then assessed using the Physiotherapy Evidence Database (PEDro) scale. The scale comprises 11 items: (1) inclusion criteria and source; (2) random allocation; (3) allocation concealment; (4) baseline comparability; (5) blinding of subjects; (6) blinding of therapists; (7) blinding of assessors; (8) over 85% follow-up; (9) intention-to-treat analysis; (10) between-group comparison; and (11) point estimates and variability. The total PEDro score is calculated by counting the "yes" responses for items 2–11 (item 1 is not used to calculate the total PEDro score because it is more related to external validity) and ranges from 0 to 10 points.

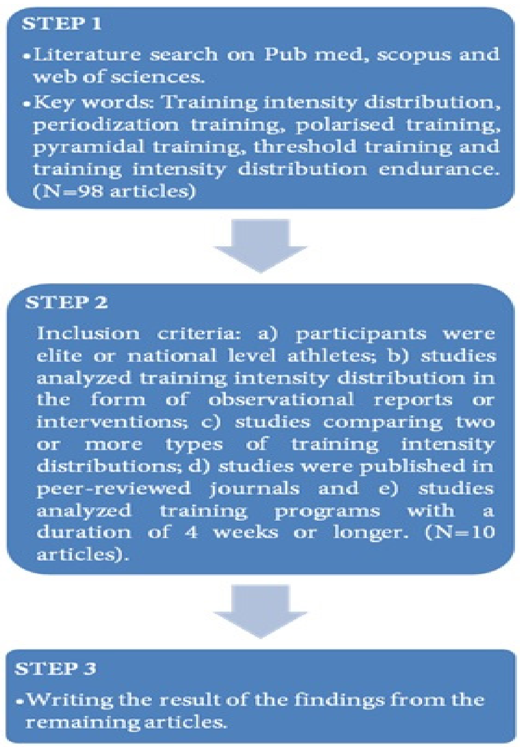

Figure 1: Flow chart of the search and study selection.

RESULTS

After adopting the above search strategy, 98 articles were yielded. After applying the inclusion criteria and excluding duplicated articles, we found 10 articles in this study. The characteristics and assessment of these studies are described in Table 1. The mean PEDro scale rating is 4.9 (Table 2).

Table 1: Characteristics of studies. (HVT= high volume training, THR= threshold training, HIIT= high intensity interval training, PYR= pyramidal training, POL= polarized training)

Article	Subjects	Age	Comparison	Outcome	Result
Filipas, L (2022) [12]	Runners	38±7 years	PYR, POL PYR to POL POL to PYR	Body mass, absolute VO_2 peak, peak heart rate, lactate peak and rating of perceived exertion.	PYR to POL is better.
Treff, G (2017) [13]	Rowers	20 ± 2 years	PYR and POL	Power in 2000 m ergometer-test, the power associated with 4 mmol/L blood lactate, and VO2 max.	Equal because of a similar time in zone 1.
Selles-Perez, S (2019) [14]	Triathletes	28.9 ± 6.9 years	PYR and POL	Swim test time, VT1 and VT2 Bike power and race pace, VO_2max Bike, and run the test.	PYR is better.
Stöggl, T., and Sperlich, B. (2014) [15]	Runners, Cyclist, Triathletes, cross-country skiers	31 ± 6 years	HVT, THR, HIIT, and POL.	An incremental test, a work economy, and a VO2peak test.	POL is better
Pla R et al. (2018)[16]	Swimmers	17 ± 3 years	POL and THR	Performance, maximal blood lactate concentration ([La]max) and oxygen consumption (VO2), and an incremental swimming test to determine speed corresponding to [La]b = 4 mmol·L-1 (V4mmol·L-1).	POL is better
Neal, C. et al. (2013) [17]	Cyclist	37 ± 6 years	POL and THR	Fasted skeletal muscle biopsies [mitochondrial enzyme activity and monocarboxylate transporter (MCT1/4)] expression, and NMR spectroscopy based metabolomics analysis. Endurance performance (40km time trial), incremental exercise, peak power 43 output, and high-intensity exercise capacity.	POL is better
Yu H et al. (2012) [18]	Speed Skaters	23 ± 1.7and 25.3 ± 6 years	POL and THR	Performance and lactate data were measured 15 and 30 min after these competitions.	POL is better
Munoz, I. et al (2014) [19]	Runners	34 ± 8 years	POL and THR	Performance	POL is better
Laursen, P. B. (2010)[3]	Rowers, Swimmers, Kayaking, Runners and cyclists.	___	High-volume and high-intensity training.	Metabolic adaptations	POL is better
Esteve-Lanao et al. (2007)[20]	runners	27 ± 2 years	Group 1 = zone 1 dominant training and group 2 = zone 2 dominant training	Performance	Group 1

TABLE 2: PEDro* assessment of studies

Study	1	2	3	4	5	6	7	8	9	10	11	Total
Filipas L et al (2022)	1	1	0	1	1	0	1	1	0	1	1	7
Treff G (2017)	1	0	0	0	0	0	0	0	1	1	1	4
Selles-Perez S (2019)	1	1	0	1	1	0	0	1	0	1	1	6
Sto¨ggl et al. (2014)	1	1	0	1	0	0	0	1	0	1	1	5
Pla R et al. (2019)	1	0	1	1	1	0	0	1	0	1	1	6
Neal et al. (2013)	1	1	0	0	0	0	0	1	0	1	1	4
Yu H et al.(2012)	1	0	0	0	0	0	0	1	1	1	0	3
Mun˜oz et al. (2014)	1	1	0	1	0	0	0	0	0	1	1	4
Laursen PB (2010)	0	1	0	1	0	0	0	1	0	1	1	5
Esteve-Lanao et al. (2007)	1	1	0	1	0	0	0	1	0	1	1	5

*(1) Eligibility; (2) randomization; (3) concealed allocation; (4) baseline comparison; (5) blind subjects; (6) blind therapists; (7) blind assessors; (8) adequate follow-up; (9) intentionto-treat analysis; (10) between group comparisons; (11) point estimates and variability. Eligibility is not included in the final 10-point score.

DISCUSSION

Training intensity distribution refers to allocating training volume and intensity across different zones or intensities within a training program. Traditionally, the threshold training model, where most of the training was done at the lactate threshold, was thought to be the best training model as it was close to the actual game level stress and thus was thought to stimulate the best training adaptations. However, few observational studies were done on the actual training practice of elite athletes from different sports, such as cross-country skiers, runners, rowers, and swimmers from different countries [2, 21-24]. It was found that these athletes spend most of their training time at low intensities and substantial time at high intensities, thus reducing the time in threshold training. This indicates a change in these years from the threshold to the polarized training model as the competition approaches. Apart from this, a few retrospective studies were also done, showing that elite athletes are shifting their majority of training time from threshold to low-intensity. This transition was recorded during 3–4-decade duration and explained the reasons for better performance by athletes, which increased by 10-20 percent in a particular sport. This training transition was seen for skaters in 38 years and rowers in 31 years [25, 26]. This shift of spending more time in the low-intensity zone helped keep these elite athletes safe from the risk of injuries. It increased or maintained their training adaptations, allowing them to perform better in their respective sports.

As the interest of elite endurance athletes changed in a few decades towards spending more time in low-intensity training zones, researchers began to explore the benefits of this type of training in other sports along with the reasons for the benefits and comparison with other training approaches. In cyclists, it was found that polarised training was superior to the threshold training approach, as there was no change in mitochondrial enzyme activity in both groups. Still, greater systemic adaptations, along with improved race time and better power output, were observed with polarised training [17]. In cyclists, there was also a decrease in muscle (quadriceps femoris) thickness and an increase in anaerobic power, both beneficial in cycling [27]. There was also improvement in race time when the polarised training approach was tested along with threshold training in recreational athletes and sub-elite runners [19, 20]. It was also reported that athletes trying to spend more time in the high-intensity training zone before a competition suffered from overtraining symptoms and had to withdraw. Even when the same athletes from a speed skating team trained for one season via threshold training approach and in the next season via polarised training approach, a remarkable improvement in their performance was seen after polarised training along with a decrease in the post-competition blood lactate level in the same group [18].

Two prominent approaches in this regard are polarized training and pyramidal training. Both methods have been extensively studied, and each has merits and drawbacks. In this discussion, we will delve into the research surrounding these two techniques to determine the best choice depending on various factors.

Polarized training involves distributing training intensity predominantly towards low-intensity (zone 1) and high-intensity (zone 3) workouts, with less emphasis on moderate-intensity (zone 2) sessions. This approach gained popularity due to its simplicity and its alignment with the training habits of elite athletes in endurance sports. Research on polarized training has demonstrated promising results, particularly in endurance sports like running, cycling, and rowing. For instance, a study by Seiler and Kjerland (2006) found that elite endurance athletes typically spent approximately 80% of their training time at low intensity, 20% at high intensity, and negligible time at moderate intensity [2]. This distribution was associated with superior performance outcomes compared to more evenly distributed intensity models. Additionally, numerous studies have shown that polarized training can improve aerobic capacity, endurance performance, and overall fitness compared to other intensity distribution models. It stimulates physiological adaptations more effectively, such as increased mitochondrial density and improved lactate threshold.

However, polarized training may not be suitable for all athletes or all phases of training. It requires careful monitoring of intensity levels to avoid overtraining, especially in high-intensity sessions. Furthermore, its efficacy in sports requiring a significant anaerobic component or strength training remains unclear. Pyramidal training, on the other hand, involves a more balanced distribution of training intensity across low, moderate, and high-intensity zones. In this model, most training time is typically spent in the moderate-intensity zone, with lower proportions dedicated to low and high-intensity sessions. Pyramidal training ensures a well-rounded development by including a substantial volume of low-intensity training to build aerobic capacity and moderate-intensity training to improve lactate threshold. This balance is particularly beneficial for endurance athletes who need a strong aerobic base and the ability to sustain higher intensities. By incorporating moderate-intensity sessions, pyramidal training exposes athletes to a wider range of physiological stimuli, promoting comprehensive adaptations and preventing stagnation in fitness improvements.

Pyramidal training's emphasis on moderate-intensity training can reduce physical strain compared to the frequent high-intensity sessions in polarized training. This can lead to a lower risk of overuse injuries and overtraining. The structured inclusion of moderate-intensity training allows for a more gradual progression in training intensity, helping athletes adapt without sudden spikes in physical stress. Moderate-intensity training enhances the body's ability to oxidize fat and spare glycogen, which is crucial for endurance performance. This metabolic efficiency is less emphasized in polarized training, focusing more on low and high intensities. Including moderate-intensity sessions can be less psychologically demanding than frequent high-intensity sessions, helping athletes maintain a balanced mental state and reducing the risk of burnout. Some studies suggest that medium-intensity training (heart rate of ≥75%) can positively affect blood fatigue indicators, inflammatory markers, and stress hormones in sprinters and can be effective, particularly for athletes aiming to improve both aerobic and anaerobic capacities [28]. It provides a more varied stimulus to the body, potentially reducing the risk of overtraining and monotony compared to polarized training.

CONCLUSION

We concluded that low-intensity dominant training distribution (pyramidal or polarised training) is more effective than other training approaches in enhancing an athlete's performance in any sport as it reduces the risk of overtraining. The choice between polarized and pyramidal training depends on various factors, including the athlete's sport, goals, individual characteristics, and training phase. Polarized training is more effective for endurance athletes, aiming to maximize aerobic capacity and performance outcomes. It offers a clear and structured approach that aligns well with the training habits of elite athletes in endurance sports. However, pyramidal training can be a viable alternative, especially for athletes seeking a more balanced approach or those participating in sports with significant anaerobic components. It provides a variety of training stimuli and may

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