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Human Kinetics
BRIEF REVIEW

# Training Periodization, Methods, Intensity Distribution, and Volume in Highly Trained and Elite Distance Runners: A Systematic Review

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***Purpose:*** This review aimed to determine (1) performance and training characteristics such as training intensity distribution (TID), volume, periodization, and methods in highly trained/elite distance runners and (2) differences in training volume and TID between event distances in highly trained/elite distance runners. ***Methods:*** A systematic review of the literature was carried out using the PubMed/MEDLINE, Scopus, and Web of Science databases. ***Results:*** Ten articles met the inclusion criteria. Highly trained/elite distance runners typically follow a pyramidal TID approach, characterized by a decreasing training volume from zone 1 (at or below speed at first ventilatory/lactate threshold [LT]) to zone 2 (between speeds associated with either both ventilatory thresholds or 2 and 4 $mmol \cdot L^{-1}$ LTs [vLT1 and vLT2, respectively]) and zone 3 (speed above vVT2/vLT2). Continuous-tempo runs or interval training sessions at vLT2 in zone 2 (ie, medium and long aerobic intervals) and those in zone 3 (ie, anaerobic or short-interval training) were both used at least once per week each in elite runners, and they were used to increase the number of either vLT2 or z3 sessions to adopt either a pyramidal or a polarized approach, respectively. More pyramidal- and polarized-oriented approaches were used by marathoners and 1500-m runners, respectively. ***Conclusions:*** Highly trained and elite middle- and long-distance runners are encouraged to adopt a traditional periodization pattern with a hard day–easy day basis, consisting in a shift from a pyramidal TID used during the preparatory and precompetitive periods toward a polarized TID during the competitive period.

***Keywords**:* endurance training, distance running, training intensity distribution, athletics

Training in endurance runners aims at improving both performance and its physiological determinants. Well-established physiological factors appear to influence performance in highly trained/elite runners competing in events from 1500-m to marathon. Among these are maximal oxygen uptake ($VO_2max$),[1] the velocity associated with $VO_2max$ ($vVO_2max$),[1] running economy (RE), defined as steady-state $VO_2$ at a given submaximal speed or as the $VO_2$ per unit of distance,[2] lactate threshold (LT), defined either as the velocity at which a nonlinear increase in blood lactate occurs, the maximal lactate steady state or the velocity corresponding to a blood lactate concentration of 4 $mmol \cdot L^{-1}$),[3] the running velocity at LT2 (vLT2),[4] and the ability to sustain a high percentage of $VO_2max$ during competition (%$VO_2max$)[5] are considered the main determining factors of distance running performance.[6]

Differences in adaptive responses to training between untrained and trained runners are well-documented.[7,8] For example, $VO_2max$, $VO_2$ kinetics, and time to exhaustion at $vVO_2max$ (Tlim) are responsive to the volume/intensity/and training intensity distribution (TID).[8] Shaw et al[9] found that both $VO_2max$ and RE correlated with training status of distance runners. Londeree[7] found that performance was not improved by increases in training volume in males with $VO_2max > 60\ mL \cdot kg^{-1} \cdot min^{-1}$. For this reason, it is necessary to understand the effects of specific characteristics of endurance training on performance and physiological determinants in highly trained/elite runners, since they differ from those found in runners with lesser performance.

Traditionally, 3 training intensity zones for endurance athletes are used,[10,11] Zone 1 (z1) represents speeds below first ventilatory or 2 $mmol \cdot L^{-1}$ LT. Zone 2 (z2) represents speeds between the 2 ventilatory thresholds, or 2, and 4 $mmol \cdot L^{-1}$ LTs (vLT1 and vLT2, respectively). Zone 3 (z3) represents speeds above VT2/vLT2.[12] In order to analyze the effect of particular combinations of training volume and intensity in each of these zones, different TID models have been described.

1. The *pyramidal* model is characterized by a decreasing training volume from z1 to z2, and z3, respectively. Approximately 80% of volume is conducted in z1 with the remaining 20% in z2 and z3.[12]
2. The *polarized* model is characterized by covering approximately 80% of the volume at z1 with most of the remaining 20% conducted at z3, and as little training as possible in z2.[12]
3. The *threshold* model features a higher proportion of overall volume conducted in z2 (ie, >35%) compared to other models. This specific percentage of training volume was used as the threshold delimiting the upper border of z2 in a pyramidal model given that it still leaves the possibility of accumulating the majority of the training volume (ie, 60%–62%) in z1.

However, these delimitations have not yet reached a full consensus in the current literature and therefore further discussion on this topic is encouraged. A recent review, examining the effectiveness of different TID approaches found that either polarized, or pyramidal approaches improved performance in distance runners to a greater extent than other models.[13]

Periodization is the cyclic ordering of training exercises, following principles of specificity, volume, and intensity, to achieve peak performance at the time of the most important competitions.[14] The objective of periodized models is to use the

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principle of overloading and to optimize the balance between stimulation and recovery.[14] When an athlete is training for an endurance event, the commonly used periodization model usually involves different TID approaches between training periods.[11] The typical linear periodized program aims to build aerobic base (eg, increased mitochondrial number and capillary density) first, through a period of high-volume/low-intensity training, before increasing the proportion of high-intensity training (which may be more stimulative of improvement in cardiac output), RE, and the capacity for sprinting.[12] However, previous studies have typically summarized the TID for a single period of time, which fails to account for changes in TID during long-term periodized training.

In addition, different interval training sessions are employed to develop different abilities involving z2 and z3. According to Billat,[15] aerobic training is characterized by intensities between 75% and 80% of $vVO_2max$ (z1), with long durations ranging from 30 to 45 minutes, with short recovery periods (2–3 min), to interval training with intensities ranging from 115% to 130% of $vVO_2max$ (short aerobic interval training) with short duration (10–15 s), and recoveries ranging from 10 to 15 seconds. Anaerobic interval training is performed at intensities approximating 95% to 105% of $vVO_2max$ (3–5 × 1000 m at v3000–5000 m) and longer recovery periods (3 min) to intensities ranging from 105% to 130% of $vVO_2max$ with 30 to 60 seconds duration and recovery periods of 30 to 60 seconds. Whereas these guidelines represent important benchmarks for scientists and coaches of distance runners, these training methods could be different from those used by highly trained/elite distance runners reported in the current scientific literature. To the best of authors' knowledge, no previous reviews have analyzed all of the training characteristics in highly trained/elite distance runners such as training periodization, methods, intensity distribution, and volume. These variables, used in conjunction, rather than isolation, are better suited to characterize training.

In addition, for runners targeting events ranging from 1500 m to marathon, their optimal training volumes, although clearly individual related, are expected to increase with competition distance.[16] However, a comparison among TID between distance running events has, to our knowledge, not been conducted as well.

Therefore, the aim of this research is to determine performance and training characteristics of training programs such as TID, training volume, and periodization in highly trained/elite distance runners, designed to enhance both performance and physiological determinants. Finally, we aimed to identify differences in training between elite 1500-m runners and marathoners, so that a trend among events of different distances could be illustrated.

# Methods

## Search Strategy

The present systematic review was conducted following the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis.[17] Electronic searches of PubMed/MEDLINE, Scopus, and Web of Science were conducted by 2 independent reviewers on December 30, 2021. The title, abstract, and keyword fields were searched using the following search syntaxes: Training AND Distance AND Running, Training AND Middle-distance AND Running, Training AND Long-distance AND Running. Two independent observers (A.C. and F.G.-M.) performed the identification, screening, eligibility, and inclusion of the studies. In the case of disagreement, a third observer (J.M.G.-R.) was consulted. The data, including subject characteristics, physiological outcomes/characteristics, derived from the training implementation/practice (ie, $VO_2max$, $vVO_2max$, vLT1, vLT2 and RE), performance (ie, best times in competition events or results from performance tests derived from the training implementation/practice), training profile, study duration, type of design, TID, training volume ($km \cdot wk^{-1}$), characteristics of training periodization (ie, time of each training period and TID and training volume conducted at each period), characteristics of training methods (ie, types of sessions, distance per session, intensity, number of repetitions, recovery between repetitions), were extracted from all eligible studies. A polarization index[18] was calculated in all the training regimes analyzed to determine whether they adopted a polarized or nonpolarized TID model.

## Inclusion and Exclusion Criteria

Studies were included when (1) they were published in a peer-review journal; (2) a training intervention/analysis of at least 6 weeks was performed; (3) an analysis of training zones, volumes, and/or periodization details was performed; (4) participants were highly trained (ie, $VO_2max$ = 52–58 and 65–71 $mL \cdot kg^{-1} \cdot min^{-1}$) or elite ($VO_2max$ = >58 and >71 $mL \cdot kg^{-1} \cdot min^{-1}$) for female and male, respectively, middle- or long-distance runners;[19,20] and (5) participants frequently competed at events from 1500 m to marathon. The exclusion criteria were: (1) studies which only relate training characteristics to performance outcomes without considering the development of physiological performance determinants and (2) studies which do not describe a specific TID according to at least the 3 intensity zones, defined by physiological tests. No limits regarding language or publication date were employed. Reference lists from the selected manuscripts were examined in order to identify other eligible manuscripts. After removing duplicates and eliminating papers based on title and abstract screening, 20 manuscripts remained with 10 studies included in the systematic review. Ten studies were discarded after not matching the eligibility criteria through full-text screening based on one or more of the following reasons: conference paper or review (n = 3), training zones, and load distributions were not specified (n = 3), physiological performance determinants were not specified (n = 4).

## Risk of Bias Assessment of the Included Studies

The methodological quality of the studies was rated using a checklist proposed by Marocolo et al,[21] which we adapted according to Downs and Black.[22] The checklist displays 3 possible scores (yes = 1 point, unclear = 0.5 points, and no = 0 points) for each item, with a maximal score of 15 points (Table 1). The sum of the 15 criteria score represents the general quality of each study. Two authors independently assessed the studies (A.C. and F.G.-M.), and if there was any disagreement, another author was consulted (J.M.G.-R.).

## TID Among 1500-m and Marathon Elite Runners

Training data belonging to 4 elite male 1500-m runners (season best times of 3:31.81–3:36.30), and 2 elite male marathoners (season best times of 2:10:55 and 2:11:06), and 2 elite female marathon runners (season best times of 2:25:38 and 2:24:11) were collected from Kenneally et al,[23] and personal communication with the coach of this group. Data represented the time in each training

**Table 1 Quality Criteria Used to Analyze the Studies Included in the Systematic Review**

| | 0 | 0.5 | 1 |
|---|---|---|---|
| Reporting | | | |
| 1. Is the hypothesis/aim/objective of the study clearly described? | No | Unclear | Yes |
| 2. Are the main outcomes to be measured clearly described in the introduction? | No | Unclear | Yes |
| 3. Are the characteristics of the subjects included in the study clearly described? | No | Unclear | Yes |
| 4. Are the interventions of interest clearly described? | No | Unclear | Yes |
| 5. Are the main findings of the study clearly described? | No | Unclear | Yes |
| 6. Does the study provide estimates of the random variability in the data for the main outcomes? | No | Unclear | Yes |
| 7. Were the instruments of testing reliable? | No | Unclear | Yes |
| 8. Was a follow-up duration sufficiently described and consistent within the study? | No | Unclear | Yes |
| 9. Number of participants included in study findings | <5 | 6–15 | >16 |
| Analysis and presentation | | | |
| 10. Have actual probability values been reported (eg, .035 rather than <.05) for the main outcomes except, where the probability value is less than .001? | No | Unclear | Yes |
| 11. Was there a statement adequately describing or referencing all statistical procedures used? | No | Unclear | Yes |
| 12. Were the statistical analyses used appropriate? | No | Unclear | Yes |
| 13. Was the presentation of results satisfactory? | No | Unclear | Yes |
| 14. Were confidence intervals given for the main results? | No | Unclear | Yes |
| 15. Was the conclusion drawn from the statistical analysis justified? | No | Unclear | Yes |

zone defined by physiological tests[23] and weekly running distance for each runner during 2 precompetitive weeks. Comparisons between 1500-m runners and marathoners TID and training volume were conducted using Cohen *d* effect sizes[24] and considered to be either trivial ($d < 0.20$), small (0.21–0.60), moderate (0.61–1.20), large (1.21–2.00), very large (2–4), or nearly perfect (>4).[25]

## Results

The literature search identified 10 studies which met the inclusion criteria (Figure 1). Four studies reported training interventions,[26–29] and 6 used an observational approach.[23,30–34] All the studies reported TID and volume characteristics of the runners, 5 studies reported periodization characteristics, and all characterized some/all of the training methods used.

Regarding the quality of the studies selected, all of the studies achieved the required standard to be considered as a low risk of bias (mean quality score [SD] [%mean quality score (SD)] = 12.5 [2.12] [81.65% (16.48%)]; Table 2).[21]

### Training Volume and Intensity Distribution

In all the studies in the current review, with the exception of Ingham et al,[26] a pyramidal approach was used. Therefore, the use of a pyramidal TID has either been shown to relate to improvements in performance[27,28] or has been related to very high performance in highly trained and elite middle- and long-distance runners.[30–32,34] In addition, the use of this approach was found to be associated with either high levels[23,31,34] or an improvement in RE.[27,28] Some studies also reported either an increase in,[27–29,33] or were associated, with high levels of $vVO_2max$.[23,30,34] A few studies using a pyramidal approach were associated with high levels of $VO_2max$.[23,31,35] Studies using a pyramidal approach also found either an increase in,[28,29] or, were associated with high levels of vLT2.[23,30,31,34]

The pyramidal approach used in most of the studies reviewed has, in most cases, one primary characteristic in common. When training was conducted in z2, a high proportion was at intensities at or near vLT2 (ie, high intensity within z2).[26–28,30–32,34]

In contrast, 2 studies which used a clearly polarized approach found an association with high levels of RE, $vVO_2max$, vLT2, $VO_2max$ and performance,[26,30] although in one of these studies 20% of the training volume was conducted at, or close to vLT2 (z2) in an elite 1500-m runner.[26] However, another study using a polarized approach, after a period in which a pyramidal TID was employed, did not find improved performance, nor improved physiological determinants. However, evidence of overtraining was reported in this study.[27]

A "hard day–easy day" pattern during the training week was routinely observed.[23,27,29,31,32,34] Athletes possessing the highest performance covered more distance during training.[23,30–32,34] This was the case even in the best-performing runners competing at shorter distances such as 1500 m.[26,31,34] All of these athletes reported training at volumes ranging from 110 to 195 $km \cdot wk^{-1}$.[23,26,30–32,34]

Details of the training conducted are indicated in Table 3. Physiological characteristics and performance are shown in Table 4.

### Training Periodization

Six studies reported data describing the training periodization carried out by highly trained/elite distance runners.[23,29,31–34] A traditional linear periodization was adopted regardless of the competition distance being targeted. The preparatory period was typically 4 months,[23,31–34] the precompetitive period ranged from 2.5 to 4 months,[31–34] and the competitive period ranged from 3 to 4 months.[31–34] Generally, training volume was similar during the preparatory and precompetitive periods. During the competitive period, training volume was substantially decreased.[31–34] Additionally, there were some variations in TID among periods. In 5

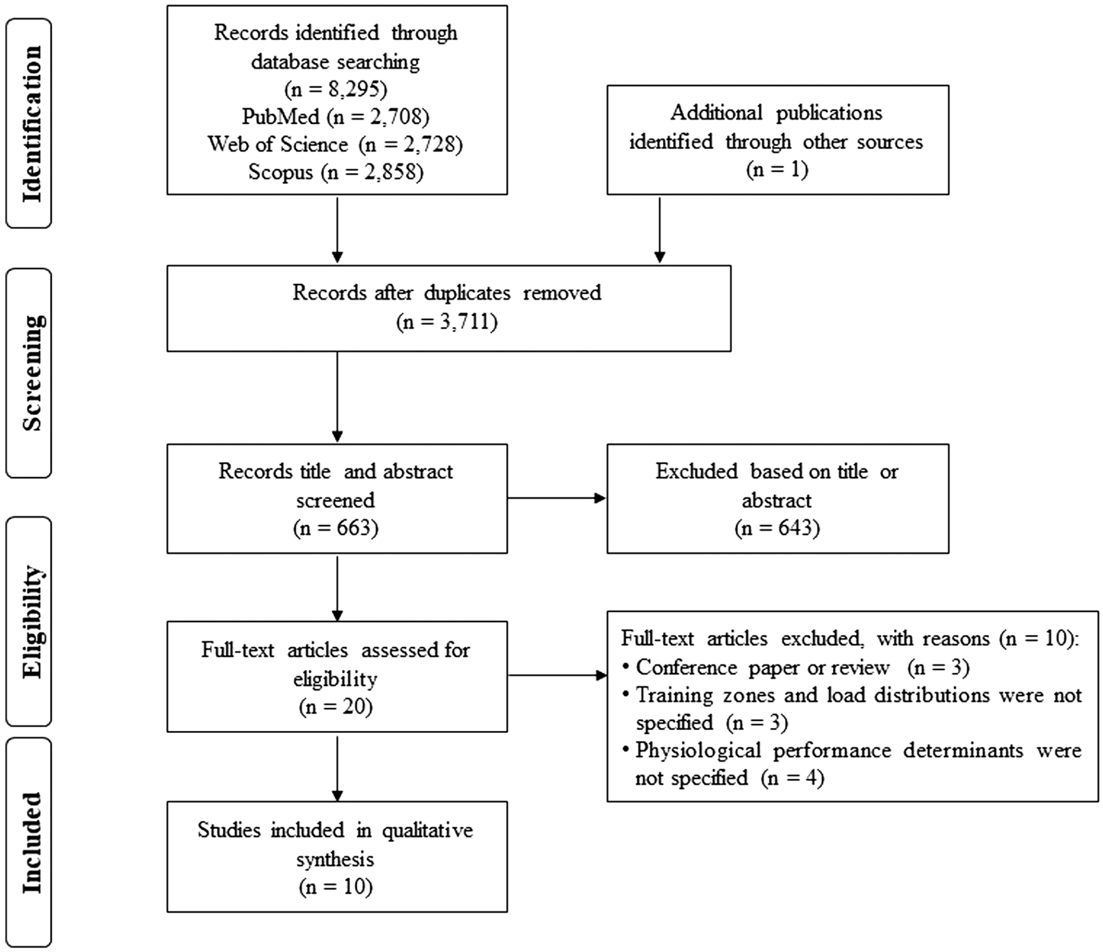


**Figure 1** — Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flow diagram of the article selections.

studies, during the preparatory and precompetitive periods, runners followed a pyramidal approach. However, during the competitive period, the amount of training conducted at vLT2 decreased, provoking a change of TID toward a more polarized approach.[23,31–34] However, a certain amount of training conducted at vLT2 was maintained during the competitive period. All these 5 observational studies found associations between a traditional periodization approach with high levels of performance and large enhancement of physiological determinants.[23,31–34] The only interventional study analyzing the effects of different training periodization approaches[29] concluded that changing the TID from a pyramidal to a polarized approach, in the second half of a 16-week intervention period, reported better performance and physiological improvements than following either a polarized or a pyramidal approach across the whole period, or even than changing the TID from a polarized to a pyramidal approach.

## Training Methods

In all the studies analyzed athletes covered several kilometer per week of continuous easy and long-easy runs at z1.[23,26–35] Other studies reported the use of continuous tempo runs covered at vLT2.[23,27,30,34] Interval training was mainly performed at z2 and z3, varying the volume, intensity, and distance depending on the training phase, and race distance. Both long and medium aerobic interval training were conducted at vLT2 in z2 and were characterized by short recovery periods of 1 minute or less.[26,28,31,32] Anaerobic and short interval training were conducted in z3.[23,27,29–32,34] The number of high-intensity training sessions (ie, z2 and z3) being conducted varied according to the level of performance of the runners analyzed. Training methods used by highly trained runners weekly while following pyramidal and polarized approaches consisted of one continuous vLT2 run and one interval training session at z3 with passive or active recovery (ie, anaerobic or short interval training),[27,29] and 2 similar z3 sessions to the latter one, respectively.[29] Alternatively, training methods used by elite runners weekly during pyramidal and polarized approaches consisted of 2 continuous- or interval-based vLT2 runs, and one interval training session at z3 with active or passive recovery (ie, anaerobic or short-interval training), and one vLT2 run and 2 interval training z3 sessions, respectively.[23,34]

## TID and Volume Among Different Events

The TID during each day of a training week in both marathoners and 1500-m runners is indicated in Figure 2A and 2B. Mean (SD) of percentages of training time (minutes) at z1, z2, and z3 were 75.85% (0.64%), 15.99% (0.78%), and 8.16% (0.29%), respectively, for marathoners, and 86.83% (0.7%), 6.73% (0.45%), and

**Table 2 Scores Assigned to Each of the Studies for Each of the Quality *(Q)* Criteria**

| References | *Q1* | *Q2* | *Q3* | *Q4* | *Q5* | *Q6* | *Q7* | *Q8* | *Q9* | *Q10* | *Q11* | *Q12* | *Q13* | *Q14* | *Q15* | Score | % of max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Billat et al[27] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 1 | 1 | 1 | 1 | 0 | 1 | 13.5 | 90.0 |
| Billat et al[30] | 0.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 13.5 | 90.0 |
| Enoksen et al[28] | 0.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 13.5 | 90.0 |
| Ingham et al[26] | 0.5 | 1 | 1 | 1 | 1 | 0.5 | 1 | 1 | 0.5 | 1 | 0.5 | 1 | 0.5 | 0 | 1 | 11.5 | 76.6 |
| Tjelta and Enoksen[32] | 0.5 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 10.5 | 70.0 |
| Tjelta[31] | 0.5 | 1 | 1 | 0.5 | 1 | 0 | 1 | 1 | 0 | 0.5 | 0.5 | 1 | 1 | 0 | 1 | 10.5 | 70.0 |
| Galbraith et al[33] | 1 | 1 | 1 | 0.5 | 1 | 1 | 1 | 1 | 0.5 | 1 | 0.5 | 0.5 | 0.5 | 0 | 1 | 11.5 | 76.6 |
| Kenneally et al[23] | 0.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 0 | 1 | 0 | 1 | 0 | 1 | 11 | 73.3 |
| Kenneally et al[34] | 0.5 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0.5 | 0.5 | 1 | 1 | 0 | 1 | 10.5 | 70 |
| Filipas et al[29] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 14 | 93.3 |

**Table 3 Characteristics of Included Studies and Performance and Training Characteristics of Athletes Participating in Each Study**

| Study | n (M/F) | Level of performance/ $VO_2$max, mL·kg$^{-1}$·min$^{-1}$ | Type of design (experimental/ observational) | Study duration | Volume and TID | Periodization | Training methods (those described in the studies) |
|---|---|---|---|---|---|---|---|
| Tjelta[31] | 1 (1/0) | 2012 1500-m European champion/84.4 | Observational | 2008 to 2012 | Pyramidal model: 80% at z1 and 20% at z2 at or close to vLT2 during all periods, excepting during CP in which some sessions conducted at vLT2 were substituted for high-intensity training sessions | Traditional periodization (2011–2012). PP1 (Nov–Dec): 146 km·wk$^{-1}$; PP2 (Jan–Mar): 156 km·wk$^{-1}$; pre-CP (Mar–May): 150 km·wk$^{-1}$; CP (May–Aug): 100–145 km·wk$^{-1}$ | IT at vLT2: 8–10 × 1000 m with 1 min of recovery or 4 × 6 min; IT above vLT2: 10 × 400 m, 4 × 300 m, 200 m + 150 m + 2 × 120 m, 5 × 200 m + 2 × 150 m, or 4–6 × 100 m strides; he usually conducted 2 sessions at vLT2 on the same day (ie, 5 × 6 min in the morning and 12 × 1000 m or 25 × 400 m in the evening session) |
| Ingham et al[26] | 1 (1/0) | Male international 1500-m runner/79.6 | Experimental | 24 mo | Threshold model (year 1) and polarized model despite conducting 20% of the training volume at or close to vLT2 in z2 (year 2) | — | Tempo runs: 5 × 1609 m close to vLT2 |
| Tjelta and Enoksen[32] | 4 (4/0) | Junior male elite long-distance runners/79.2 (4.8) | Observational | 12 mo | Pyramidal model: z1: (80%); z2 close to vLT2: 20% during PP and CC season, 10% during CP; z3: 10% during CP | Traditional periodization. PP (Jan–Apr): 132 (25.9) km·wk$^{-1}$; CP (May–Aug): 115 (22.9) km·wk$^{-1}$; CC (Sep–Dec):145 ( 22.9) km·wk$^{-1}$ | IT: 20 × 400 m (10,000/5000 m pace) with 100-m jog recovery, 7 × 2000 m (90% of $HR_{max}$) with 60-s jog recovery, 8 × 1000 m (90% of $HR_{max}$) with 60-s jog recovery, or 3 × 2 × 200 m with 200- and 400-m jog between sets. In the track competition phase, the athletes ran 1–3 interval sessions at vLT2 and one to 2 sessions at race pace |
| Billat et al[30] | 20 (13/7) | Elite Kenyan runners/M: 78.4 (2.1); F: 68. 6 (1.1) | Observational | 8 wk | LVPol. M: 158 (19) km·wk$^{-1}$. F: 127 (8) km·wk$^{-1}$. 88.4% and 11.6% of the total training volume was performed at z1 and z3, respectively. HVPyr: M: 174 (17) km·wk$^{-1}$. 84.2%, 14.4%, and 1.4% of the total training volume were performed in z1, z2, and z3, respectively | — | LVPol: 2 IT sessions per week (ie, 10–20 × 400–600 m at or above $vVO_2$max, 7 × 200 m at 120% of $vVO_2$max, or a session at an intermediate velocity between vLT2 and the velocity at $vVO_2$max, 10 × 1000 m or 5 × 2000 m); HVPyr: inclusion of tempo runs (30–45 min) at vLT2 (15% of total volume) and long-IT (6 × 1609 m at an intermediate speed between race paces of 3000 m and 10,000 m, resting 200–400 m jog in between) |
| Kenneally et al[23] | 7 (3/4) | World-class middle- and long-distance runners/M: 73.8 (2.1); F: 61.4 (4.2) | Observational | 50 wk | Polarized and pyramidal models (depending on the phase). Volume: 135.4 (29.4) km·wk$^{-1}$. z1: 87.2% (1.2%), z2: 6.1% (0.7%), and z3: 6.6% (0.9%) | Traditional periodization. Two macrocycles: 1: 28 wk for the World Athletics Championships. 2: 20 wk until the Commonwealth Games | A typical training week conducted during the preparatory period consisted of 30–60 min easy runs at z1, one long-run around 105 min at z1, one tempo run (9 km) per week at vLT2 in z2, one interval training session at z3 (8 × 1000 m, with 60 s of recovery), and one short-interval training session on hills at z3 (6 × 800 m at 5-km pace) |

*(continued)*

**Table 3 (continued)**

| Study | n (M/F) | Level of performance/ $VO_2$max, mL·kg$^{-1}$·min$^{-1}$ | Type of design (experimental/ observational) | Study duration | Volume and TID | Periodization | Training methods (those described in the studies) |
|---|---|---|---|---|---|---|---|
| Kenneally et al[34] | 1 (1/0) | World-class middle-distance runner/73.5 | Observational | 52 wk | Pyramidal (87%, 8%, and 5% of total training volume were performed at z1, z2, and z3, respectively) and polarized (87%, 6%, and 7% of total training volume were performed at z1, z2, and z3, respectively) during the whole season and competitive phase, respectively. Volume: 145.8 (24.8) and 132.7 (26.9) km·wk$^{-1}$ during the whole season and competitive phase, respectively | | A typical training week conducted during the preparatory period consisted of 30–60 min easy runs at z1, one long-run around 105 min at z1, one tempo run (9 km) per week at vLT2 in z2, one hilly 7.2 km run at vLT2 in z2 and one anaerobic interval training session at z3 (8 × 1000 m, with 60 s of recovery). These 2 last sessions were substituted during the competitive period for one short-interval training session on hills at z3 (6 × 800 m at 5 km pace) and an anaerobic interval training session at z3 (4 × 1600 m [2-min rest] at 10 km pace, 6 × 400 m [30-s rest] at 3–5 km pace) |
| Galbraith et al[33] | 14 (14/0) | Male competitive middle- and long-distance club and national-level runners/73.5 (6.2) | Observational | 12 mo | Pyramidal during most of the season but more polarized oriented during the competitive period. 79 (31.33) km·wk$^{-1}$ in the preparatory period and 56.5 (34.33) km·wk$^{-1}$ in the competitive period. 69%, z2. 17%, z3: 14% of the total training volume were performed in z1, z2, and z3, respectively | Traditional periodization. Two macrocycles of 6 mo each. | — |
| Billat et al[27] | 8 (8/0) | Well-trained endurance runners/72.7 (5.1) | Experimental | 4 wk of normal training; 5 wk of overtraining | Volume: always 85 – 90 km·wk$^{-1}$; preintervention: HVLI; first period: pyramidal approach; second period: polarized approach adding more training at z3 | — | First period: 4 sessions in z1 (ie, 45–60 min of easy run at 60%–70% of $VO_2$max), 1 session at vLT2 (ie, 2 × 20 min at 85% of v$VO_2$max with 5 min of easy run at 60% v$VO_2$max in between) and 1 session at v$VO_2$max (ie, 5 repetitions at 50% of Tlim with a recovery period of the same duration at 60% v$VO_2$max); second period: 2 sessions at z1, 1 session at vLT2, and 4 sessions at v$VO_2$max (ie, 5 × 1050 m in 3 min with 3-min rest at 50% v$VO_2$max) |
| Enoksen et al (2012) | 26 (26/0) | Well-trained middle-distance runners/70.4 (3.8) | Experimental | 10 wk | 2 Pyramidal models. HVLI: 70 km·wk$^{-1}$and HILV 50 km·wk$^{-1}$. HILV: 67% in z1 and 33% in z2 close to vLT2. HVLI: 87% in z1 and 13% in z2 close to vLT2 | — | — |

*(continued)*

**Table 3 (continued)**

| Study | n (M/F) | Level of performance/ $VO_2max$, $mL·kg^{-1}·min^{-1}$ | Type of design (experimental/ observational) | Study duration | Volume and TID | Periodization | Training methods (those described in the studies) |
|---|---|---|---|---|---|---|---|
| Filipas et al[29] | 60 (60/ 0) | Well-trained long-distance runners/ 67 (4) | Experimental | 16 wk | Four models (15 subjects per model). Eight weeks of polarized training consisted of 279, 21, and 48 $min·wk^{-1}$ in z1, z2, and z3, respectively, and 8 wk of pyramidal training consisted of 279, 55, and 25 $min·wk^{-1}$ in z1, z2, and z3, respectively. Same volume (463 $min·wk^{-1}$) in both types of training. POL and PYR conducted 16 wk of polarized and pyramidal approach, respectively. POL–PYR and PYR–POL conducted 2 blocks of 8 wk of polarized and pyramidal, and pyramidal and polarized approach (in this order), respectively | Traditional-oriented periodization in PYR–POL and reverse-oriented periodization in POL–PYR, without changes in volume in both groups | Four sessions in z1 (ie, 30–70 min easy runs) in both polarized and pyramidal approaches, 1 session of z2 (ie, 55-min continuous run), and 1 in z3 (ie, 4 × 7 min in z3 [3-min rest in z2]) in pyramidal approach, and 2 sessions of z3 (ie, the same one which was used in the pyramidal approach and 12 × 2 min in z3 [1-min rest in z2]) |

Abbreviations: CC, cross-country season; CP, competition period; F, females; HILV, high-intensity low-volume training group; $HR_{max}$, maximum heart rate; HVLI, high-volume low-intensity training group; HVPyr, high-volume pyramidal-oriented training group; IT, interval training; LVPol, low-volume polarized-oriented training group; M, males; PP, preparatory period; RE, running economy; TID, training intensity distribution; Tlim, time to exhaustion at $vVO_2max$; vLT2, velocity at lactate threshold; $vVO_2max$, velocity at $VO_2max$; z1, zone 1; z2, zone 2; z3, zone 3.

**Table 4 Physiological Characteristics and Outcomes and Performance Derived From the Training Implementation at Each Study**

| Study | $vVO_2max$ | $VO_2max$ | vLT2 | RE | Performance (time) |
|---|---|---|---|---|---|
| Tjelta[31] | | 84.4 $mL \cdot kg^{-1} \cdot min^{-1}$ | 18.2 $km \cdot h^{-1}$ | At 16 $km \cdot h^{-1}$: 190 $mL \cdot kg^{-1} \cdot km^{-1}$ | 1500 m: 3:35.43 (min:s) |
| Ingham et al[26] | From 20.3 (first year) to 23.2 $km \cdot h^{-1}$ (second year) | From 72.4 (first year) to 79.6 $mL \cdot kg^{-1} \cdot min^{-1}$ (second year) | From 16 (first year) to 18 $km \cdot h^{-1}$ (second year) | From 210 to 205 $mL \cdot kg^{-1} \cdot km^{-1}$ | 1500 m: from 3:38.9 to 3:32.4 (min:s) |
| Tjelta and Enoksen[32] | | 79.2 (4.8) | | | 1500 m: 3:50.10 (3) (min:s); 3000 m: 8:19.01 (4.99) (min:s); 5000 m: 14:29.98 (21.23) (min:s) |
| Billat et al[30] | HVPyr: M: 21.6 (0.4) $km \cdot h^{-1}$; LVPol: M: 22.7 (0.6) $km \cdot h^{-1}$; F: 19.9 (0.4) $km \cdot h^{-1}$ | HVPyr: M: 74.7 (2.6) $mL \cdot kg^{-1} \cdot min^{-1}$; LVPol: M: 78.4 (2.1) $mL \cdot kg^{-1} \cdot min^{-1}$; F: 68.6 (1.1) $mL \cdot kg^{-1} \cdot min^{-1}$ | HVPyr: M: 19.9 (0.4) $km \cdot h^{-1}$; LVPol: M: 20.2 (0.4) $km \cdot h^{-1}$; F: 16.8 (0.8) $km \cdot h^{-1}$ [1] | Measured at subLT2 speed. HVPyr: M: 203 (8) $mL \cdot kg^{-1} \cdot km^{-1}$; LVPol: M: 214 (6) $mL \cdot kg^{-1} \cdot km^{-1}$; F: 208 (14) $mL \cdot kg^{-1} \cdot km^{-1}$ | 10,000 m. HVPyr: M: 28:54 (0:33) (min:s); LVPol: M: 28:15 (0:15) (min:s); F: 32:22 (0:35) (min:s) |
| Kenneally et al[23] | M: 22.1 (0.4) $km \cdot h^{-1}$; F: 19.3 (0.1) $km \cdot h^{-1}$ | M: 73.8 (2.1) $mL \cdot kg^{-1} \cdot min^{-1}$; F: 61.4 (4.2) $mL \cdot kg^{-1} \cdot min^{-1}$ | M: 19.7 (0.6) $km \cdot h^{-1}$; F: 17.5 (0.07) $km \cdot h^{-1}$ | M: 191.9 (6.2) $mL \cdot kg^{-1} \cdot km^{-1}$; F: 173.1 (17.1) $mL \cdot kg^{-1} \cdot km^{-1}$ | Performance time (M): 3:34.38–3:36.30 (1500 m); 13:05.23–13:26.38 (5000 m). Performance time (F): 4:04.93–4:10.42 (1500 m) and 15:06.67–15:18.91 (5000 m) |
| Kenneally et al[34] | | 73.5 $mL \cdot kg^{-1} \cdot min^{-1}$ | 20.3 $km \cdot h^{-1}$ (vLT1 = 18.3 $km \cdot h^{-1}$) | At vLT1 (18.3 $km \cdot h^{-1}$): 193 $mL \cdot kg^{-1} \cdot km^{-1}$ At vLT2 (20.3 $km \cdot h^{-1}$): 198 $mL \cdot kg^{-1} \cdot km^{-1}$ | Performance time: 3:31.81 (1500 m); 7:34.79 (3000 m); and 13:05.23 (5000 m) |
| Galbraith et al[33] | From 19.1 (1.7) to 20.1 (1.4) $km \cdot h^{-1}$ (1 y after) | From 69.8 (6.3) to 73.5 (6.2) $mL \cdot kg^{-1} \cdot min^{-1}$ (1 y after) | From 15.7 (1.2) to 15.6 (1.2) $km \cdot h^{-1}$ (1 y after) | At 16 $km \cdot h^{-1}$: from 222.6 (14.5) to 223.2 (12) $mL \cdot kg^{-1} \cdot km^{-1}$ (1 y after) | 1500 m: 3:58.20 (3) (min:s); Half-marathon: 1:10:02 (0:3:48) (h·min:s); Marathon: 2:28:50 (0:12:27) (h·min:s) |
| Billat et al[27] | First period: from 20.5 (0.8) to 21.1 (0.8) $km \cdot h^{-1}$; second period: from 21.1 (0.8) to 20.9 (0.9) $km \cdot h^{-1}$ | First period: from 71.2 (5) to 72.7 (5.1) $mL \cdot kg^{-1} \cdot min^{-1}$; second period: from 72.7 (5.1) to 70.9 (4) $mL \cdot kg^{-1} \cdot min^{-1}$ | First period: from 17.6 (1) to 17.8 (0.9) $km \cdot h^{-1}$; second period: from 17.8 (0.9) to 18.2 (1.1) $km \cdot h^{-1}$ | $VO_2$ at 14 $km \cdot h^{-1}$; first period: from 50.6 (3.2) to 47.5 (2.5) $mL \cdot kg^{-1} \cdot min^{-1}$; second period: from 47.5 (2.5) to 46.7 (3.2) $mL \cdot kg^{-1} \cdot min^{-1}$ | Time to exhaustion at $vVO_2max$. First period: from 301.3 (3 54) to 283 (42) s; second period: from 283 (42) to 254 (62) s |
| Enoksen et al (2012) | HVLI: from 16.6 (0.8) to 17.1 (0.7) $km \cdot h^{-1}$ (0.5% [0.7%] of change); HILV: from 16 (1.1) to 16.8 (0.8) $km \cdot h^{-1}$ (0.8% [0.8%] of change) | HVLI: from 70.4 (3.8) to 69.2 (3.6) $mL \cdot kg^{-1} \cdot min^{-1}$ (–1.2% [2.8%] of change); HILV: from 70.2 (2.7) to 71.4 (2.4) $mL \cdot kg^{-1} \cdot min^{-1}$ (1.2% [2.4%] of change) | HVLI: from 15.3(0.8) to 15.7 (0.7) $km \cdot h^{-1}$ (0.4% [0.7%] of change); HILV: from 14.6 (1) to 15.2 (0.8) $km \cdot h^{-1}$ (0.7% [0.7%] of change) | $VO_2$ at 13 $km \cdot h^{-1}$; HVLI: from 49.6 (2.3) to 47.5 (1.7) $mL \cdot kg^{-1} \cdot min^{-1}$ (–2.1% [1.3%] of change); HILV: from 51.1 (3.8) to 48.7 (3) $mL \cdot kg^{-1} \cdot min^{-1}$ (–2.4% [1.6%] of change) | Time to exhaustion at $vVO_2max$. HVLI: from 8.2 (2.1) to 9.1 (2.9) min (0.9% [1.8%] of change); HILV: from 8.4 (2.2) to 9.4 (3.9) min (1% [2.8%] of change) |
| Filipas et al[29] | | % of change (post–pre): POL: 2.1 (2.6); PYR: 1.3 (2.2); PYR–POL: 3.0 (2.8); POL–PYR: 2.7 (1.6) | vLT2 is considered velocity at 4 $mmol \cdot L^{-1}$. Percentage of change (post–pre): POL: 1.2 (1.1); PYR: 0.6 (0.6); PYR–POL: 1.5 (0.7); POL–PYR: 0.9 (0.8) | | 5-km time-trial time. Percentage of change (post–pre): POL: –1.1 (1.1); PYR: –0.6 (0.6); PYR–POL: –1.5 (0.7); POL–PYR: –0.9 (0.8) |

Abbreviations: F, females; HILV, high-intensity low-volume training group; HVLI, high-volume low-intensity training group; HVPyr, high-volume pyramidal-oriented training group; LVPol, low-volume polarized oriented training group; M, males; RE, running economy; vLT2, velocity at lactate threshold; $vVO_2max$, velocity at $VO_2max$. Note: First period: 4-week first training period characterized by a pyramidal approach; second period: 5-week second training period characterized by a polarized approach.

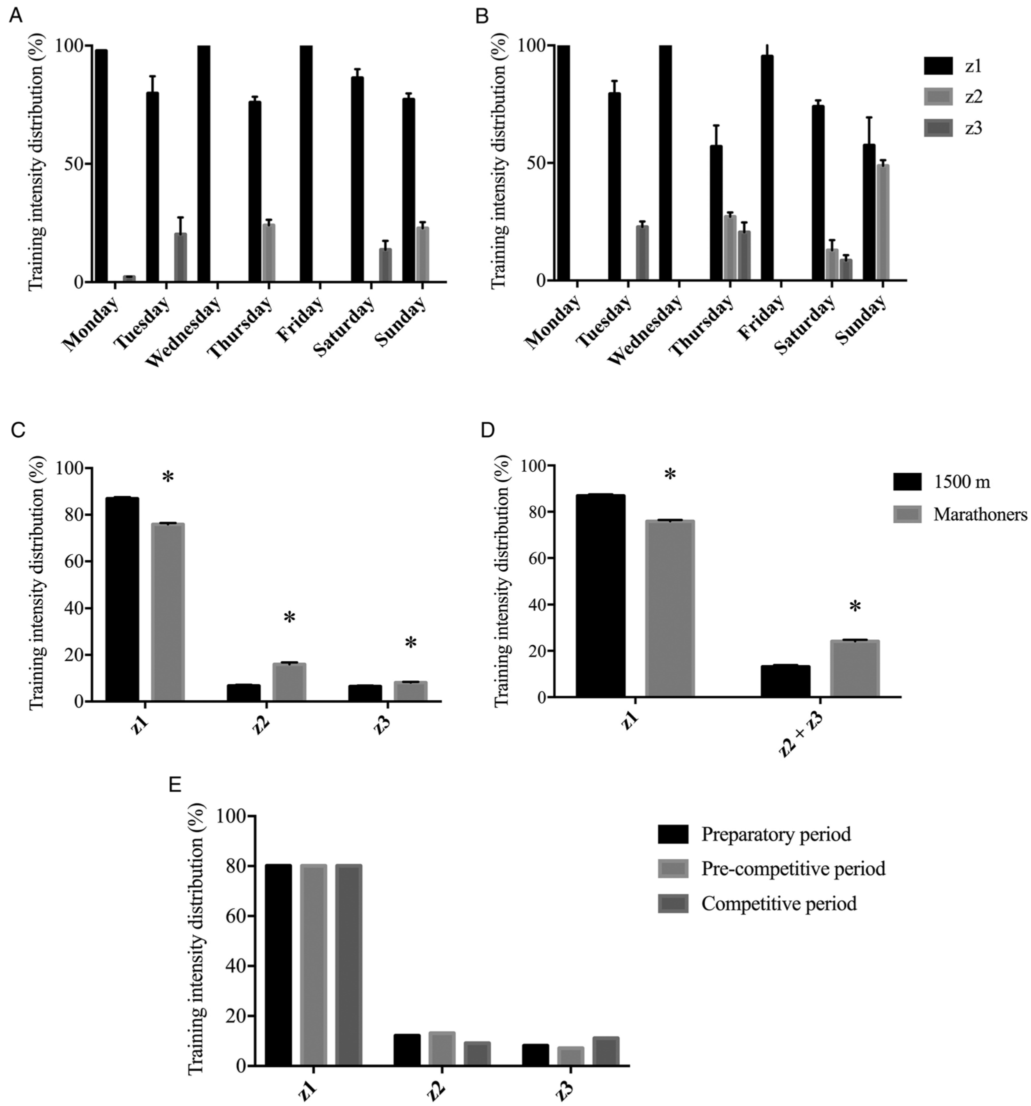


**Figure 2** — Training intensity distribution during a training week in 4 world-class 1500-m runners (A) and 4 world-class marathoners (B), comparison between world-class 1500-m runners and marathoners in training intensity distribution based on a 3-zone model (C), and a 2-zone (z1 and z2 + z3) model (D) and hypothetical periodization characteristics in a highly trained/elite distance runner (E). z1 indicates zone 1; z2, zone 2; z3, zone 3. *Cohen *d* effect sizes at least nearly perfect (>4); data were provided by Kenneally et al[23] with permission and personal communication with the coach of this training group.

6.43% (0.47%), respectively, for 1500-m runners. Mean (SD) of percentages of training time (minutes) at z2 + z3 were 24.15% (0.64%) for marathoners, and 13.17% (0.7%) for 1500-m runners. Mean (SD) of training distance per week were 195.38 (6.69) km·wk$^{-1}$ for marathoners and 154.63 (4.37) km·wk$^{-1}$ for 1500-m runners. Effect size were always nearly perfect (>4.42) between groups in running distance, and training zones (Figure 2C and 2D). Most z2 training conducted by all the runners was just below or at vLT2.

## Discussion

The main finding of the present review is that highly trained middle- and long-distance runners typically follow a pyramidal TID characterized by conducting much of the training within z2 at or just below vLT2. This kind of TID was related to high levels of performance and a significant development of physiological determinants. Furthermore, only linear traditional periodization models have been observed in the limited number of studies conducted in this population. In addition, regardless of the racing distance being prepared for, a strong majority of training (76%–87%) was conducted in z1, and most athletes used a clearly hard-day, easy-day approach.

### Training Intensity Distribution

Whereas polarized training has been found to be a very effective TID approach to improve performance in well-trained and elite endurance athletes,[11] and in middle- and long-distance runners,[13] it seems that pyramidal TID is a more commonly used approach in highly trained and elite middle- and long-distance runners. This pyramidal approach has also been observed in the training used by other highly trained and elite athletes such as a group of nationally rank New Zealand distance runners,[35] the Norwegian marathoner

Grete Waitz,[36] top-class Portuguese and French marathoners,[37] or highly trained subelite middle-distance Spanish runners.[38] Additionally, improvements in performance have been reported after 5 months of pyramidal TID in highly trained subelite middle- and long-distance runners on a cross-country time trial.[2] Accordingly, different studies have found that training conducted at vLT2 intensity is associated with improvement in either performance physiological determinants such as $VO_2$max and maximum anaerobic power in highly trained middle- and long-distance runners,[39] or performance in world-class long-distance runners.[40,41] While the mechanistic explanation for the relationship between training conducted near vLT2 and the improvement in performance and its physiological determinants cannot be elucidated yet, it has been proposed that exercising at this specific intensity improves muscle-specific clearing of lactate, as opposed to reducing lactate production mechanisms.[42] Since only recruited motor units are likely to experience increases in mitochondrial and capillary density, it may be speculated that training near vLT2 optimizes the number of motor units recruited without the consequences of elevated levels of catecholamines likely to be experienced with z3 training.

Furthermore, specific training characteristics in highly trained and elite distance runners appear to influence performance and physiological determinants globally. For example, if vLT2 is increased as a result of a particular training intervention, it will also likely increase $vVO_2$max.[43] Furthermore, the most effective type of TID to improve performance and to develop physiological determinants is apparently the pyramidal TID. However, a polarized TID has been shown to be effective as well. In any case, the results suggest an obligatory need to accumulate ~20% of training above z1.

Hypothetical examples of TID approaches based on those found here, during the different phases of the periodization process, and during shorter time periods are illustrated in Figure 2E. In addition, the TID comparison between 1500-m runners and marathoners showed that whereas marathoners followed a “pure” pyramidal approach, 1500-m runners accumulated similar amounts of training volume in z2 and z3, very likely due to the higher amount of training at marathon pace (“highz2” close to vLT2) in the marathoners.[13] Therefore, this comparison dictates a trend as long as event distance increases from a more polarized to a more pyramidal TID. Every distance running event likely possesses its own characteristics, probably overlaid by individual differences, and further research, perhaps experimental in subelite runners, should try to fill the gaps existing in the literature regarding which type of training develops performance optimally. The contrast between the amount of low-intensity training (z1) with high-intensity training in these runners (z2 + z3) is very important (Figure 2D). This specific training characteristic may be related to a more rapid recovery of the autonomic nervous system and hormonal balance from one session to another attributable to the use of high training volumes at low intensities.[12] This emphasizes the need for developing an aerobic base in order to be able to conduct higher intensity sessions, in the sense that greater volumes of z1 training may be permissive of a greater volume of z2 + z3.[12] In addition, the way training volume and different intensities are distributed during a training week very likely has implications in the adaptations achieved. Both world-class 1500-m runners and marathoners followed a “hard day–easy day” basis with at least 3 easy days per week in which the intensity was in z1 and a fourth intermediate-effort day in which runners performed a long run (typically z1 with a “drift” into z2 at the run progressed; Figure 2A and 2B). This training basis and the avoidance of monotony during the training process may be useful in order to prevent nonfunctional overreaching and to maintain a sufficient recovery period allowing for adaptive responses such as the gene expression for mitochondrial proliferation.[12,44] This specific training pattern is also followed by other highly trained and elite long- and middle-distance runners.[27,31,32,45]

## Training Volume

The overall volume conducted by athletes discriminated their level of performance and the extent to which physiological determinants were developed (Tables 3 and 4). This is in agreement with Billat et al,[37] who reported that top-class marathoners covered more distance during training than high-level marathoners. Similarly, Casado et al[40] reported that world-class long-distance runners accumulated more training volume than highly trained competitive runners with lower performance. Overall training volume could explain 59% of the variability in performance achieved by world-class long-distance runners during their sport careers.[40]

Additionally, the evidence from the present study showed that world-class marathoners accumulated larger volume during training than world-class 1500-m runners. This is in agreement with other studies suggesting that elite marathoners usually cover longer distances (ie, from ~186 to 206 $km \cdot wk^{-1}$)[37,46] than elite 1500-m runners (ie, from ~110 to 156 $km \cdot wk^{-1}$).[26,31,47] However, Tjelta et al[36] found the exception in a world-class female marathoner who routinely covered ~123 $km \cdot wk^{-1}$.

## Training Periodization

These findings are also in line with studies reporting the use of linear periodization approaches in competitive distance runners.[2,38,46] TID for a hypothetical distance runner at each period is illustrated in Figure 2E based on the results of aforementioned studies,[23,31–34] which indicates the use of pyramidal and polarized approaches during the preparation and precompetitive, and competitive period, respectively, along with a decrease of overall training volume during the competitive period. The durations observed for the preparation, precompetitive, and competitive periods are 4, 2.5 to 4, and 3 to 4 months, respectively. For the first time, the effectiveness of the shift from a pyramidal toward polarized approach has recently been tested in an intervention study.[29] This trend is in line with findings from Enoksen et al[46] in elite runners. Whereas it is still not possible to fully understand the physiological mechanisms underpinning performance peaking during a traditional linear periodization approach in endurance sports, it has been speculated that the aerobic physiological adaptations achieved during the preparatory and precompetitive periods could positively alter genomic sensitivity to training during the competitive period through epigenetic mechanisms.[48] Such adaptations in the cellular level may remain unaltered during the competitive period, and explain the improvement in performance when training volume is reduced, and benefits from a higher intensity training may be achieved.[49] Accordingly, Losnegard et al[50] found that aerobic physiological adaptations were maintained as well as anaerobic adaptations and were even enhanced after reducing the training volume during several months in elite cross-country skiers. However, the fact that other periodization models have not been tested by highly trained and elite distance runners in previous studies does not imply that they would not be effective. In this sense, block periodization has been found effective in other endurance sports.[51]

## Training Methods

The most important consideration derived from the examination of the training methods used by highly trained and elite distance runners is that rather than focusing on a single interval training mode, the use of several types involving differences in overall volume, number of repetitions and intensity was observed. For example, during a typical training week runners may conduct 2 (or more) different interval training sessions covered at vLT2 and $vVO_2max$, respectively.[23,29–32,34] More specifically, at least one continuous or medium/long aerobic interval training session at vLT2/z2, and one anaerobic/short interval training session in z3 per week is required to develop performance optimally in highly trained and elite runners.[23,27,29,31,34] Elite runners used to increase the number of either vLT2 or z3 sessions to adopt either a pyramidal or polarized approach, respectively. However, most of the current studies examining interval training methods have focused on detecting which of those yields greater improvements on performance, $VO_2max$, and other physiological endurance performance determinants.[52] In this sense, maybe the correct research question, is rather which is the most effective combination of methods to improve performance and its physiological determinants according to the specific athlete and competitive goal. Within these different combinations observed, interval training methods typically were conducted at z3 and vLT2, consisting the latter in covering $4-20 \times 400-2000$ m with 1 minute of recovery between repetitions[31,32,46] (Table 3). Nonetheless, it is important to note that these characteristics are different from those recommended by Billat[15] when describing the characteristics of interval training designed to train at vLT2, which consisted of covering 2 repetitions of 20 to 30 minutes with 3 minutes of recovery between repetitions. That inclusion of a greater number of intervals and rest periods may enhance the recovery of runners within the session so that the absolute speed associated with LT2 intensity may be increased at each repetition compared with conducted during a more continuous run. Increasing that speed while generating that similar metabolic response may provide additional neuromuscular adaptations.

## Novelties

Three different novel aspects have been found in the present systematic review regarding the current training practices to improve performance in highly trained and elite distance runners. First, this is the first study attempting to differentiate TID among different running events (ie, distances). The most important finding is that while a polarized approach is typically followed by specialists belonging to short events such as 1500-m runners, as they tend to cover a greater amount of training volume in z3, a pyramidal approach is usually adopted by those from longer events such as marathon, as they accumulate longer distances at, or close to, vLT2 pace. Second, this systematic review has examined a very recent article,[29] which for the first time demonstrated through a 4-armed paralleled control trial that a periodization strategy consisting in a shift from a pyramidal to a polarized TID approach was more effective than other strategies such as both pure polarized or pyramidal, or a shift from a polarized to a pyramidal TID. Finally, this is the first systematic review on training characteristics in distance runners suggesting that a moderate training volume at z2 specifically conducted at vLT2 or close to this speed is recommended to improve performance optimally in this population.

## Further Research and Limitations

Some limitations have to be acknowledged in this study. First, a very limited number of studies examining the specific population targeted has been found in the literature. Second, 4 of the studies reviewed are case studies with limited sample size, which accounts for anecdotical observations rather than generalizations which could lead to general recommendations in training practice. Third, only 4 experimental studies in this population have been found, the rest of the studies reviewed followed an observational approach. Therefore, most of the results indicate the outcomes derived from the use of different TID approaches, periodization models, or training methods employed without comparing these outcomes with the use of others systematically. In this sense, it is not possible to establish whether the use of a pyramidal or polarized TID approach would have led to greater performance improvements and physiological adaptations. Thus, the results require the assumption that high level and elite runners somehow self-optimize their training. Further interventional studies on the examination of training characteristics in highly trained/elite distance runners are encouraged, although well-controlled experimental studies in the latter are, in a practical sense, impossible. Furthermore, the use of a traditional periodization has been observed in the studies involving a longitudinal approach across entire training seasons. Accordingly, it is not possible to know whether the use of a different model (ie, block or reverse periodization) would have led to different outcomes. Therefore, further research comparing the outcomes derived from using different periodization models may help to determine their effectiveness compared to traditional periodization. Fourth, given that the comparison between world-class 1500-m runners and marathoners was made in athletes who belong to the same training group and share the same coach, findings could have been different in a different group with a different coach, who might have followed a different training philosophy. Therefore, further research focused on the analysis of differences in training characteristics in runners among different events/distances is encouraged in order to develop better evidence which is lacking in the existing literature. And finally, further research examining the interactive effect derived from different combinations of interval training methods targeting different intensities within the same training week on physiological and performance adaptations is encouraged as it represents the "real-world" practice of highly trained and elite distance runners.

# Conclusions

Highly trained/elite distance runners typically follow a pyramidal TID with training in z2 usually conducted near vLT2. While a pyramidal approach was more strongly associated with the development in performance and its physiological determinants than a polarized approach, the latter also showed performance-related benefits. It seems that as event distance increases (ie, from 1500 m to marathon), a trend from polarized toward pyramidal approach exists. Additionally, training volume increased with competitive distance. Highly trained/elite distance runners normally report the use of linear periodization models in which TID and volume remain similar during both preparatory and precompetitive periods, typically following a pyramidal approach, but the amount of volume in z2 substantially decreases during the competitive period, toward a more polarized TID approach. Runners usually followed a hard day–easy day basis. High overall training volume, typically greater than 100 $km \cdot wk^{-1}$, and more specifically that conducted at vLT2 seems to be associated with both performance and the enhancement of physiological determinants in highly trained and elite distance runners. Continuous tempo runs, and long and medium aerobic interval training with short recovery periods, are the methods which these runners use to train at vLT2.

## Practical Applications

Highly trained/elite middle- and long-distance runners are encouraged to accumulate >100 $km \cdot wk^{-1}$ while following a pyramidal TID approach on a hard day–easy day basis. A polarized pattern might be also effective. Linear periodization is generally recommended for this population although further research is needed to understand whether other periodization models are effective in improving performance and physiological determinants. Runners should decrease the amount of training at vLT2 (z2), as well as increase the amount of training in z3 (race pace) during the competitive period.

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## References

1. Billat LV, Koralsztein JP. Significance of the velocity at $\dot{V}O_2$max and time to exhaustion at this velocity. *Sports Med*. 1996;22(2):90–108. PubMed ID: 8857705 doi:10.2165/00007256-199622020-00004
2. Esteve-Lanao J, Foster C, Seiler S, Lucia A. Impact of training intensity distribution on performance in endurance athletes. *J Strength Cond Res*. 2007;21(3):943–949. PubMed ID: 17685689 doi:10.1519/r-19725.1
3. Billat LV. Use of blood lactate measurements for prediction of exercise performance and for control of training. Recommendations for long-distance running. *Sports Med*. 1996;22(3):157–175. PubMed ID: 8883213 doi:10.2165/00007256-199622030-00003
4. Billat V, Bernard O, Pinoteau J, Petit B, Koralsztein JP. Time to exhaustion at $VO_2$max and lactate steady state velocity in sub elite long-distance runners. *Arch Physiol Biochem*. 1994;102(3):215–219. doi:10.3109/13813459409007541
5. Péronnet F, Thibault G, Rhodes EC, McKenzie DC. Correlation between ventilatory threshold and endurance capability in marathon runners. *Med Sci Sports Exerc*. 1987;19(6):610–615. PubMed ID: 3431378 doi:10.1249/00005768-198712000-00012
6. Joyner MJ, Coyle EF. Endurance exercise performance: the physiology of champions. *J Physiol*. 2008;586(1):35–44. doi:10.1113/jphysiol.2007.143834
7. Londeree BR. Effect of training on lactate/ventilatory thresholds: a meta-analysis. *Med Sci Sports Exerc*. 1997;29(6):837–843. PubMed ID: 9219214 doi:10.1097/00005768-199706000-00016
8. Caputo F, Mello MT, Denadai BS. Oxygen uptake kinetics and time to exhaustion in cycling and running: a comparison between trained and untrained subjects. *Arch Physiol Biochem*. 2003;111(5):461–466. PubMed ID: 16026035 doi:10.3109/13813450312331342337
9. Shaw AJ, Ingham SA, Atkinson G, Folland JP. The correlation between running economy and maximal oxygen uptake: cross-sectional and longitudinal relationships in highly trained distance runners. *PLoS One*. 2015;10(4):1–10. doi:10.1371/journal.pone.0123101
10. Seiler S, Tønnessen E. Intervals, thresholds, and long slow distance: the Role of intensity and duration in endurance training. *Training*. 2009;13(13):32–53. http://sportsci.org/2009/ss.htm
11. Stöggl TL, Sperlich B. The training intensity distribution among well-trained and elite endurance athletes. *Front Physiol*. 2015;6(OCT):295. doi:10.3389/fphys.2015.00295
12. Seiler S. What is best practice for training intensity and duration distribution in endurance athletes? *Int J Sports Physiol Perform*. 2010;5(3):276–291. PubMed ID: 20861519 doi:10.1123/ijspp.5.3.276
13. Kenneally M, Casado A, Santos-Concejero J. The effect of periodization and training intensity distribution on middle-and long-distance running performance: a systematic review. *Int J Sports Physiol Perform*. 2018;13(9):1114–1121. PubMed ID: 29182410 doi:10.1123/ijspp.2017-0327
14. Bompa TO, Haff GG. *Periodization: Theory and Methodology of Training*. 5th ed. Human Kinetics; 2009.
15. Billat LV. Interval training for performance: a scientific and empirical practice. Special recommendations for middle- and long-distance running. Part I: aerobic interval training. *Sports Med*. 2001;31(2):75–90. doi:10.2165/00007256-200131020-00001
16. Tjelta LI. The training of international level distance runners. *Int J Sports Sci Coach*. 2016;11(1):122–134. doi:10.1177/1747954115624813
17. Shamseer L, Moher D, Clarke M, et al. Preferred reporting items for systematic review and meta-analysis protocols (prisma-p) 2015: elaboration and explanation. *BMJ*. 2015;349:g7647. doi:10.1136/bmj.g7647
18. Treff G, Winkert K, Sareban M, Steinacker JM, Sperlich B. The polarization-index: a simple calculation to distinguish polarized from non-polarized training intensity distributions. *Front Physiol*. 2019;10:Article 707. doi:10.3389/fphys.2019.00707
19. de Pauw K, Roelands B, Cheung SS, de Geus B, Rietjens G, Meeusen R. Guidelines to classify subject groups in sport-science research. *Int J Sports Physiol Perform*. 2013;8(2):111–122. PubMed ID: 23428482 doi:10.1123/ijspp.8.2.111
20. Decroix L, de Pauw K, Foster C, Meeusen R. Guidelines to classify female subject groups in sport-science research. *Int J Sports Physiol Perform*. 2016;11(2):204–213. PubMed ID: 26182438 doi:10.1123/ijspp.2015-0153
21. Marocolo M, Simim MAM, Bernardino A, Monteiro IR, Patterson SD, da Mota GR. Ischemic preconditioning and exercise performance: shedding light through smallest worthwhile change. *Eur J Appl Physiol*. 2019;119(10):2123–2149. PubMed ID: 31451953 doi:10.1007/s00421-019-04214-6
22. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J Epidemiol Community Health*. 1998;52(6):377–384. PubMed ID: 9764259 doi:10.1136/jech.52.6.377
23. Kenneally M, Casado A, Gómez-Ezeiza J, Santos-Concejero J. Training intensity distribution analysis by race [ace vs. physiological approach in World-Class middle- and long-distance runners. *Eur J Sport Sci*. 2020;26(3):819–826. doi:10.1080/17461391.2020.1773934
24. Cohen J. *Statistical Power Analysis for the Behavioural Sciences/Jacob Cohen*. (2nd ed.); 1988.
25. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc*. 2009;41(1):3–12. PubMed ID: 19092709 doi:10.1249/MSS.0b013e31818cb278

26. Ingham SA, Fudge BW, Pringle JS. Training distribution, physiological profile, and performance for a male international 1500-m runner. *Int J Sports Physiol Perform*. 2012;7(2):193–195. PubMed ID: 22634971 doi:10.1123/ijspp.7.2.193
27. Billat VL, Flechet B, Petit B, Muriaux G, Koralsztein JP. Interval training at $\dot{V}O_2$max: effects on aerobic performance and overtraining markers. *Med Sci Sports Exerc*. 1999;31(1):156–163. PubMed ID: 9927024 doi:10.1097/00005768-199901000-00024
28. Enoksen E, Shalfawi SAI, Tønnessen E. The effect of high- vs. low-intensity training on aerobic capacity in well-trained male middle-distance runners. *J Strength Cond Res*. 2011;25(3):812–818. PubMed ID: 20647950 doi:10.1519/JSC.0b013e3181cc2291
29. Filipas L, Bonato M, Gallo G, Codella R. Effects of 16 weeks of pyramidal and polarized training intensity distributions in well-trained endurance runners. *Scand J Med Sci Sports*. 2021;32(3): 498–511. PubMed ID: 34792817 doi:10.1111/sms.14101
30. Billat VL, Lepretre PM, Heugas AM, Laurence MH, Salim D, Koralsztein JP. Training and bioenergetic characteristics in elite male and female Kenyan runners. *Med Sci Sports Exerc*. 2003;35(2): 297–304. PubMed ID: 12569219 doi:10.1249/01.MSS.0000053556.59992.A9
31. Tjelta LI. A longitudinal case study of the training of the 2012 European 1500 m track champion. *Int J Appl Sports Sci*. 2013;25(1): 11–18. doi:10.24985/ijass.2013.25.1.11
32. Tjelta LI, Enoksen E. Training characteristics of male junior cross country and track runners on European top level. *Int J Sports Sci Coach*. 2010;5(2):193–203. doi:10.1260/1747-9541.5.2.193
33. Galbraith A, Hopker J, Cardinale M, Cunniffe B, Passfield L. A 1-year study of endurance runners: training, laboratory tests, and field tests. *Int J Sports Physiol Perform*. 2014;9(6):1019–1025. PubMed ID: 24664950 doi:10.1123/ijspp.2013-0508
34. Kenneally M, Casado A, Gomez-Ezeiza J, Santos-Concejero J. Training characteristics of a World Championship 5000-m finalist and multiple continental record holder over the year leading to a World Championship final. *Int J Sports Physiol Perform*. 2021; 17(1):142–146. PubMed ID: 34426556 doi:10.1123/ijspp.2021-0114
35. Robinson DM, Robinson SM, Hume PA, Hopkins WG. Training intensity of elite male distance runners. *Med Sci Sports Exerc*. 1991; 23(9):1078–1082. PubMed ID: 1943629 doi:10.1249/00005768-199109000-00013
36. Tjelta L, Tønnessen E, Enoksen E. A case study of the training of nine times New York Marathon winner Grete Waitz. *Int J Sports Sci Coach*. 2014;9(1):139–158. doi:10.1260/1747-9541.9.1.139
37. Billat VL, Demarle A, Slawinski J, Paiva M, Koralsztein JP. Physical and training characteristics of top-class marathon runners. *Med Sci Sports Exerc*. 2001;33(12):2089–2097. PubMed ID: 11740304 doi:10.1097/00005768-200112000-00018
38. Esteve-Lanao J, San Juan AF, Earnest CP, Foster C, Lucia A. How do endurance runners actually train? Relationship with competition performance. *Med Sci Sports Exerc*. 2005;37(3):496–504. PubMed ID: 15741850 doi:10.1249/01.MSS.0000155393.78744.86
39. Priest JW, Hagan RD. The effects of maximum steady state pace training on running performance. *Br J Sports Med*. 1987;21(1):18–21. PubMed ID: 3580721 doi:10.1136/bjsm.21.1.18
40. Casado A, Hanley B, Santos-Concejero J, Ruiz-Pérez LM. World-Class long-distance running performances are best predicted by volume of easy runs and deliberate practice of short-interval and tempo runs. *J Strength Cond Res*. 2021;35(9):2525–2531. PubMed ID: 31045681 doi:10.1519/JSC.0000000000003176
41. Casado A, Hanley B, Ruiz-Pérez LM. Deliberate practice in training differentiates the best Kenyan and Spanish long-distance runners. *Eur J Sport Sci*. 2020;20(7):887–895. PubMed ID: 31724902 doi:10.1080/17461391.2019.1694077
42. Philp A, Macdonald AL, Carter H, Watt PW, Pringle JS. Maximal lactate steady state as a training stimulus. *Int J Sports Med*. 2008; 29(6):475–479. PubMed ID: 18302077 doi:10.1055/s-2007-965320
43. Midgley AW, McNaughton LR, Jones AM. Training to enhance the physiological determinants of long-distance running performance: can valid recommendations be given to runners and coaches based on current scientific knowledge? *Sports Med*. 2007;37(10):857–880. PubMed ID: 17887811 doi:10.2165/00007256-200737100-00003
44. Foster C. Monitoring training in athletes with reference to overtraining syndrome. *Med Sci Sports Exerc*. 1998;30(7):1164–1168. PubMed ID: 9662690 doi:10.1097/00005768-199807000-00023
45. Haugen T, Sandbakk O, Enoksen E, Seiler S, Tonnessen E. Crossing the golden divide: the science and practice of training world-class 800- and 1500-m runners. *Sports Med*. 2020;51(9):1835–1854. doi:10.1007/s40279-021-01481-2
46. Enoksen E, Tjelta AR, Tjelta LI. Distribution of training volume and intensity of elite male and female track and marathon runners. *Int J Sports Sci Coach*. 2011;6(2):273–293. doi:10.1260/1747-9541.6.2.273
47. Tjelta LI. Three Norwegian brothers all European 1500 m champions: what is the secret? *Int J Sports Sci Coach*. 2019;14(5):694–700. doi:10.1177/1747954119872321
48. Tanaka H. Effects of cross-training: transfer of training effects on $\dot{V}O_2$max between cycling, running and swimming. *Sports Med*. 1994; 18(5):330–339. PubMed ID: 7871294 doi:10.2165/00007256-199418050-00005
49. Tnønessen E, Sylta Ø, Haugen TA, Hem E, Svendsen IS, Seiler S. The road to gold: training and peaking characteristics in the year prior to a gold medal endurance performance. *PLoS One*. 2014;9(7): e0101796. doi:10.1371/journal.pone.0101796
50. Losnegard T, Myklebust H, Spencer M, Hallén J. Seasonal variations in VO2max, O2-cost, O2-deficit, and performance in elite cross-country skiers. *J Strength Cond Res*. 2013;27(7):1780–1790. PubMed ID: 22996025 doi:10.1519/JSC.0b013e31827368f6
51. Mølmen KS, Øfsteng SJ, Rønnestad BR. Block periodization of endurance training—a systematic review and meta-analysis. *Open Access J Sports Med*. 2019;10:145–160. PubMed ID: 31802956 doi:10.2147/OAJSM.S180408
52. MacInnis MJ, Gibala MJ. Physiological adaptations to interval training and the role of exercise intensity. *J Physiol*. 2017;595(9): 2915–2930. doi:10.1113/JP273196