Lactate-Guided Threshold Interval Training

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Contributor: Arturo Casado , Carl Foster , Marius Bakken , Leif Inge Tjelta

A novel training model based on lactate-guided threshold interval training (LGTIT) within a high-volume, low-intensity approach, which characterizes the training pattern in some world-class middle- and long-distance runners was proposed. This training model consists of performing three to four LGTIT sessions and one VO_{2max} intensity session weekly. In addition, low intensity running is performed up to an overall volume of 150–180 km/week. During LGTIT sessions, the training pace is dictated by a blood lactate concentration target (i.e., internal rather than external training load), typically ranging from 2 to 4.5 mmol·L^{-1}, measured every one to three repetitions. That intensity may allow for a more rapid recovery through a lower central and peripheral fatigue between high-intensity sessions compared with that of greater intensities and, therefore, a greater weekly volume of these specific workouts.

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1. External and Internal Training Load in Distance Running

The training load, which refers to the interaction between training intensity and training volume, can be understood as either external (i.e., measurable aspects of training occurring externally to the athlete such as volume or intensity (i.e., running speed)) or internal (actual psychophysiological response that the body initiates to cope with the requirements elicited by the external load) [1]. Therefore, external load refers to the actual distance covered and speed achieved during a given training session. In turn, internal load can be measured through the monitoring of heart rate or [BLa]. While external training load represents an important reference to understand the performance evolution during the training process [2], it is generally believed that internal load may be the most accurate indicator of the effort for distance runners [3] as well as for other sports [1]. Accordingly, measuring internal training load (i.e., [BLa]) during training and using that information to control the absolute training intensity (i.e., speed or duration of repetitions) in order to achieve the most optimal stimulus represents a conceptually attractive training protocol which agrees with current recommendations [1].

2. Training Volume and Intensity Distribution Analysis in Runners Based on Their Internal Response to Exercise

The aerobic–anaerobic transition as a framework for predicting performance in endurance events was introduced in 1979 by Kindermann et al. [4]. During the last five decades, this framework has been espoused and updated by several scientists using either gas exchange or [BLa] markers [5][6][7][8]. During the last 50–60 years, several definitions related to the LT parameter have been presented [5]. Today it is common to refer to two breakpoints from a plot of the [BLa] during an incremental exercise test in a laboratory. The first threshold (LT1) was named aerobic threshold by Skinner and McLellan [7] and refers to the upper limit of aerobic metabolism. Intensities up to this point could last for hours. The second threshold or second lactate threshold (LT2) that has also been associated with the MLSS is known as the highest constant workload during continuous dynamic work, where there is an equilibrium between lactate production and lactate elimination [5][9][10][11]. At a slightly higher intensity than MLSS, the critical power (CP) concept, which is related to the hyperbolic relationship between speed or power output and the duration for which that speed or power output can be sustained, is an alternative approach to defining the maximal metabolic steady state [12].

According to these concepts, three training intensity zones for endurance athletes are commonly used [3][13]. Zone 1 represents speeds below first ventilatory threshold or 2 $mmol \cdot L^{-1}$ [BLa]. Zone 2 is represented by speeds between the two ventilatory thresholds or 2 and 4.5 $mmol \cdot L^{-1}$ [BLa] (vLT1 and vLT2, respectively). Zone 3 represents speeds above vLT2 [14]. However, this classification does not differentiate between low- and high-intensity Zone 2 training, nor does it demarcate the different intensity zones that are in Zone 3, such as lactate tolerance and sprint training, being both above the VO_{2max} intensity.

Furthermore, the transition between the different intensity zones does not follow clearly defined limits and are not anchored on exactly defined physiological markers [3]. The relationship between HR and [BLa] will also vary among different runners and in the same athlete across different training periods or seasons [15].

3. Physiological and Performance Development Using Lactate-Guided Threshold Interval Training (LTIT) within a High-Volume Low-Intensity Approach

3.1. Physiological Mechanisms Underpinning the Effectiveness of the Use of High Training Volume at Low Intensity

Different hypotheses have been proposed to explain the underpinning mechanisms regarding the reason why a great proportion (70–80%) of overall training volume conducted at low intensity yields optimal performance development in endurance athletes who will race at comparatively high intensities (e.g., low specificity of training). The improvement of endurance performance through high volume of low/moderate continuous training is generated by sustaining increased cardiac output over a prolonged time (therefore augmenting oxygen delivery to working skeletal muscle) and by increased capacity for the oxidative metabolism through mitochondrial biogenesis and capillarization in Type I skeletal muscle fibers [16][17]. Importantly, the mozaic architecture of human skeletal muscle dictates that increased capillarization in Type I skeletal muscle fibers also serves to augment O_2 delivery in Type II muscle fibers. Two primary signaling pathways for mitochondrial proliferation (both convergent on PGC1-α expression) exist. One is based on calcium signaling, which is more likely used with high-volume training [17][18], and the other is based on signaling derived from adenosine monophosphate (AMP)-activated protein kinase (AMPK) pathway, which is more likely used with high-intensity training, as [ATP] and AMP levels are reduced and increased, respectively [19][20]. As recruiting certain motor units elicited during competitive intensity exercise is needed in order to generate adaptative responses leading to increase mitochondrial density and aerobic metabolism, it can be achieved through the completion of at least a modicum of high-intensity training. The fact that most studies conclude that most of the training volume in distance runners should be covered at easy intensity to optimize performance development implies that adaptive potential of calcium signaling pathway is much larger than that of the AMPK signaling pathway. Accordingly, only relatively small training volume of the latter is needed to reach saturation in the adaptive response using this pathway [18][21].

Alternatively, evidence suggests that some homeostatic disturbances leading to failure to adapt to training (i.e., overtraining or non-functional overreaching) may be related to either inflammatory responses [22] or that slow autonomic recovery following high intensity training [23] may be caused by monotonic loads of high intensity training. These disturbances could lead to a reduction of the capacity for aerobic ATP generation through deficiencies in the mitochondrial electron transport chain or selective delivery of blood flow and/or reductions in maximal cardiac output [24]. Despite the mechanisms involved, quasi-experimental observations [25][26] have suggested the negative effects of an excessive amount of high intensity training. The optimal combination of low- and high-intensity training is typically achieved with a hard day–easy day pattern which avoids monotony during the training process and may act to ensure a sufficient recovery period and to prevent non-functional overreaching. This may augment adaptive responses, such as gene expression for mitochondrial proliferation [14][27]. This specific training pattern is adopted by well-trained and elite long- and middle-distance runners [25][28][29][30][31][32][33]. However, evidence of the exact balance of different types of training on mitochondrial adaptive responses is limited. Particularly in already well-trained athletes, the range of options for achieving additional adaptive responses seems likely to be relatively small. Given the large volume of low-intensity training already performed by high-level athletes, further adaptive responses may largely lie in optimizing adaptive responses in Type II muscle fibers.

3.2. Physiological Mechanisms Explaining the Effectiveness of LT2 Intensity Training

It is widely accepted that lactate metabolism serves as a useful index [6][34], although not likely as a cause [35], of muscular fatigue and that a strong correlation exists between lactate accumulation and level of performance in endurance events [36][37][38][39][40]. The relationship between running intensity/speed and [BLa] is widely used to predict and identify performance in distance runners [5][6][38]. A strong correlation between the speed at vLT2/vMLSS and performance in long-distance running has been consistently observed, regardless of the method used to determine these physiological variables [37][41][42][43]. In this sense, Tjeta et al. [15] demonstrated that VO_{2max}, RE, and $\%VO_{2max}$ explained 89% of the variation in vLT2 among distance runners of national to international level. According to Billat et al. [9], vLT2/vMLSS is a running speed that a well-trained distance runner can sustain for approximately one hour (half-marathon pace for elite runners). Similarly, Roecker et al. [38] found that vLT2/vMLSS was slightly faster than half-marathon pace in 427 competitive runners. This was especially the case for the best runners. As vLT2 during continuous running is close to half-marathon pace, continuous tempo runs from 8–20 km are classified as threshold training in z2 and z3. Tempo runs have been included in the training regime of distance runners from the 1970s up to now [33][44][45][46]. Casado et al. [47] found that elite Kenyan distance runners performed more of their total training volume as tempo runs compared with that in the best Spanish distance runners.

The combination of high training volumes in z1 with moderate volumes in z2 and z3 is a very common pattern in contemporary distance runners. It generated improvements in performance [25][48] or has been associated with very high performance in highly trained and elite middle- and long-distance runners [9][30][31][32]. Furthermore, the use of this approach was reported to be related to either high levels [30][32][33] or an improvement in RE [25][48]. Some research also found either improvements in [25][48][49][50] or were related to high levels of vVO_{2max} [9][32][33]. A few studies, using high volumes in z1 and moderate volumes in z2 and z3, were associated with high levels of VO_{2max} [30][33][51]. Studies using this training pattern also found either improvements in [48][50] or were related with high levels of vLT2 [9][30][32][33]. In any case, there are comparatively few contemporary elite runners who have a total training volume <100 km/week, and most perform >160 km/week [29][52]. This approach has, in most cases, one primary characteristic in common, a high proportion of z2 and z3 training was covered at intensities at or near vLT2 (i.e., high intensity within z2–z3) [9][25][30][31][32][48][53].

The underpinning mechanisms explaining the relationship between training near/at vLT2 and the development of performance and its physiological determinants are not clear. However, it has been hypothesized that the use of this specific exercise intensity improves muscle specific adaptations, including clearing of lactate as opposed to reducing lactate production [54]. Since only recruited motor units are likely to experience increases in mitochondrial number and capillary density, with the exception that increases in capillary density in Type I muscle fibers may benefit O_2 delivery to Type II muscle fibers, it may be speculated that training near vLT2 optimizes the number of motor units recruited without having to accept the consequences of elevated levels of catecholamines likely to be experienced with z4 training. It is also important to consider that the speed associated with a [BLa] of 4 $mmol·L^{-1}$ is somewhat specific to the pace of competitions in the 10–20 km range, which represents a large percentage of available competitions. Additionally, this velocity can be thought of as «speed work» for marathon runners. Sjodin et al. [40] tried to elucidate the effects of training at the speed associated with onset of [BLa] (vOBLA or speed associated with a [BLa] of 4 $mmol·L^{-1}$) and the mechanisms involved explaining those effects in eight well-trained middle-distance runners. After the addition of one weekly training session consisting of 20 min of continuous running at vOBLA to their usual training regime for 8 weeks, the rate of glycogenolysis during exercise decreased (i.e., reduction of phosphofructokinase/citrate synthase ratio), while the potential to oxidize pyruvate and/or lactate increased (i.e., increased relative activity of heart-specific lactate dehydrogenase). These enzymatic changes were accompanied by an increase in vOBLA and/or a decrease of [BLa] at a same absolute speed.

3.3. Potential Benefits of Lactate-Guided Threshold Interval Training

In any case, the association between this physiological intensity (i.e., vLT2 or vOBLA) and speed is usually assumed when the run is continuous. However, manipulating the variables composing an interval training session (i.e., repetition velocity, duration, and inter-repetition recovery time) to match vLT2/vMLSS through [BLa] monitoring during the session may allow for the adoption of faster speeds (i.e., faster than those derived from continuous runs) and, thus, optimize the adaptive potential of muscle-fiber-type-specific adaptations required for race pace achievement (i.e., in middle-distance runners). In this sense, Kristensen et al. [55] demonstrated that an interval training program using a higher intensity than that derived from continuous exercise yielded a greater activation of AMP-activated protein kinase in Type II muscle fibers. In this way, conducting training in z2 and z3 while recruiting Type II muscle fibers may provide the mechanical and metabolic advantages both of running close to race pace and at LT2 intensity, respectively. Furthermore, there is an additional advantage of covering interval training at LT2 intensity rather than in z4, which is related to fatigue generation. Burnley et al. [56] found that isometric quadriceps contractions conducted at 10% above the critical torque (i.e., just above LT2 intensity in z4) generated a rate of global and peripheral fatigue four to five times greater than that yielded by the same contractions at 10% below of critical torque (i.e., just below LT2 intensity in z3). These findings agree with the existence of a threshold in fatigue development dependent on whether exercise is carried out at, just below, or just above LT2 intensity. Accordingly, distance runners may benefit from covering some of their interval training sessions at z3 but at faster absolute speeds than vLT2 (assessed through a continuous incremental test) rather than in z4. Nonetheless, this should be done through short duration repetitions so that [BLa] does not progressively rise, as by doing so runners would be able to recover faster from ‘high-intensity’ training sessions. However, the use of intensities within z4–z5 has also been found to be useful in performance development in distance runners (2, 82). A recent systematic review by Rosenblat et al. [57] determined that high-intensity interval training at or below intensities of VO_{2max} allows the improvement in central factors influencing VO_{2max}, such as plasma volume, left ventricular mass, maximal stroke volume, and maximal cardiac output. However, peripheral factors influencing VO_{2max}, such as skeletal muscle capillary density, maximal citrate synthase activity, and mitochondrial respiratory capacity in Type II fibers can be developed through sprint interval training (i.e., 30 s repetitions) [57].

4. Putting This Training Model into Practice

These theoretical physiological advantages derived from LGTIT within a high-volume low-intensity model are attributed as beneficial by current Norwegian middle- and long-distance runners specialized in events ranging from 1500 m to 10,000 m. In the late 1990s, Marius Bakken (co-author of the present article), a Norwegian elite 5000 m runner, started to test a new training model on himself, which consisted of accumulating a high volume of training at an easy pace, a moderate volume of interval training at threshold intensity while controlling the pace through [BLa] testing during the session and including a low volume of interval training in z5 [58]. He typically covered 180 km overall, conducted four interval training sessions (i.e., two double sessions through a hard day–easy day pattern) at threshold intensity (i.e., at [BLa] ranging from 2 to 4.5 $mmol \cdot L^{-1}$ depending on the specific goal of the session) and one session at z5 per week [58]. Bakken experienced that when following LGTIT, he could perform a much higher training volume compared with that when he carried out interval training in z4. On the assumption that a higher total volume of training is associated with larger adaptive responses, this pattern might be thought of as beneficial. This assumption also agrees with findings of Burnley et al. [56] on the reduced fatigue generation at LT2 intensity when compared with that yielded by z4 training. Bakken developed this training model through a ‘trial and error’ approach and achieved a personal best time in 5000 m of 13:06.39 (min:s), which remains as the second all-time best Nordic best. He transmitted his training knowledge and experience to Gjert Ingebrigtsen, father and former coach of the three Ingebrigtsen brothers, who developed it for the achievement of their well-known athletic performances [58]. Bakken's approach became a model for contemporary Norwegian runners, and much of the success of Norwegian huge runners at present is based on Bakken's training principles. For example, Tokyo 2021 triathlon Olympic champion, Norwegian Kristian Blummenfelt, also used LGTIT [58]. This model has been developed within a successful system of endurance training. Norway, with a population of only 5.5 million, has similar men's national records in distance running events to those of the USA: 1:42.58, 3:28.32, 7:27.05, and 12:48.45 (min:s) and 2:05:48 (h:min:s) for the 800, 1500, 3000, and 5000m and marathon, respectively. For women, Norwegians have held some of the previous 3000, 5000, and 10,000 m and marathon world records. They also achieved the top national medal count for the cross-country and biathlon skiing events at the 2022 Winter Olympic Games, and both the triathlon 2019 and 2021 World Champion (Gustav Iden) and the aforementioned 2021 Olympic champion (Blummenfelt) are Norwegians [BLa] measurement and scientific testing are/were part of their training processes in most of these athletes.

It has been reported that the Ingebrigtsen brothers conducted LGTIT over distances from 2000 m to 3000 m at close to half-marathon pace as well as over distances from 400 m to 1000 m at paces between 5000 m and 10,000 m race paces. The volume of this LGTIT sessions ranges between 8 and 12 km, and the recovery time between repetitions ranges between 20 s and 1.5 min. They often covered two LGTIT sessions in the same day and a fifth specific session at a much higher intensity in z4 or z5 (i.e., 20 × 200 m uphill jogging back in 70 s) (1, 67, 92). Their training intensity has been tightly controlled via measures of heart rate and [BLa] during all interval sessions (1). While the extensive use of LGTIT (i.e., up to four sessions per week) represents a novelty in the training of elite distance runners, several studies have reported the combined use of LT2 and z4/z5 training during the training week. For example, runners may conduct two (or more) different interval training sessions per week covered at LT2 and VO_{2max} intensities, respectively (41, 68–70, 85). On the one hand, the addition of a greater number (i.e., two or three) of 'high-intensity' sessions to those typically observed in highly trained and elite runners may represent an advantage in training adaptation, as assimilating this higher training load may provide greater performance improvements. On the other hand, it also may represent an increased risk of injury/overtraining syndrome. Furthermore, the characteristics of LGTIT are different from those accepted in the current literature in distance runners given that traditionally LT2 training is conducted as continuous runs at much slower absolute speeds (31). Furthermore, the use of one sprint training session as well as some strength training sessions have been suggested as part of this training model [58]. In addition, it has been reported that this model involved the completion of a high training volume (i.e., 157–185 km/week) [30][58], which also agrees with the accepted efficacy of high training volume in elite distance runners [29][47][59]. However, the longest run does not exceed 21 km [58]. Finally, while no mention of the periodization approach adopted by these runners through this training model exists, the authors' personal observations suggest that this training pattern involves the use of a traditional periodization approach, as observed in other elite distance runners [29]. Furthermore, during the competitive period, the z5 hill interval training session should be partly substituted for track workouts targeting competition pace at high [BLa] (i.e., from 5 to 10 $mmol \cdot L^{-1}$), and two LGTIT sessions are removed from the weekly plan. In this way, the goal during the competitive period is to achieve the minimum dose of threshold work which can sustain the previously developed aerobic base allowing for the completion of high volumes of competition pace above z3. This would be consistent with the current literature regarding optimal training periodization in highly trained and elite distance runners and shows a trend from a pyramidal TID during the preparatory period towards a polarized TID during the competitive period [29][32][50][60]. The main goal of the present approach is to improve the speed while keeping [BLa] (and heart rate) stable during LGTIT sessions across the season.

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