SPECIAL COMMUNICATIONS

Contrasting Perspectives

Polarized Training Is Optimal for Endurance Athletes

CARL FOSTER[1], ARTURO CASADO[2], JONATHAN ESTEVE-LANAO[3], THOMAS HAUGEN[4], and STEPHEN SEILER[5]

[1]*University of Wisconsin–La Crosse, La Crosse, WI;* [2]*Centre for Sport Studies, Rey Juan Carlos University, Madrid, SPAIN;* [3]*All in Your Mind Training System, Mérida, MEXICO;* [4]*Kristiana University College, Oslo, NORWAY; and* [5]*University of Adger, Kristiansand, NORWAY*

The training of endurance athletes has been and remains a central topic of study in exercise physiology. The physiology of endurance athletes has been studied for many years (1). Their performance is widely understood in terms of the model of Joyner and Coyle (2), which integrates the sustained ability to produce ATP aerobically and convert muscular work to power/speed. Beyond the well-documented favorable effect of doing a larger volume of training, often exceeding 1000 h·yr^{-1} in some elite athletes, there is clear evidence of a historical trend toward more lower-intensity training and of a dose–response relationship between the training load and subsequent performance (3–6). Expressed simply, successful athletes attempt to optimize the adaptive effects (improved performance) while mitigating side effects (fatigue, injury, overreaching, overtraining syndrome) of their training regimes (7).

Historical context. High-volume training has been important for at least 200 yr, beginning with the era of "pedestrian competitions." A decade-long debate persists regarding how other details of the training program might interact with the volume of training to maximize performance (8,9). Although numerous training "systems" have been described, within the last century, the development of repetition training (A.V. Hill, and the "Flying Finns") in the 1920s, *Fartlek* training, in Sweden (Gosta Holmer), and interval training, in Germany (Gershler and Reindell) in the 1930s, defined early approaches to training systemization. From the late 1940s onward, the dominant training model was of larger and larger volumes of competition-specific interval training, often mimicking the training programs of champion athletes.

Address for Correspondence: Carl Foster, Ph.D., F.A.C.S.M., Department of Exercise and Sport Science, University of Wisconsin–La Crosse, La Crosse, WI 54601; E-mail: cfosteruwl@gmail.com.
Submitted for publication December 2021.
Accepted for publication December 2021.

0195-9131/22/5406-1028/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/MSS.0000000000002871

Beginning about 1960, with the emergence of runners following Arthur Lydiard's concept of performing large volumes of relatively low-intensity running during the preparatory period, there has been growing interest in how the training intensity distribution (TID) might contribute to the outcome of training. This was driven by a better understanding of physiological phenomena, particularly the presence of two distinct lactate/ventilatory thresholds (10,11). Indeed, during the 1970s–1990s, much interest was focused on the intensity zone *between* the two lactate/ventilatory thresholds as a potential "sweet spot" for optimizing the volume-intensity equation of training. That this intensity window (e.g., tempo training) approximated the range of competitive intensities in events such as 10- to 42-km running and 40- to 100-km cycling made it attractive based on the principle of training specificity. It is still an important element in the training "menu" of many athletes and is reportedly widely used by the highly successful runners from Kenya (6,12,13). However, continued individual successes with other approaches to training suggest that large volumes of low-intensity training may be a key part of a *generalizable* approach to endurance training.

Around the turn of the 21st century, taking advantage of improved methods of monitoring training, several observational reports emerged that elite endurance athletes, in a number of sporting disciplines, were apparently self-selecting for a TID dominated by a high (70%–90%) percentage of training below the lactate/ventilatory threshold (zone 1), a very low percentage (<10%) of training between the first and second lactate/ventilatory thresholds (zone 2), and a limited amount (10%–20%) of training at intensities in excess of the second lactate/ventilatory thresholds (zone 3) (3,4,6,8,9,12–15). Regardless of the specific details by different coaching groups, this organizational pattern can be understood in terms of three intensity zones anchored by the two thresholds. Recognizing that the lactate and ventilatory thresholds are not precisely the same, the general practice in the TID literature has been to treat them as more or less equivalent, and with the second lactate/ventilatory threshold seen as broadly equivalent to the maximal lactate steady state or critical power/speed. It seems that athletes self-select for a large total percentage of low-intensity (zone 1) training, combined with a smaller, *but apparently obligatory*, percentage of competition-specific (or higher) intensity training. Depending on how the intermediate intensity zones are computed, this pattern of training has been referred to as polarized (~70%–10%–20%) or pyramidal (~70%–20%–10%). In athletic disciplines where orthopedic stress is low, and thus a very large total training volume is performed (swimming, cycling, rowing), there seems to be selection for a particularly large volume of training in zone 1, although the relative percentages of the TID seem to be remain consistent. TID can be computed either on the basis of days with an intended training pattern (e.g., interval vs tempo/steady-state vs high-intensity intervals/repetitions) or as cumulative time in various heart rate, lactate, or RPE zones. There is conceptual matching, particularly for actual muscular time and heart rate, but a less perfect matching for RPE (4,16).

Observational studies. Numerous studies, most since 2000, have documented that endurance athletes across disciplines (cross-country skiing, rowing, cycling, running, speed skating, and swimming) use either polarized or pyramidal TID patterns, characterized by a high percentage (60%–90%) of training in zone 1 (<LT), with lesser amounts of training in zones 2 and 3. Fundamentally, the TID described across divergent sports can be dichotomized into 1) low-intensity, low-stress "background training" including high volume days performed at low intensity, and 2) higher-intensity, high-stress, race-specific "deliberate practice" (6,13,17). Regardless of the details of the TID, essentially all elite performers use at least some higher-intensity training during the main preparatory period, with an increasing volume of higher-intensity training and decreasing total volume during the race preparation/peaking period (8,9). Although not controlled, these studies represent the collective experience of coaches and athletes, who often develop training best practices long before the scientific basis for best practices is understood.

Intervention studies. There have been at least five reasonably well-controlled studies of polarized/pyramidal versus threshold centric training programs in well-trained, subelite, athletes (18–22). The percentage change in performance-based measures is on the order of 45% greater (4.2% vs 2.9%) after 6- to 12-wk preparatory training intervention periods in athletes randomized to polarized/pyramidal versus threshold centric intervention training (Fig. 1). One study (20) had the zone 1 training volume "clamped" at 93%, which hardly allows for differences in polarized versus threshold centric programs to emerge and unsurprisingly showed little difference in improved performance. This is comparable to the very small negative performance results when training was "clamped" as only high-volume training by

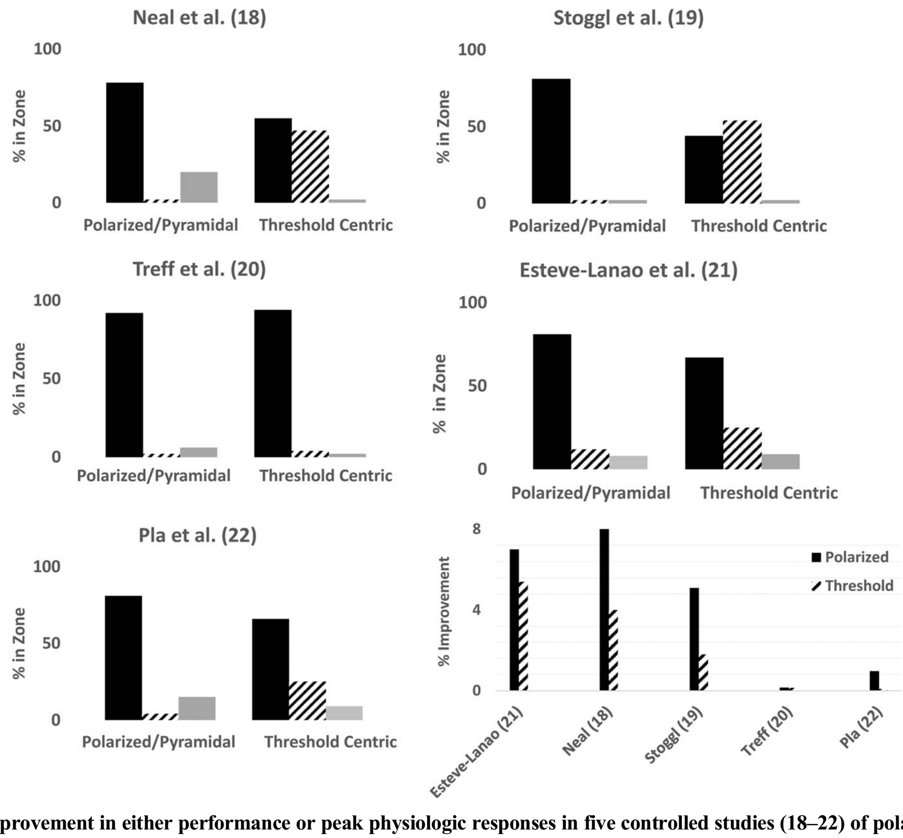

FIGURE 1—Percent improvement in either performance or peak physiologic responses in five controlled studies (18–22) of polarized/pyramidal training (>70% zone 1 (*solid bars*)) vs threshold centric training (~50% zone 2 (*hatched bars*)) and in zone 3 (*gray bars*) in subelite runners, cyclists, rowers, or swimmers. In all five studies, the improvement over a 6- to 12-wk training intervention was ~45 greater (~4.2% vs 2.4%) in the polarized training groups. In the third study (20), zone 1 training was "clamped" at 93% of training, which is a distinctly different TID than usually evaluated for polarized/pyramidal (~70%–10%–20%) vs threshold centric (~40%–50%–10%) training programs. In this group, the magnitude of improvement across the intervention period was remarkably low, supporting the concept that there is an obligatory need for some higher-intensity training. In the fifth study (22), the magnitude of improvement across the intervention period (crossover design) was remarkably small because the athletes were already very highly trained.

Stöggl and Sperlich (19). As such, it reinforces the concept that there is an *obligatory* need for a regular "dose" of higher-intensity training to promote improved performance, although the advantages of a large volume of low-intensity training over threshold centric training remains evident.

Causal hypotheses. Different hypotheses can be proposed for why more polarized/pyramidal training might promote better results than threshold centric training. First, we know that there are two primary signaling pathways for mitochondrial proliferation (both convergent on PGC1-α expression), one based on calcium signaling (more likely with high-volume training) (1,23) and the other based on AMPK signaling (more likely with high-intensity training) (24). The latter may preferentially drive mitochondrial development in type II motor units as well as increased capillary density (1). Because unrecruited motor units are unlikely to demonstrate adaptive increases in mitochondrial density, it follows that at least some regular higher-intensity training is necessary for improved aerobic metabolism in motor units needed during competitive intensity exercise. We also know that the relative amount of lower-intensity training is somewhat less in middle-distance athletes compared with long-distance athletes, potentially reflecting that the realities of different patterns of motor unit recruitment in events of different duration (9). What we need to know are the kinetics and saturation points of these two pathways. If more polarized training is optimal, then one might suspect that the calcium signaling pathway has a much larger adaptive potential and, conversely, that relatively small amounts of training relying on AMPK signaling are sufficient to saturate the adaptive response (23,24). Second, there is evidence that monotonic loads of high-intensity training may cause homeostatic disturbances that are associated with inflammatory responses (7) or slow autonomic recovery from training (25). This supports the concept that failures to adapt to training (e.g., nonfunctional overreaching or overtraining syndrome) are associated with dysfunction in the autonomic nervous system and/or with chronic inflammation (7). This could reasonably contribute to reductions in maximal cardiac output, abnormalities in the selective delivery blood flow, or mitochondrial electron transport chain efficiency. Any of these possibilities could reduce the capacity for aerobic ATP generation. This concept of a negative effect of too much higher-intensity training is supported by the quasi-experimental observations of Billat et al. (26) and the report by Esteve-Lanao et al. (21) that runners could only tolerate ~10% of zone 3 training, measured by heart rate summation.

Summary. The potential advantages of a more polarized (including pyradimal) TID for endurance athletes, particularly during the precompetitive period, have emerged over decades, with evidence favoring polarized TID more evident in the observational literature, and evidence favoring pyramidal TID more evident in the experimental literature. This TID model proposes that the relative proportion of training effort should be organized relative to lactate/ventilatory thresholds along the general plan that 70%–80% of either training hours or sessions are conducted below the intensity of the first lactate/ventilatory threshold. Abundant observational and interventional data support the concept that this TID has advantages over threshold centric training programs, with the best designed of the intervention studies (18,21) providing the strongest evidence. The underlying physiological causes for this apparent advantage remain to be determined but may relate to differences in both the pattern and magnitude intracellular adaptive signaling (particularly that amplifying mitochondrial synthesis) and to prevention of autonomic dysfunction and/or inflammatory responses associated with excessive higher-intensity training. The polarized/pyradimal TID may be particularly important for elite athletes, with high training frequency/load and a greater risk of training maladaptations (7). Less accomplished athletes with lower training frequency/load are less likely to experience negative effects from threshold centric training, although our collective experience still supports the value of an approach to training dominated by a TID favoring low-intensity training.

No funding was received for this work, and the authors have no conflicts of interest to declare.

REFERENCES

1. Van der Zwaard S, Brocherie F, Jaspers RT. Under the hood: skeletal muscle determinants of endurance performance. *Front Sports Act Living*. 2021;3:719434.
2. Joyner MJ, Coyle EF. Endurance exercise performance: the physiology of champions. *J Physiol*. 2008;586(1):35–44.
3. Fiskerstrand A, Seiler KS. Training and performance characteristics among Norwegian international rowers 1970–2001. *Scand J Med Sci Sports*. 2004;14(5):303–10.
4. Seiler KS, Kjerland GØ. Quantifying training intensity distribution in elite endurance athletes: is there evidence for an "optimal" distribution? *Scand J Med Sci Sports*. 2006;16(1):49–55.
5. Foster C, Daines E, Hector L, Snyder AC, Welsh R. Athletic performance in relation to training load. *Wis Med J*. 1996;95(6):370–4.
6. Casado A, Hanley B, Santos-Concejero J, Ruiz-Perez 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):2525–31.
7. Meeusen R, Duclos M, Foster C, et al. Prevention, diagnosis, and treatment of the overtraining syndrome: joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. *Med Sci Sports Exerc*. 2013;45(1):186–205.
8. Seiler S. What is best practice for training intensity and duration distribution in endurance athletes? *Int J Sports Physiol Perform*. 2010;5(3):276–91.
9. Haugen T, Sandbakk Ø, Enoksen E, Seiler S, Tønnessen E. Crossing the golden training divide: the science and practice of training world-class 800- and 1500-m runners. *Sports Med*. 2021;51(9):1835–54.
10. Hollmann W, Rost R, Liesen H, Dufaux B, Heck H, Mader A. Assessment of different forms of physical activity with respect to preventive and rehabilitative cardiology. *Int J Sports Med*. 1981;2(2):67–80.
11. Sjödin B, Jacobs I, Svedenhag J. Changes in onset of blood lactate accumulation (OBLA) and muscle enzymes after training at OBLA. *Eur J Appl Physiol Occup Physiol*. 1982;49(1):45–57.

12. 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):2089–97.
13. Casado A, Hanley B, Ruiz-Perez LM. Deliberate practice in training differentiates the best Kenyan and Spanish long-distance runners. *Eur J Sport Sci*. 2020;20(7):887–95.
14. Steinacker JM, Lormes W, Lehmann M, Altenburg D. Training of rowers before world championships. *Med Sci Sports Exerc*. 1998; 30(7):1158–63.
15. Orie J, Hofman N, de Koning JJ, Foster C. Thirty-eight years of training distribution in Olympic speed skaters. *Int J Sports Physiol Perform*. 2014;9(1):93–9.
16. Bellinger P, Arnold B, Minahan C. Quantifying the training intensity distribution in middle distance runners: influence of different methods of training intensity quantification. *Int J Sports Physiol Perf*. 2020;15(3):319–23.
17. 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):495–504.
18. Neal CM, Hunter AM, Brennan L, et al. Six weeks of a polarized training-intensity distribution leads to greater physiological and performance adaptations than a threshold model in trained cyclists. *J Appl Physiol (1985)*. 2013;114(4):461–71.
19. Stöggl T, Sperlich B. Polarized training has greater impact on key endurance variables than threshold, high intensity, or high volume training. *Front Physiol*. 2014;5:33.
20. Treff G, Winkert K, Sareban M, Steinacker JM, Becker M, Sperlich B. Eleven-week preparation involving polarized intensity distribution is not superior to pyramidal distribution in national elite rowers. *Front Physiol*. 2017;8:515.
21. 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):943–9.
22. Pla R, Le Meur Y, Aubry A, Toussaint JF, Hellard P. Effects of a 6-week period of polarized or threshold training on performance and fatigue in elite swimmers. *Int J Sports Physiol Perform*. 2019;14(2): 183–9.
23. Bishop DJ, Botella J, Granata C. CrossTalk opposing view: exercise training volume is more important than training intensity to promote increases in mitochondrial content. *J Physiol*. 2019; 597(16):4115–8.
24. MacInnis MJ, Skelly LE, Gibala MJ. CrossTalk proposal: exercise training intensity is more important than volume to promote increases in human skeletal muscle mitochondrial content. *J Physiol*. 2019; 597(16):4111–3.
25. Seiler S, Haugen O, Kuffel E. Autonomic recovery after exercise in trained athletes: intensity and duration effects. *Med Sci Sports Exerc*. 2007;39(8):1366–73.
26. Billat VL, Flechet B, Petit B, Muriaux G, Koralsztein JP. Interval training at VO_2max: effects on aerobic performance and overtraining markers. *Med Sci Sports Exerc*. 1999;31(1):152–63.