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Effects of Polarized Training vs. Other Training Intensity Distribution Models on Physiological Variables and Endurance Performance in Different-Level Endurance Athletes: A Scoping Review

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Abstract

Rivera-Köfler, T, Varela-Sanz, A, Padrón-Cabo, A, Giráldez-García, MA, and Muñoz-Pérez, I. Effects of polarized training vs. other training intensity distribution models on physiological variables and endurance performance in different-level endurance athletes: a scoping review. *J Strength Cond Res* XX(X): 000–000, 2024—This scoping review aimed to analyze the long-term effects of polarized training (POL) on key endurance physiological- and performance-related variables and to systematically compare them with other training intensity distribution (TID) models in endurance athletes of different performance levels. Four TID models were analyzed: POL, pyramidal (PYR), threshold (THR), and block (BT) training models. The literature search was performed using PubMed, SportDiscus, Scopus, and Web of Science databases. Studies were selected if they met the following criteria: compared POL with any other TID model, included healthy endurance athletes, men, and/or women; reported enough information regarding the volume distribution in the different training intensity zones (i.e., zone 1, zone 2, and zone 3), assessed physiological (i.e., maximum/peak oxygen uptake, speed or power at aerobic and anaerobic thresholds, economy of movement), and performance in competition or time-trial variables. Of the 620 studies identified, 15 met the eligibility criteria and were included in this review. According to scientific evidence, POL and PYR models reported greater maximum oxygen uptake enhancements. Both POL and PYR models improved the speed or power associated with the aerobic threshold. By contrast, all TID models effectively improved the speed or power associated with the anaerobic threshold. Further research is needed to establish the effects of TID models on the economy of movement. All TID models were effective in enhancing competitive endurance performance, but testing protocols were quite heterogeneous. The POL and PYR models seem to be more effective in elite and world-class athletes, whereas there were no differences between TID models in lower-level athletes.

Key Words: long-distance athletes, polarization, physiological adaptations, competition performance, training load

Introduction

Exercise intensity and its distribution over time have a key role in endurance training programming for sports success in sport-specific endurance disciplines (11,74,75). The training intensity distribution (TID) represents the percentage of volume (i.e., time or distance) an athlete spends training at low, moderate, or high intensity. In this sense, 3 training zones based on the triphasic model traditionally proposed by Skinner and McLellan (69) are often identified to quantify TID in endurance sports. This model is characterized by determining the training zones according to the 2 physiological milestones, the aerobic and anaerobic thresholds, assessing both ventilatory (i.e., first ventilatory threshold [VT_1] and second ventilatory threshold [VT_2], respectively) or lactate (i.e., first lactate threshold [LT_1] and second lactate threshold [LT_2], respectively) thresholds. In this regard, the gold standard for determining both aerobic and anaerobic thresholds is the gas exchange analysis, which allows to establish VT_1 and VT_2, respectively (51,67). Furthermore, aerobic and anaerobic thresholds can also be estimated by measuring blood lactate concentration, the so-called LT_1 and LT_2, respectively (51,67). Thus, zone 1 (Z1) is defined as low-intensity training (LIT) and represents the intensity below the aerobic threshold, also called moderate exercise domain; zone 2 (Z2) is often named moderate-intensity training and represents the intensity between the aerobic and anaerobic thresholds, also called heavy exercise domain; zone 3 (Z3) is usually defined as the high-intensity training (HIT) and represents the intensity above the anaerobic threshold, also called severe exercise domain (64–67,74,75). More recently, a 5-zone model has been proposed as an effective method for establishing the main training zones in endurance sports, including easy (i.e., Z1), moderate (i.e., Z2), threshold (i.e., Z3), interval (i.e., zone 4), and maximal intensity (i.e., zone 5) training efforts

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(66). However, the great majority of studies performed with different-level endurance athletes report TID according to the traditional triphasic model. Figure 1 represents the relationship between the triphasic and the 5-zone model and the associated main physiological and performance variables.

On the other hand, the training volume (i.e., time or distance) accumulated in each zone produces different physiological adaptations in the short and long term. Concretely, training in Z1 is associated with peripheral adaptations (67), such as a proliferation in the number of mitochondria (64) and increased capillarization of type I fibers (9), among others. Training in Z2 leads to an improvement in glucose utilization through the oxidative pathway, lactate oxidation, and increased activity of peroxisome proliferator-activated receptor-γ coactivator (PGC1α) through a higher rate of adenosine monophosphate-activated protein kinase activity (27), thereby increasing mitochondrial biogenesis. Training accumulated in Z3 elicits enhanced maximum oxygen uptake ($\dot{V}O_2max$) (30,67), improved mitochondrial respiration function (6,27), and an increase in the proportion of type II muscle fibers (14), among others. However, it is important to consider that the lines delimiting different training intensity zones are dynamic, and the overlap of these training zones during a single training session may lead to similar physiological adaptations (6,9,14,27,30,67).

The latest scientific evidence established 3 main TID models in endurance sports training (11,75,77). In this regard, the polarized training model (POL) is traditionally characterized by accumulating ~75–80% of training volume in Z1, ~5% in Z2, and ~15–20% in Z3 (i.e., Z1 > Z3 > Z2) (74,77). Another model of TID is the so-called threshold training or lactate threshold model (THR), which is characterized by emphasizing the accumulation of training volume in Z2, spending ~45–50% of training volume in Z1, ~45–50% in Z2, and ~5–10% in Z3 (i.e., Z1 ≥ Z2 > Z3) (47,74). Finally, the pyramidal training model (PYR) is distinguished by accumulating the highest percentage of training volume in Z1 (i.e., ~70%) and correlatively decreasing in Z2 and Z3 (i.e., ~20% and ~10%, respectively) (20,74,77). In addition, some studies (33,71,74) present other TID approaches characterized by the use of specific intensities, such as LIT and HIT, usually organized in training blocks (BT) (45).

Previous research has consistently demonstrated that TID models produce different effects in the short- and long-term on key endurance performance-related variables. These variables are: $\dot{V}O_2max$; the energy cost of the sport-specific movement pattern, which is a complex influenced by different underpinning factors (i.e., cardiorespiratory, biomechanical, neuromuscular); and the ability to maintain a submaximal exercise intensity (i.e., high % of $\dot{V}O_2max$) related to the critical power/speed, that is near to the anaerobic threshold (1,3,11,25,36,37,46,53,73). In fact, the interaction of these variables determines athletes' endurance sport-specific performance (i.e., time-trial [TT] and competition performance) (29,36,38). In this sense, a recent systematic review and meta-analysis has determined that POL leads

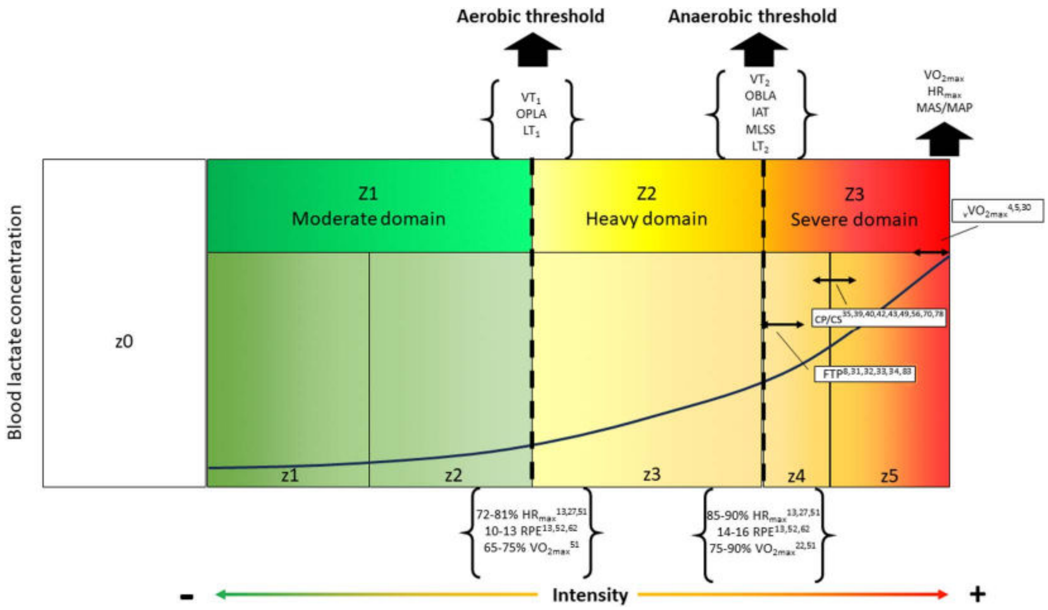

Figure 1. Training intensity zones and associated physiological and performance variables in endurance sports according to the traditional triphasic model and a 5-zone model. The classification of intensity zones was based on the traditional triphasic model proposed by Skinner and McLellan (1980), which distinguishes between moderate, heavy, and severe exercise domains (i.e., Z1, Z2, and Z3, respectively). The 5-zone model is typically used to delimit training zones in endurance sports. This figure relates both models and simplifies different concepts to facilitate the reader's comprehension. Note that training zones in the triphasic model are referred to as Z (capital letter), while training zones of the 5-zone model are presented as z (lowercase letter). Z1 = training intensity zone 1 in the triphasic model; Z2 = training intensity zone 2 in the triphasic model; Z3 = training intensity Z3 in the triphasic model; z0 = training intensity zone 0 in the 5-zone model; z1 = training intensity zone 1 in the 5-zone model; z2 = training intensity zone 2 in the 5-zone model; z3 = training intensity Z3 in the 5-zone model; z4 = training intensity zone 4 in the 5-zone model; z5 = training intensity zone 5 in the 5-zone model; VT_1 = first ventilatory threshold; OPLA = onset of plasma lactate accumulation; LT_1 = first lactate threshold; VT_2, second ventilatory threshold; OBLA = onset of blood lactate accumulation; IAT = individual anaerobic threshold; MLSS = maximal lactate steady-state; LT_2 = second lactate threshold; $\dot{V}O_2max$ = maximum oxygen uptake; HR_{max} = maximal heart rate; MAS/MAP = maximal aerobic speed/maximal aerobic power; vVO_{2max} = velocity associated with the maximum oxygen consumption; CP/CS = critical power/speed; FTP = functional threshold power; RPE = rating of perceived exertion in the Borg 6–20 scale.

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to greater long-term adaptations than other TID models (59). In addition, Kenneally et al. (41) examined the effectiveness of different TID models in running performance, showing that both POL and PYR models improved performance in distance runners compared with other TID models. In this line, Casado et al. (12) established that elite runners who usually follow a PYR model accumulate the great majority of training volume in Z1 (□76–86%). These authors concluded that the PYR model is the most effective TID model to improve performance and develop key endurance performance-related variables. Similarly, previous studies carried out by Muñoz et al. (46) and Esteve-Lanao et al. (18) had already shown a positive correlation between training time spent in Z1 and endurance performance. Therefore, it seems that POL and PYR models reported greater improvements in endurance performance. However, there is a lack of consensus in scientific evidence concerning the effectiveness of the most appropriate TID model to optimize endurance performance, especially when reported training volume in each training zone and athletes' performance levels are considered (10,23). In this regard, McKay et al. (44) have recently established a 6-tiered Participant Classification Framework considering training volume and performance variables. To the best of our knowledge, this is the first scoping review providing the polarization index (PI) developed by Treff et al. (77) for categorizing the TID models implemented in experimental research designs, as well as a classification framework for establishing athletes' level according to McKay et al. (i.e., tier 1) (44). Therefore, the aim of this scoping review was to analyze the long-term effects of POL on key endurance physiological- and performance-related variables in different-level endurance athletes and to systematically compare these effects with other TID models (i.e., PYR, THR, BT). Based on previous scientific evidence (20,59), we hypothesize that POL and PYR training models will lead to greater enhancements in highly trained/national level, elite/international level, and world-class endurance athletes (i.e., tiers 3–5), while other TID models (e.g., THR model) might be more effective in lower-level endurance athletes.

Methods

Experimental Approach to the Problem

This scoping review was conducted with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (50) and registered in the Open Science Framework (OSF) platform with the number 10.17605/OSF.IO/HSJPW.

Search Strategy

In September 2023, an electronic literature search was conducted on PubMed, Web of Science, SportDiscus, and Scopus. The search was performed using the following keywords combined with Boolean operators (AND, OR): "runn*" OR "marathon*" OR "cyclist*" OR "athlet*" OR "triathlet*" OR "rowe*" OR "rowing*" OR "ski*" OR "swim*" AND "polari* training" OR "pyramidal training" OR "threshold training" OR "training intensity distribution*."

Inclusion and Exclusion Criteria

The selection criteria were established according to the population, intervention, comparison, outcomes, and study design questions as follows.

Population. Studies with healthy men and/or women endurance athletes of different levels were classified based on McKay et al. (44) Classification Framework as follows: tier 0: sedentary; tier 1: recreationally active; tier 2: trained/developmental; tier 3: highly trained/national level; tier 4: elite/international level; or tier 5: world class.

Intervention. All articles included implemented at least 1 intervention with the POL model and reported enough information to establish training load volume distribution in the different training intensity zones (i.e., Z1, Z2, and Z3). The PI was calculated to categorize different TID models in nonpolarized and polarized TID, fixing a cut-off >2.00 a.u. to be considered as a polarized TID model. In addition, a higher PI coefficient indicates a more polarized TID model. In the case that $Z3 = 0$, PI is zero by definition; and if $Z3 > Z1$, the PI cannot be calculated (77).

Comparison. Studies that compared POL model intervention with other TID models were selected for this review.

Outcomes. The outcomes selected were physiological ($\dot{V}O_2max$/$\dot{V}O_2peak$, speed or power at aerobic and anaerobic thresholds, economy of movement) and performance in competition or TT variables.

Exclusion Criteria. Studies involving nonendurance athletes or individuals with pathologies or injuries, intervention periods <4 weeks, and studies that did not report enough information to determine training load volume distribution in the different training intensity zones (i.e., Z1, Z2, and Z3) on the selected variables were excluded. In addition, letters to the editor, systematic reviews and meta-analyses, abstracts, opinion articles, or conference papers were also excluded.

Study Design. Original articles with a comparison between POL and other TID models. In addition, all included articles were published in English or Spanish.

Study Selection. From scientific databases, potential studies were directly exported into Covidence (Covidence Systematic Review Software; Veritas Health Innovation, Melbourne, Australia; available at www.covidence.org) to remove duplicates and perform the screening by applying the inclusion and exclusion criteria previously determined. During the process, 2 researchers (A.V.-S. and T.R.-K.) independently performed the screening and eligibility from studies to avoid potential bias. First, researchers performed a screening of titles and abstracts. After that, they carried out an independent review of full texts to assess final study eligibility (Figure 2). In case of disagreement, both researchers (A.V.-S. and T.R.-K.) first discuss to resolve conflicts regarding the selection process. If a consensus was not reached, a third researcher (A.P.-C.) was consulted to make a final decision.

Data Extraction. In reference to data extraction, 1 researcher (T.R.-K.) was responsible for data collection, while 2 researchers (A.V.-S. and T.R.-K.) checked the extracted data. These 2 researchers discussed disagreements, whereas a third researcher (A.P.-C.) was consulted to make a final decision if a consensus had not been previously reached. The following information was extracted from each study included in the scoping review, based on population, intervention, comparison, outcomes (PICO) questions, and compiled in Table 1: reference, sample

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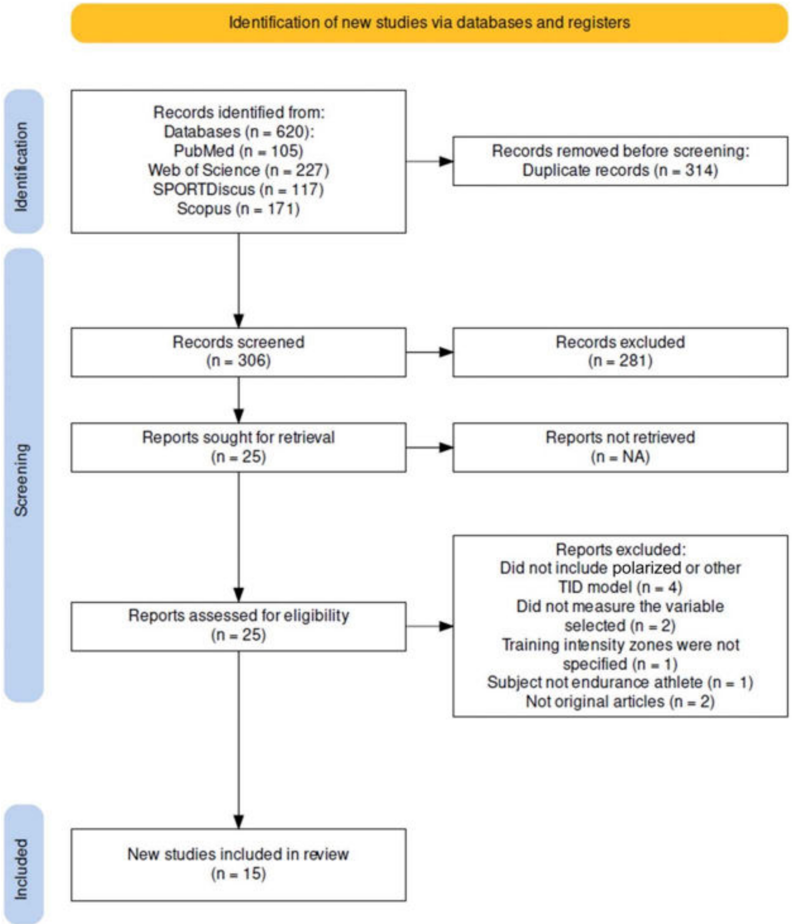

Figure 2. Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram of the process used in the selection of the journal articles included in the scoping review.

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characteristics (age, sex, weight, $\dot{V}O_2max$—when applicable, sport modality), athletes' performance classification, training intervention, and comparison description (implemented TID models, training program duration, TID in each zone, weekly training impulse [TRIMPs], weekly training frequency, weekly training volume, PI), and reported outcomes ($\dot{V}O_2max$ or $\dot{V}O_2peak$, speed or power associated with VT_1 or LT_1, speed or power associated with VT_2 or LT_2, economy of movement, TT or competition performance). Moreover, the effect size (ES), calculated as Cohen's *d*, was extracted and included in Table 1 for significant differences regarding the selected outcomes. In the case that ES was not reported, it was calculated, where applicable, as the difference between the means of the groups divided by the pooled standard deviations. Thresholds for effects were as follows: 0.20 "small," 0.50 "medium," and 0.80 "large."

Assessment of Methodological Quality of Included Studies

Two reviewers (T.R.-K. and A.V.-S.) independently scored the methodological quality of each included study using the PEDro scale (15). Specifically, the PEDro is a 10-point ordinal scale used to determine specific methodological components: (criteria 2) randomization, (criteria 3) concealed allocation, (criteria 4) baseline comparison, (criteria 5) blind subjects, (criteria 6) blind therapists, (criteria 7) blind assessors, (criteria 8) adequate follow-up, (criteria 9) intention-to-treat analysis, (criteria 10) between-group comparisons, and (criteria 11) point estimate and variability. In reference to the item of subject eligibility (criteria 1), this is not included in the final 10-point score. During the assessment of the methodological quality, when the 2 reviewers (T.R.-K and A.V.-S.) were in disagreement, they first discussed, and if they finally did not reach a consensus a third reviewer (A.P.-C.) was consulted to reach a final decision according to a specific item. In addition, based on their methodological quality, the studies were categorized as poor (scores ≤4 points), moderate (scores 5–6 points), and high quality (scores ≥7 points).

Results

Study Selection

A total of 620 articles were originally identified in the databases (Pubmed, $n = 105$; Web of Science, $n = 227$; SportDiscus, $n = 117$; Scopus, $n = 171$). Following the removal of duplicate records, a total of 306 articles were considered for the next stage. Afterward, the title and abstract were screened, removing a total of 281 articles. Then, 25 studies were selected for full-text analyses applying inclusion and exclusion criteria. Finally, 15 studies that accomplished the inclusion and exclusion criteria were included in this review. The PRISMA flowchart displays the identification, screening, and inclusion procedure (Figure 2).

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Table 1

Sample and studies' characteristics.*

			Training intervention and comparison							Reported outcomes [ES]				
Ref.	Sample characteristics	Performance classification	Intervention TID model	Study duration	TID (% Z1/Z2/Z3)	TRIMPs per week	Sessions per week	Volume ($h \cdot wk^{-1}$)	Pol. Index	$\dot{V}O_2max$/$\dot{V}O_2peak$	s/p AerThr	s/p AnThr	EM	Time trial/competition
(2)	12 elite adolescent swimmers (12 women)	Tier 3: highly trained/national level	POL PYR	12 wk	82/0/18 60/30/10	N/A	6	N/A	3.14 1.30	↑ [0.16]† ↑ [0.81]†	N/A	N/A	N/A	(S)100-m t↓ [0.83]† (S)800-m t↓ [0.48]†
(19)	38 recreational runners (19 women), 41.3 ± 8.5 y, $\dot{V}O_2max$ 53.1 ± 8.2	Tier 2: trained/developmental	POL THR	8 wk	77/3/20 40/50/10	308 ± 47 320 ± 28	4	3.7 ± 0.3 3.1 ± 0.25	2.71 0.90	↑ ↓	↑ [0.30]† ↑ [0.30]†	↑ [0.40]† ↑ [0.30]†	↑ [0.40]† ↑ [0.60]†	(R)s↑ [0.10]† (R)s↑ [0.10]†
(20)	60 well-trained runners (60 men), 37 ± 6 y, $\dot{V}O_2peak$ 68 ± 4	Tier 3: highly trained/national level	POL PYR PYR + POL POL + PYR	16 wk	80/6/14 77/17/6	464 ± 81 463 ± 77 462 ± 78 465 ± 80	6	5.8 ± 0.9 5.9 ± 1 5.7 ± 0.9 5.9 ± 1	2.27 1.43	↑ [0.40]† ↑ ↑ [0.40]† ↑ [0.47]†	↑ [0.25]† ↑ [0.10]† ↑ [0.22]† ↑ [0.13]†	↑ [0.25]† ↑ [0.10]† ↑ [0.22]† ↑ [0.15]†	N/A	(R)t↓ [0.24]† (R)t↓ [0.11]† (R)t↓ [0.28]† (R)t↓ [0.16]†
(21)	60 well-trained runners (60 men), 34 ± 6 y, $\dot{V}O_2peak$ 69 ± 3	Tier 3: highly trained/national level	POL PYR	8 wk	80/6/14 77/17/6	463 ± 15 464 ± 20	6–7	5.9 ± 0.9 5.8 ± 0.9	2.27 1.43	↑ ↑	↑ ↑ [0.33]†	↑ ↑	N/A	(R)t↓ [0.21]† (R)t↓ [0.29]†
(46)	32 recreational runners (32 men), 34 ± 2.8 y, $\dot{V}O_2max$ 63 ± 7,9	Tier 2: trained/developmental	POL THR	10 wk	75/5/20 45/35/20	330 ± 67 370 ± 98	5–6	3.9 ± 0.79 3.6 ± 0.81	2.48 1.41	N/A	N/A	N/A	N/A	(R)t↓ [0.41]† (R)t↓ [0.34]†
(47)	12 trained cyclists (12 men), 37 ± 6 y	Tier 3: highly trained/national level	POL THR	6 wk	80/0/20 57/43/0	517 ± 90 633 ± 119	N/A	6.3 ± 1.4 7.7 ± 2	3.18 0	N/A	↑ [0.59]† ↑	↑ ↑	N/A	(C)PO↑ [0.57]† (C)PO↑ [0.35]†
(55)	22 elite junior swimmers (10 women), 17 ± 3 y	Tier 4: elite/international level	POL THR	6 wk	81/4/15 65/25/10	N/A	N/A	8 ± 2 8 ± 2	2.48 1.41	= ↑	N/A	= ↑	N/A	(S)t↓ (S)t=
(57)	18 trained cyclists (6 women), 38 ± 7 y	Tier 2: trained/developmental	POL THR	4 wk	88/0/12 70/30/0	N/A	4	4.26 4.61	2.98 0	N/A	N/A	N/A	N/A	(C)PO↑ [0.30]† (C)PO↑
(58)	15 moderately trained triathletes (4 women), 29.7 ± 6.9 y	Tier 2: trained/developmental	POL THR	6 wk	92/0/8 65/35/0	788 941	12	10.8 ± 2.4 10.0 ± 2.7	2.81 0	N/A	(R)↑ (C)↑ (R)↓ (C)↓	(R)↑ (C)↑ (R)↑ (C)↓	N/A	N/A N/A
(63)	18 competitive mountain bike cross-country Olympic cyclists (4 women), 17.9 ± 3.6 y	Tier 3: highly trained/national level	POL LIT	4 wk	87/0/13 100/0/0	N/A	5	8.3 13.3	3.02 0	N/A	N/A	↑ [n/a]† ↑	N/A	(C)2100-m t= (C)2100-m t=
(68)	18 recreational triathletes (18 men), 28.9 ± 6.9 y, $\dot{V}O_2max$ 56.9 ± 5.7	Tier 2: trained/developmental	POL PYR	13 wk	85/4/11 78/19/3	N/A	N/A	12 12	2.37 1.09	(R)↑(C)↑ [n/a]† (R)↑(C)↑ [n/a]†	(R)↑ (C)†↑ [n/a]† (R)↑ (C)†↑ [n/a]†	(R)↑(C)↑ [n/a]† (R)↑ (C)†↑ [n/a]†	N/A	(S)800-m t↓ [n/a]† (S)800-m t↓ [n/a]†
(73)	48 competitive endurance		POL THR	9 wk	68/6/26	N/A	6 5	11.5 ± 2.2	2.47 0	↑ [0.85]†	↑ =	↑ [n/a]† =		N/A

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Table 1

Sample and studies' characteristics.* *(Continued)*

			Training intervention and comparison							Reported outcomes [ES]				
Ref.	Sample characteristics	Performance classification	Intervention TID model	Study duration	TID (% Z1/ Z2/ Z3)	TRIMPs per week	Sessions per week	Volume ($h\cdot wk^{-1}$)	Pol. Index	$\dot{V}O_2max$/ $\dot{V}O_2peak$	s/p AerThr	s/p AnThr	EM	Time trial/ competition
	athletes, 31 ± 6 y, $\dot{V}O_2max$ 62 ± 6	Tier 3: highly trained/ national level	LIT HIIT		46/54/0 83/16/1 43/0/57		5 5	9.3 ± 0.7 11.3 ± 1.2 7.3 ± 0.1	0.71 N/A	= ↑ ↑ [0.45]†	= ↑ [n/a]†	= ↑ [n/a]†	↓ [0.29]† ↓ ↓ ↓	
(72)	36 competitive endurance athletes (3 women), 31 ± 6 y, $\dot{V}O_2max$ 61.9 ± 8	Tier 3: highly trained/ national level	POL HIIT LIT	9 wk	68/6/26 43/0/57 64/35/1	N/A	6 ± 1 5 ± 0.1 6 ± 1	11.5 ± 2.3 7.3 ± 0.1 10.3 ± 1.4	2.47 N/A 0.26	N/A	N/A	↓ ↑ ↑	N/A	N/A
(76)	14 elite rowers, 20 ± 2 y, $\dot{V}O_2max$ 66 ± 5	Tier 4: elite/ international level	POL PYR	11 wk	93/1/6 94/4/2	N/A	8 ± 1 7 ± 0.3	8,9 ± 1,8 9 ± 4.7	2.75 1.67	= =	= ↑	= ↑	N/A	(RO)2000-m PO↑, t= (RO)2000-m PO↑, t=
(84)	9 top-level speed skaters (4 women), 24 ± 4 y, $\dot{V}O_2max$ 50.1 ± 2	Tier 5: world class	POL THR	1 season THR 1 season POL	85/5/10 41/51/10	N/A	12 ± 0.3 12 ± 0.3	6 ± 1.9 6 ± 1.2	2.23 0.90	N/A	N/A	N/A	N/A	(SS)500-m t↓ [men: 0.89, women: 1.54]† (SS)1000-m t↓ [men: 0.80, women: 3.53]† (SS)500-m t= (SS)1000-m t=

*Ref. = references; TID = training intensity distribution; Z1 = training zone 1 (volume below the aerobic threshold); Z2 = training zone 2 (volume between the aerobic and the anaerobic thresholds); Z3 = training zone 3 (volume above the anaerobic threshold); POL = polarized training model; PYR = pyramidal training model; THR = threshold training model; HIIT = high-intensity interval training; LIT = low-intensity training; Pol. Index = polarization index; [ES] = effect size reported as Cohen's *d*. Please note that ES is only reported for intra-subject significant differences. Thresholds for effects were as follows: 0.20 "small," 0.50 "medium," and 0.80 "large." When nonparametric tests were performed or when only percentage values were reported, ES was not calculated and it is indicated as "not applicable" [n/a]; $\dot{V}O_2max$ = maximum oxygen uptake expressed in $ml\cdot kg^{-1}\cdot min^{-1}$; $\dot{V}O_2peak$ = peak oxygen uptake expressed in $ml\cdot kg^{-1}\cdot min^{-1}$; s/p AerThr = speed or power within the aerobic threshold; s/p AnThr = speed or power within the anaerobic threshold; EM = economy of movement; TRIMP = training impulse; t = time; s = speed; PO = power output; (R) = running performance; (C) = cycling performance; (S) = swimming performance; (RO) = rowing performance; (SS) = speed skating performance; N/A = not applicable.

†Significant differences between pretest and posttest ($p < 0.05$).

Study Characteristics

The main characteristics of the 15 articles included in this scoping review are shown in Table 1. All studies included a total of 412 endurance athletes ($n = 62$ women) through a crossover design ($n = 3$) or a randomized trial ($n = 12$), while training interventions lasted between 4 and 52 weeks. Eight articles included the comparison of the POL model with the THR model, and the other studies analyzed the effects of the POL model in comparison with PYR ($n = 5$) or BT models ($n = 3$). The main internal load variables included in this review were $\dot{V}O_2max$ or $\dot{V}O_2peak$ ($n = 8$) and economy of movement ($n = 3$). Regarding external load, speed or power at the aerobic threshold ($n = 8$), speed or power at the anaerobic threshold ($n = 11$), and TT or competition performance ($n = 13$) were analyzed.

The interventions in the included studies focused on running (19–21,46), cycling (47,57,63), swimming (2,55), triathlon (58,68), rowing (76), speed skating (84), and a mix of endurance sports (72,73). In this regard, 7 of the included studies were performed with highly trained/national level athletes (i.e., tier 3),

Table 2

Physiotherapy evidence database (PEDro).

	PEDro ratings											
Study	1	2	3	4	5	6	7	8	9	10	11	Total
Arroyo-Toledo et al. (2)	No	−	−	−	−	−	−	−	+	+	+	3
Festa et al. (19)	Yes	+	−	+	−	−	−	+	+	+	+	6
Filipas et al. (20)	Yes	+	+	+	−	−	−	+	+	+	+	7
Filipas et al. (21)	Yes	+	+	+	−	−	−	+	+	+	+	7
Muñoz et al. (46)	Yes	+	−	+	−	−	−	+	+	+	+	6
Neal et al. (47)	Yes	−	−	−	−	−	−	+	+	+	+	4
Pla et al. (55)	Yes	+	−	+	−	−	−	−	+	+	+	5
Rivera-Kofler et al. (57)	Yes	+	−	−	−	−	−	−	+	−	+	3
Röhrken et al. (58)	Yes	+	−	+	−	−	−	−	+	+	+	5
Schneeweiss et al. (63)	Yes	+	−	+	−	−	−	−	+	+	+	5
Selles-Perez et al. (68)	Yes	−	−	+	−	−	−	−	+	+	+	4
Stöggl and Sperlich (73)	Yes	+	−	+	−	−	−	+	+	+	+	6
Stöggl and Björklund (72)	Yes	+	−	+	−	−	−	−	+	+	+	5
Treff et al. (76)	Yes	−	−	+	−	−	−	+	+	+	+	5
Yu et al. (84)	No	−	−	+	−	−	−	+	+	+	+	5

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5 studies were carried out with trained/developmental athletes (i.e., tier 2), while only 2 studies were performed with elite/international level athletes (i.e., tier 4) and 1 with world-class endurance athletes (i.e., tier 5).

The PI was determined for each TID intervention. The corresponding values for each model were (for more details, see Table 1): 2.23–3.18 for POL, 1.3–1.67 for PYR, 0–1.41 for THR, and 0–0.71 for LIT.

Effect size, reported as Cohen's *d*, was also extracted and reported for significant differences regarding the selected outcomes of the included studies (Table 1).

Risk of Bias

Table 2 presents the scores of each study for each specific methodological component according to the PEDro scale. In this regard, 4 studies (28%) were categorized as poor quality, 9 studies (64%) as moderate quality, and only 2 (13%) as high quality. Concretely, the criteria related to subject blinding (criteria 5) and assessor blinding (criteria 6–7) were not accomplished in any of the selected studies. Similarly, only 2 studies provided information about concealed allocation (criteria 3).

Maximum Oxygen Uptake. There were 8 studies describing changes in $\dot{V}O_2max$ or $\dot{V}O_2peak$. Stöggl and Sperlich (73) showed that POL leads to a greater improvement than THR and LIT after 9 weeks of intervention in a group of well-trained endurance athletes of different modalities (i.e., tier 3). In addition, 2 studies (2,68) reported positive changes in $\dot{V}O_2max$ but with no significant differences compared with the PYR model in a group of highly trained women swimmers (i.e., tier 3) and recreational triathletes (i.e., tier 2). Moreover, Filipas et al. (20) showed, in a group of well-trained runners (i.e., tier 3), a significant interaction effect between POL and PYR models, but differences between groups were not reported. By contrast, 3 studies (19,21,76) revealed no effects on $\dot{V}O_2max$ after different endurance training interventions applying POL and PYR models in recreational women runners (i.e., tier 2), well-trained runners (tier 3), and elite rowers (i.e., tier 4). Finally, Pla et al. (55) only reported quantitative changes of differences, thus no statistical differences within- and between-groups were presented after following POL and THR TID models in elite junior swimmers (i.e., tier 4).

Aerobic Threshold. Eight studies analyzed the effects of POL vs. other TIDs models on the performance within the aerobic threshold assessing speed or power. In this line, 3 studies (19,68,73) found that POL was an effective strategy to increase speed or power associated with the aerobic threshold. Neal et al. (47) reported significant enhancements only after POL in trained cyclists (i.e., tier 3), but no significant effects were observed after THR. In addition, Filipas et al. (20,21) showed positive changes in the speed associated with the aerobic threshold after 16 weeks of endurance training, independently of the TID and training sequence implemented (i.e., POL, PYR, PYR-POL, and POL-PYR training sequences) in well-trained runners (i.e., tier 3). In another research design, these authors (21) also reported significantly greater improvements only after 8 weeks of PYR, but not after POL in a group of well-trained runners (i.e., tier 3). Contrary to these findings, Treff et al. (76) determined no significant changes in national elite rowers (i.e., tier 4) after 11 weeks of POL and PYR training. Similarly, Röhrken et al. (58) also reported no significant changes in running and cycling performance within the aerobic threshold after performing 6 weeks of POL and THR training in a group of trained triathletes (i.e., tier 2).

Anaerobic Threshold. Eleven studies analyzed the effects of different TID models on the performance within the anaerobic threshold, assessing speed or power. Specifically, 3 studies (19,47,58) reported positive effects on speed or power associated with the anaerobic threshold after applying POL and THR TID models. In addition, Schneeweiss et al. (63) obtained significant enhancements only after POL intervention in comparison with the baseline measures in a group of mountain bike cross-country Olympic cyclists (i.e., tier 3). However, these authors did not find significant differences after LIT. Similarly, Stöggl and Sperlich (73) reported a significant increase in POL and high-intensity interval training (HIIT) groups when comparing pretest and posttest values in a group of different endurance athletes (i.e., tier 3). Concretely, this study determined significant differences favoring the POL model compared with the remaining TID models (i.e., THR and LIT), except HIIT. Furthermore, Filipas et al. (20) reported significant improvements in the speed associated with the anaerobic threshold after 16 weeks of endurance training for all TID training intervention groups (i.e., POL, PYR, PYR-POL, and POL-PYR training sequences) in well-trained runners (i.e., tier 3). On the other hand, the study conducted by Selles-Perez et al. (68) determined a significant increase in both running speed and cycling power associated with the anaerobic threshold after applying the PYR training model in recreational triathletes (i.e., tier 2). In contrast to the aforementioned studies, no substantial changes were observed after POL and THR training in junior swimmers (i.e., tier 4) (55). Similarly, Stöggl and Björklund (72) determined no significant differences between POL, HIIT, and LIT groups in regional-level endurance athletes (i.e., tier 3). Finally, Treff et al. (76) did not report significant changes regarding performance within the anaerobic threshold after applying POL and PYR models in elite rowers (i.e., tier 4). Similarly, a recent study by Filipas et al. (21) also found a nonsignificant increase in the speed associated with the anaerobic threshold after 8 weeks of POL or PYR training in well-trained runners (i.e., tier 3).

Economy of Movement. Only 2 studies analyzed the economy of movement after the application of TID training models in endurance athletes. In this sense, Festa et al. (19) reported positive changes after 8 weeks of training on running economy after POL and THR models in recreational runners (i.e., tier 2). Similarly, Stöggl and Sperlich (73) observed an improvement in work economy after 9 weeks of POL in endurance athletes (i.e., tier 3), with no differences compared with other TID models.

Time-Trial and Competition Performance. There were 10 studies (2,19–21,46,47,57,63,68,84) reporting significant TT or competition performance improvements (i.e., decreased time for a given distance; or increased speed or power output for a given time or distance) after implementing different TID models. Neal et al. (47) determined significant improvements regarding mean power output in a 40-km TT after both POL and THR models in well-trained cyclists (i.e., tier 3), but they did not provide data concerning the time spent to cover the 40 km. In addition, Rivera-Kofler et al. (57) also reported increased power output at the functional threshold in a 20-minute TT after following the POL model in trained cyclists (i.e., tier 2). On the other hand, Schneeweiss et al. (63) showed no significant changes in

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a simulated 2100-m race TT in both LIT and POL models in mountain bike cross-country Olympic cyclists (i.e., tier 3). Regarding running performance, Filipas et al. (21) demonstrated an improvement in 5-km TT after implementing 8 weeks of POL or PYR training, and 16 weeks of different sequences of both POL and PYR models among well-trained runners (i.e., tier 3) (20). In this regard, Festa et al. (19) and Muñoz et al. (46) reported enhanced running performance in a 2 km TT and a 10-km race, respectively, after 8–10 weeks of POL or THR training in recreational runners (i.e., tier 2 for both). Concerning swimming performance, 2 studies (2,68) showed significant reductions in 100-m and 800-m TT after applying POL and PYR models. In addition, Yu et al. (84) concluded that the POL model significantly enhanced the percentage of change in both 500- and 1000-m TT performance compared with the THR model in world-class speed skaters (i.e., tier 5). However, these authors reported no differences between TID models regarding the total TT for both distances. Conversely, Treff et al. (76) found no significant differences between pretest and posttest in 2000-m TT performance after following POL or PYR models in national elite rowers (i.e., tier 4). In this line, Pla et al. (55) also reported no significant changes in swimming (i.e., tier 4) performance after implementing POL and THR models.

Discussion

To the best of our knowledge, this is the first review examining the effects of different TID models on key physiological and performance variables reporting the PI and endurance athletes' level according to a classification framework (44). The main findings of our review were as follows: (a) POL and PYR models seem to be more effective than other TID models regarding functional capacity enhancement (i.e., $\dot{V}O_2max$ or $\dot{V}O_2peak$), without differences between them; (b) POL and PYR models are effective strategies to enhance speed or power within the aerobic threshold; (c) POL, PYR and THR TID models reported positive effects on speed or power within the anaerobic threshold; however, the results are quite heterogeneous; (d) both POL and THR models may enhance economy of movement; nevertheless, the results are inconclusive, as there are scarce studies analyzing this variable; and (e) TT and competition performance increased after applying different TID models (i.e., POL, PYR, LIT, and THR), but testing protocols were not comparable; however, POL and PYR models seem to be more effective in elite/international or world-class athletes, while in lower-level athletes the differences between TID models are negligible.

The majority of studies reported greater improvements in $\dot{V}O_2max$ or $\dot{V}O_2peak$ after following POL or PYR TID models. In this regard, the POL model (68%/6%/26% for Z1/Z2/Z3, PI = 2.47) seems to be superior to the THR and LIT models for highly trained/national level endurance athletes (i.e., tier 3) after performing 9 weeks of training (73). Further, when POL (80%/6%/14% for Z1/Z2/Z3, PI = 2.27) and PYR TID models are implemented, scientific evidence found positive changes in $\dot{V}O_2max$ in a group of highly trained/national level runners (i.e., tier 3) after 16 weeks of training (20), but after 8 weeks of training these improvements were not significant (21). Similarly, other studies performed with highly trained/national level swimmers (i.e., tier 3) (2) and trained/developmental triathletes (i.e., tier 2) (68) showed $\dot{V}O_2max$ enhancements after following 12–13 weeks of POL (82%/0%/18% for Z1/Z2/Z3, PI = 3.14; and 85%/4%/11% for Z1/Z2/Z3, PI = 2.37, respectively) or PYR, without significant differences between both TID models. On the other hand, Festa et al. (19) and Treff et al. (76) found no significant improvements in $\dot{V}O_2max$ after implementing POL (77%/3%/20% for Z1/Z2/Z3, PI = 2.71; and 93%/1%/6% for Z1/Z2/Z3, PI = 2.75, respectively) and PYR models. In this sense, it is important to mention that both studies carried out a shorter intervention period (i.e., 8 and 11 weeks, respectively) and the level of athletes was categorized as trained/developmental runners (i.e., tier 2) (19) and elite/international level rowers (i.e., tier 4) (76). Finally, Pla et al. (55) showed no statistical differences between POL (81%/4%/15% for Z1/Z2/Z3, PI = 2.48) and THR models in a group of elite/international level swimmers (i.e., tier 4), as they only reported quantitative changes of differences.

Taken together, the heterogeneity of the present results could be partially due to the studies' sample characteristics (i.e., endurance sport modality, athletes' level, etc.), as most of the positive changes on $\dot{V}O_2max$ or $\dot{V}O_2peak$ were reported in athletes classified as tier 3 or higher after performing POL or PYR training. Another fact that could explain the differences between TID models is the percentage of training accumulated in each training zone. For instance, POL training interventions ranged from 68 to 93% in Z1, from 0 to 6% in Z2, and from 6 to 26% in Z3. Furthermore, PI was quite consistent between studies, ranging from 2.27 to 3.14, which could be considered a high level of polarization (77). In this sense, scientific literature recommended the implementation of HIIT consisting of 2–3-minute work intervals performed close to 100% of the maximal aerobic speed or maximal aerobic power (i.e., Z3), interspersed with active or passive recovery intervals with a work-to-rest ratio of 1:1 and a high training volume (i.e., ≥15 minutes) for optimizing $\dot{V}O_2max$ (79). These recommendations would support the application of both POL and PYR models, as they allow athletes to accumulate a greater volume of training in Z3 than other TID approaches. Similarly, from a physiological mechanism standpoint, and according to previous scientific literature, it could be hypothesized that both POL and PYR TID may produce superior $\dot{V}O_2max$ gains by optimizing both central (i.e., increased cardiac output and plasma volume) and peripheral (i.e., increased mitochondrial biogenesis and capillary density of the skeletal muscle) aerobic adaptations (7,29,81). On the other hand, based on the studies analyzed, the intervention period could also influence changes in functional capacity, as longer training periods seem to report greater improvements in $\dot{V}O_2max$. Therefore, from a practical perspective, the implementation of POL and PYR TID models seems to be appropriate for improving $\dot{V}O_2max$ or $\dot{V}O_2peak$, especially in high-level endurance athletes, while other TID models may also be effective in lower-level athletes.

More than half of the studies included in the present review analyzed the effects of different TID models on performance within the aerobic threshold. Three of them found POL training as an effective strategy to enhance power or speed associated with the aerobic threshold. Festa et al. (19) reported significant improvements in the speed associated with the aerobic threshold after performing 8 weeks of POL (i.e., 77%/3%/20% for Z1/Z2/Z3, PI = 2.71) and THR training with trained/developmental runners (i.e., tier 2), without differences between interventions (4 vs. 3.2% improvement, respectively). Selles-Pérez et al. (68) also found significant enhancements in running and cycling performance within the aerobic threshold in a group of trained/developmental triathletes (i.e., tier 2) who performed 13 weeks of POL (i.e., 85%/4%/11% for Z1/Z2/Z3, PI = 2.37) and PYR training, without differences between models. Similarly, Stöggl and Sperlich (73) implemented 9 weeks of POL (i.e., 68%/6%/

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26% for Z1/Z2/Z3, PI = 2.47) vs. other TID models (including THR, LIT, and HIIT) in highly trained/national level endurance athletes (i.e., tier 3). They found a nonsignificant enhancement in the power or speed associated with the aerobic threshold in the POL group (9.3 ± 12.4%), while the HIIT group (12.1 ± 8.8%) reported significant improvements, but without differences between protocols. On the other hand, Neal et al. (47) demonstrated significant improvements only after performing POL training in highly trained/national-level cyclists (i.e., tier 3). These authors carried out a study implementing 6 weeks of POL (i.e., 80%/0%/20% for Z1/Z2/Z3, PI = 3.18) vs. THR training. This study reported significant enhancements in the power within the aerobic threshold for the POL group compared with the THR group (improvement of 9 ± 9% vs. 2 ± 14% W, respectively). Furthermore, an interesting study by Filipas et al. (20) consisting of 16 weeks of training following POL (i.e., 80%/6%/14% for Z1/Z2/Z3, PI = 2.27), PYR, POL-PYR sequence and PYR-POL sequence (i.e., 8 weeks each TID model for the sequences) in highly trained/national level runners (i.e., tier 3) showed positive significant changes for all interventions. However, the authors demonstrated that the PYR-POL training sequence led to higher enhancements in the speed associated with the aerobic threshold than other TID models. Similarly, in a more recent study, these authors (21) also found significant improvements in the speed within the aerobic threshold after performing 8 weeks of PYR training, but not after POL, among well-trained runners (i.e., tier 3). Finally, Treff et al. (76) reported no significant changes in power associated with the aerobic threshold after 11 weeks of POL (i.e., 93%/1%/6% for Z1/Z2/Z3, PI = 2.75) and PYR training in elite/international level rowers (i.e., tier 4). In this line, Röhrken et al. (58) also found no significant changes in running and cycling performance within the aerobic threshold after following 6 weeks of POL (i.e., 92%/0%/8% for Z1/Z2/Z3, PI = 2.81) and THR training in a group of trained/developmental triathletes (i.e., tier 2).

Considering the data mentioned above, most of the studies analyzed reported positive changes in performance within the aerobic threshold after applying POL and PYR models. These studies were carried out with endurance athletes classified in tiers 2 and 3, while the percentage of training volume accumulated in Z1 for the different POL training interventions ranged from 68 to 93%. In this regard, previous scientific literature consistently demonstrated that training volume spent in Z1 correlates with endurance performance in different endurance-sport modalities (17,18,46). Furthermore, training interventions lasted between 6 and 16 weeks and PI ranged from 2.27 to 3.18, which is categorized as highly polarized (77). Thus, different-level endurance athletes aiming to improve their speed or power within the aerobic threshold should implement POL or PYR models and, therefore, accumulate a great volume of exercise in Z1 for enhancing endurance performance.

The effects of different TID models on the performance within the anaerobic threshold were investigated in 11 of the included studies. Festa et al. (19) showed significant improvements in the speed associated with the anaerobic threshold after performing 8 weeks of POL (i.e., 77%/3%/20% for Z1/Z2/Z3, PI = 2.71) and THR training with trained/developmental runners (i.e., tier 2), without differences between interventions (5.7 vs. 3.4% improvement, respectively). Neal et al. (47) and Röhrken et al. (58) also compared the effects of POL (i.e., 80%/0%/20% for Z1/Z2/Z3, PI = 3.18, and 92%/0%/8% for Z1/Z2/Z3, PI = 2.81, respectively) and THR TID models on the performance within the anaerobic threshold, reporting positive but nonsignificant changes in this variable after following 6 weeks of training in highly trained/national level cyclists (i.e., tier 3) and trained/developmental triathletes (i.e., tier 2), respectively. However, other studies (63,73) found significant positive changes in the speed or power associated with the anaerobic threshold only after implementing POL, without significant differences compared with other TID models. Specifically, Schneeweiss et al. (63) reported a significant enhancement in cycling power output at both individual anaerobic lactate threshold (5.1%) and 4 mmol lactate threshold (6.1%) in a group of highly trained/national level (i.e., tier 3) mountain bike cross-country Olympic cyclists after performing only 4 weeks of POL training (i.e., 87%/0%/13% for Z1/Z2/Z3, PI = 3.02). In the same line, Stöggl and Sperlich (73) found significant enhancements in the power or speed within the anaerobic threshold (8.1 ± 4.6% for POL vs. 5.6 ± 4.8% for HIIT models) after implementing 9 weeks of POL (i.e., 68%/6%/26% for Z1/Z2/Z3, PI = 2.47) vs. other TID models (including THR, LIT, and HIIT) with highly trained/national level endurance athletes (i.e., tier 3), but without differences between protocols. Moreover, Filipas et al. (20), demonstrated that 16 weeks of PYR-POL training sequence led to higher enhancements in the speed associated with the anaerobic threshold than the opposite sequence order, or isolated POL or PYR training in a group of highly trained/national level runners (i.e., tier 3). Regarding triathlon performance, Selles-Perez et al. (68) found a significant increase in cycling power associated with the anaerobic threshold after performing 13 weeks of POL or PYR training in recreational triathletes (i.e., tier 2). However, the running speed within the anaerobic threshold was only significantly higher after following the PYR model (2.6%, ES $d = 0.27$).

On the other hand, 4 studies (21,55,72,76) reported no significant changes in the performance within the anaerobic threshold. In a recent study, Filipas et al. (21) showed a nonsignificant enhancement in the running speed associated with the anaerobic threshold after performing 8 weeks of either POL or PYR training in well-trained runners (i.e., tier 3). Pla et al. (55) determined no significant changes in elite/international level junior swimmers (i.e., tier 4) after 6 weeks of POL (i.e., 81%/4%/15% for Z1/Z2/Z3, PI = 2.48) and THR training. Stöggl and Björklund (72) also found no positive changes after 9 weeks of POL training (i.e., 68%/6%/26% for Z1/Z2/Z3, PI = 2.47) compared with other TID models (i.e., HIIT and LIT) in highly trained/national level endurance athletes (i.e., tier 3). Similarly, Treff et al. (76) reported no significant changes in power within the anaerobic threshold after 11 weeks of POL (i.e., 93%/1%/6% for Z1/Z2/Z3, PI = 2.75) and PYR training in elite/international level rowers (i.e., tier 4).

Taken together, POL, PYR, and THR TID models seem to be valid for improving speed or power associated with the anaerobic threshold. Concerning this, it is important to note that performance within the anaerobic threshold may be enhanced by training at different intensities (36,39), which may make it appropriate for the implementation of different TID models. On the other hand, the heterogeneity of the studies regarding athletes' level and endurance-sport modality, percentage of total training volume accumulated in each training zone, and intervention period durations makes it difficult to generalize the results of scientific evidence. In this regard, the studies that reported positive effects on performance within the anaerobic threshold were performed with endurance athletes classified as tier 2 or 3, who accumulated between 68 and 93% of the total training volume in Z1, 0–6% in Z2, and 8–26% in Z3, while PI ranged from 2.27 to 3.18. Interestingly, the 3 studies that found no effects of POL on

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this variable were carried out with high performance level endurance athletes (i.e., tiers 3 and 4). Therefore, further studies are needed to elucidate the optimal TID model for maximizing speed or power within the anaerobic threshold. To date, scientific evidence suggests the appropriateness of implementing POL, PYR, and THR models for this purpose, without differences between them.

Two of the selected studies analyzed the economy of movement in athletes of different endurance-sport modalities. Festa et al. (19) demonstrated significant enhancements in running economy, which is traditionally defined as the energy cost for a submaximal running speed (36,61), after applying 8 weeks of POL (i.e., 77%/3%/20% for Z1/Z2/Z3, PI = 2.71) and THR training in trained/developmental (i.e., tier 2) runners, without differences between interventions (−5.3% vs. −8.7% for POL and THR, respectively). Another study performed by Stöggl and Sperlich (73) with highly trained/national level endurance athletes (i.e., tier 3) also reported significant improvements in the economy of movement of approximately −5% (expressed as a percent of $\dot{V}O_2$peak) after 9 weeks of POL (i.e., 68%/6%/26% for Z1/Z2/Z3, PI = 2.47), without differences compared with other TID models (i.e., THR, LIT, HIIT). Owing to the scarce number of scientific studies investigating the effects of different TID models on the economy of movement, it is difficult to draw conclusions. Further studies are needed to determine what TID model optimizes the economy of movement, especially when athletes' level and endurance-sport modality are considered.

Concerning endurance performance, scientific evidence highlighted POL and PYR TID models as 2 of the most effective TID models for enhancing athletic performance. Based on previous results (2,20,21,68,76), there were no significant differences regarding endurance performance between POL and PYR TID models. In addition, it was reported no significant improvements for POL and LIT models during a simulated mountain bike cross-country race (58,63). This lack of significant differences is independent of the percentage of volume accumulated in each zone. Therefore, there seems to be no optimal distribution between training zones that would result in greater performance. In this sense, a minimum percentage of training volume in Z3 seems to be necessary for performance improvement, although a large percentage in the so-called severe domain does not result in higher performance. There are different interventions in which the percentage of training in Z3 for the POL model ranges from 6% (76) to 26% (72,73). Although all of these studies reported performance enhancements following POL, they did not show significant differences compared with other TID models (2,68,76). Therefore, it is necessary to train a minimum percentage of the total time in the severe domain. However, the question of how much volume an athlete should train in this zone remains unclear.

The hypothetical superiority of POL and PYR has only been demonstrated in elite/international or world-class athletes (tiers 4 and 5, respectively) (55,84). For a major understanding of this topic, we encourage to revise the studies performed by Burnley et al. (10) and Foster et al. (23) in which 2 different perspectives are exhaustively discussed. The superiority of these TID models (i.e., POL and PYR) in elite and world-class athletes might be supported by the necessity of accumulating a great LIT volume combined with HIT to achieve new adaptations and hence, improve endurance performance. This situation makes it difficult to perform a high volume of training in Z2 (i.e., heavy domain), which traditionally corresponds to the THR model (10,12). Nevertheless, when comparing performance results in lower-level endurance athletes (tiers 2 and 3) following different TID models, no study has shown significant differences in sports performance. This lack of differences in endurance performance (e.g., TT and competition performance) and physiological variables (i.e., $\dot{V}O_2$max, speed or power associated with both aerobic and anaerobic thresholds, and economy of movement) (Table 1) between the different TID models has been well documented in early studies that implemented THR with athletes classified as tiers 1–3 (i.e., recreationally active to highly trained) (16,24,42).

One possible explanation for this absence of difference between TID models in lower tiers could be the heterogeny characteristics of the tests or competitions in which performance was measured. For example, in our analyses, only 1 study (47) measured endurance performance with a TT proxy for a duration of 1 hour, which allows the development of an exercise intensity close to the anaerobic threshold. In the present review, all the remaining works that have measured endurance performance implemented tests or competitions that vary from 36 seconds (84) to 43 minutes (63), which leads to the assumption that the intensity of execution was clearly above the anaerobic threshold. In this sense, POL and PYR models accumulate more training time close to a specific race pace. Nevertheless, these models are characterized by accumulating not only an important volume of training in the severe domain but also a great volume in Z1, which could be related to a specific race pace in long-distance events (e.g., ultramarathon, Ironman, etc). For this reason, it is very difficult to determine the superiority of a TID model regarding endurance performance, as the way it is measured could represent a specific training intensity vs. another model that barely focuses on that training zone. Therefore, available scientific evidence has reported endurance performance enhancements by following different TID models. Further, based on previous studies it seems that higher-level endurance athletes may be more benefited from POL and PYR models, while among lower-level athletes the differences between TID models are negligible.

One of the main limitations of the present review is the heterogeneity of the included studies. Considering the total sample, it was composed of endurance athletes of various modalities (i.e., running, cycling, triathlon, swimming, skiing, speed skating, and rowing) and levels (i.e., tiers 2–4). This fact may limit the extrapolation of a specific modality to other exercise regimes. The great majority of studies were performed with trained/developmental and highly trained/national level athletes (12 of 15 studies), which could make it difficult to extrapolate conclusions to higher-level athletes. Similarly, TID varied between POL interventions, and accumulated training volume ranged from 68 to 93% for Z1, from 0 to 6% for Z2, and from 6 to 26% for Z3. However, the PI of most of the studies reported POL interventions that could be considered as highly polarized (i.e., PI quite higher than 2.0) (77). Furthermore, many of the included studies did not consider an equaled total training load and training volume per week, which makes it difficult to establish the superiority of 1 TID over others. Similarly, endurance and competition performance evaluation protocols include a plethora of durations and intensities barely comparable between them. In this respect, we recommend for future research to report the percentage of volume spent in, at least, a 5-zone model as shown in Figure 1. This 5-zone model is widely used to establish main training zones for endurance sports, including easy, moderate,

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threshold, interval, and maximal intensity training efforts (66). Furthermore, recent scientific evidence has suggested that a 5-zone model may aid in understanding physiological performance progression in highly trained rowers (82). To date, the majority of studies reported TID based solely on the classical triphasic model (69). This makes it difficult to accurately assess the real TID of a training program. For instance, an athlete may accumulate a training volume of 3 hours per week at an intensity slightly above the aerobic threshold, while another athlete may perform the same volume but at an intensity slightly below the anaerobic threshold. Following the triphasic model proposed by Skinner and McLellan (69), the TID in both cases would be reported as Z2 (i.e., heavy domain). However, even if both athletes would theoretically accumulate the same training volume in the same training intensity zone, variations in exercise intensity can lead to different physiological adaptations that impact endurance performance. In this sense, it would be necessary to report the amount of training (i.e., time or kilometer) spent in Z1 and Z2 (i.e., below the aerobic threshold), and in Z3 (i.e., between the aerobic and anaerobic thresholds) of the above-mentioned 5-zone model to establish potential differences in physiological adaptations and, hence, in the percentage of TID. While in this 5-zone model, Z1 is more closely related to recovery intensity, Z2 has been rediscovered as a potential zone for improving oxidative phosphorylation of the cell, thereby improving mitochondrial biogenesis and function (26,27,80), without depleting glycogen stores by maximizing fat oxidation (48,60). On the other hand, Z3 of the 5-zone model is related to tempo training. This zone is one of the widest in terms of the range of developed intensities (Figure 1). Similarly, zone 4 is located close to the anaerobic threshold, which is a key metabolic point and is highly related to athletic performance (54). Finally, zone 5 represents the intensity range from the steady-state point to the break of this state and the achievement of $\dot{V}O_2$max intensity. This rationale may support the appropriateness of reporting training volume in a 5-zone model, thus new TIDs could be determined and other paradigms could be proposed in future research.

Practical Applications

The main findings of our scoping review were that POL and PYR models seem to be more sensitive than other TID models regarding functional capacity enhancement (i.e., $\dot{V}O_2$max or $\dot{V}O_2$peak). Concerning both aerobic and anaerobic thresholds, POL and PYR seem to have a greater impact in improving speed or power associated with the aerobic threshold, while many other TID models (i.e., POL, PYR, and THR) were effective in enhancing speed or power associated with the anaerobic threshold. However, more research is needed to establish the effects of different TID models on the economy of movement. Finally, endurance performance seems to be improved with all TID models due to the heterogeneity of testing protocols. In conclusion, POL and PYR models seem to be more effective in elite/international and world-class athletes, whereas in lower-level athletes the differences between TID models are negligible. We consider this information of great interest, as it can shed some light to help coaches and athletes to better select the optimal TID model for maximizing sport-specific endurance performance, especially when athletes' level and endurance-sport modality are considered.

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