Threshold Training
in Competition, in Training

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The following document is my response to a query by a college coach about training types and patterns during the competition season. It can apply just as well throughout the entire training year, in blocks, to be sure, with varying emphasis. But it can be observed, echoing a number of researchers and theorists, that the older conservative theory of periodization has been fairly drastically modified. Now, even with periods where base endurance or strength or speed dominate, highly varied and multi-tiered training is sustained. This has become practice largely because of the recognition that total training volumes are significantly higher, even for juniors, and because it has become clear that varying training stimuli have the effect of not only loading but, just as importantly, relieving and refreshing the athlete's systems. It no longer makes sense, therefore, to slot this or that type of training into a rigidly periodized yearly plan. Above all, modern ski training maintains volumes throughout the winter which a few years ago would have been considered foolhardy. Some of the rationale for this difference approach follows.

reference: *Adaptation in Sports Training*, Atko Viru

Variants of the Interval Method of Influence of Different Mechanisms in Runners p245

Main mechanism for ATP resynthesis	time/set	reps	sets	reps/set	run:rest	type of relief
Phosphocreatine mechanism	10-25s	50-32	4-5	8-10	1:3	rest (walking, flexing)
Phosphocreatine + anaerobic glycogen-olysis	30-80s	25-10	2-5	5	1:3, 1:2	work relief (jogging)
Anaerobic glycogen-olysis + oxidative phosphorylation	1:30-3:00	8-4	1-2	4-6	1:, 1:1	work relief rest relief
Oxidative phosphor-ylation	3-5 min	3-4	1	3-4	1:1, 1:0.5	rest relief

Fox, Mathews, 1981

The following energy use patterns express the same information graphically. It will become clear that the area of energy use most often over-used, and therefore counterproductive and limiting to overall training progress is the area of anaerobic glycolysis where it exceeds the aerobic curve.

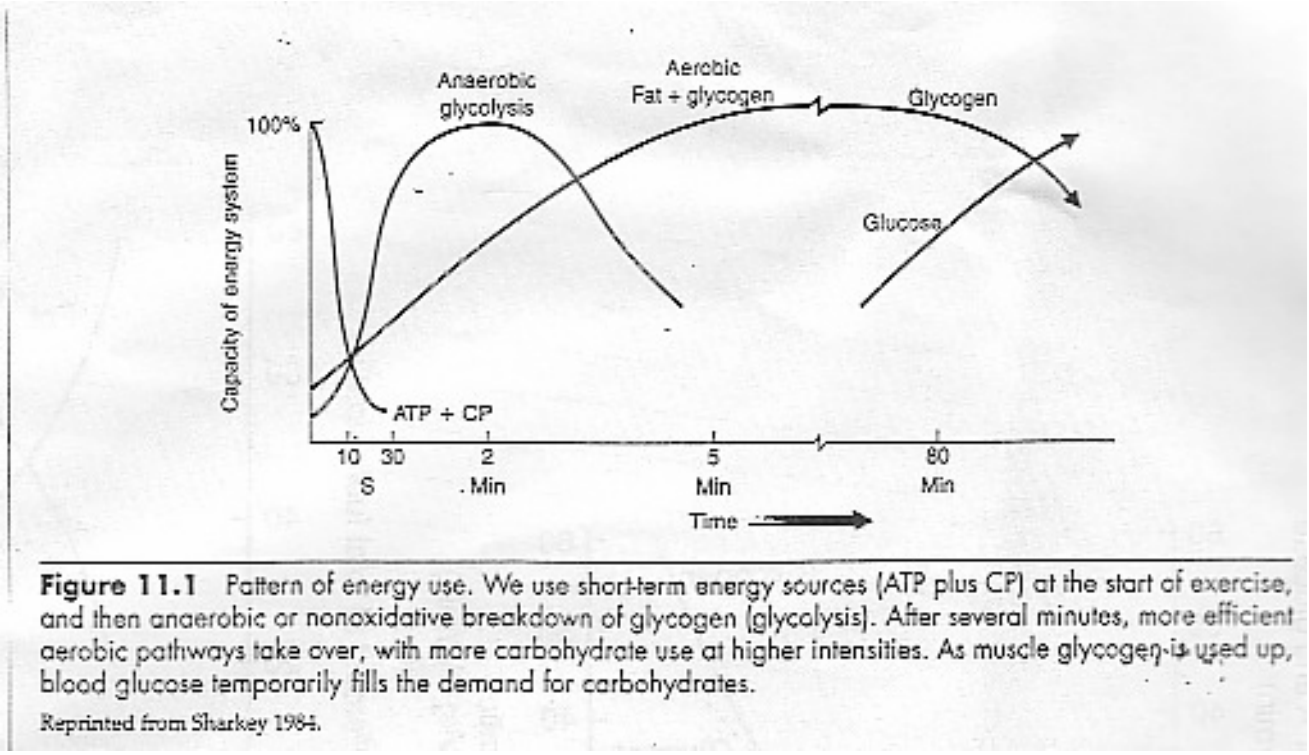

Figure 11.1 Pattern of energy use. We use short-term energy sources (ATP plus CP) at the start of exercise, and then anaerobic or nonoxidative breakdown of glycogen (glycolysis). After several minutes, more efficient aerobic pathways take over, with more carbohydrate use at higher intensities. As muscle glycogen is used up, blood glucose temporarily fills the demand for carbohydrates.

Reprinted from Sharkey 1984.

(courtesy of Dr. Don Christie)

Viru differs with Fox and Mathews in one regard: in describing cases in which anaerobic glycogenolysis and oxidative phosphorylation both contribute to ATP resysnthesis, that is at quite a high level of exercise intensity, their ratio defines their relative prevalence. “In exercises lasting from 30s to 5 min, the prevalence belongs to anaerobic glycogenolysis, and in exercises of 5 to 30 min it belongs to oxidative phophorylation.” (Viru, 142, 1995) The distinction will become important when I discuss 3-5 min intervals, which are widely assumed to increase VO2max.

Questions surrounding the subject of “The Specificity of Training Effects on Aerobic Working Capacity and the Cardiovascular System” (Viru 159) lead to some useful conclusions about optimal types of training, particularly during the competition season. Despite the dramatic increase in yearly training hours since the 90's, the traditional approach to winter has remained to reduce volumes substantially, by 40+/-%. More recent practice in Europe indicates maintaining a cyclical regime of stimuli at a much higher volume level of fitness.

The rationale for reducing hours has been based on the assumption that (1) so-called maxVO2 stimuli create and maintain racing fitness and (2) the most effective maxVO2 intervals were in the 1-5:00 range. The tendency is to read the “max” and not think enough about the “VO2.” (See the highlighted area above).

This past winter I almost totally avoided that area with Adele Espy and in the process was able to maintain her competition season per period (3-week) volume at 7% of her year/hours rather than the more usual 5%. This also resulted in her doing 113% of her planned hours (450) and reaching 510.

My reasoning was as follows: (1) since aerobic metabolism is 18 times more efficient than

anaerobic metabolism, the more time you spend breathing aerobically, particularly at your highest aerobic (threshold) output levels, the more race-effective you'll become, as opposed to intense anaerobic training. My approach has long been, if you're going to race 15-20km, you have to condition your breathing apparatus to get comfortable with that amount of time at its highest aerobic level of operation. You take your whole body out for a "breathing trip," breaking down the time into blocks small enough to account for pace maintenance but long enough to provide a true endurance stimulus to the lung muscles. Overdistance in these terms then means 1.5 to 2 x race distance.

(2) Just that middle, mixed region of stimuli creates the most intense loading, and consequently allows sessions of only short duration and requires the longest recovery periods. Training time is sacrificed, more exactly time for conditioning the lungs to breath better at a speed quite close to race-pace. The dominance of anaerobic responses carries with it a further deficit: as a comparison of strength protocols demonstrated, 4 x 1 minute bouts of strength work produced high lactate levels but low power outputs, not what we are looking for in training.

(3) Adele clearly thrived on more training time, not just metabolically but in terms of neuromuscular coordination – more time on skis at a higher speed. (4) We varied the long threshold intervals (usually 6-10 minutes, and cumulatively 40-60 minutes per session) with sessions of 30/30s or 30/15s which accumulated to at least 15 minutes or 5km per session. These were race speed or slightly over and amounted to anaerobic stimuli, but they were both short and they were divided into two sets separated by 10-20 minutes of easy skiing. The result was that the lactate never rose above threshold levels. The speed was very high but the metabolic load was relatively low. (5) My goal was to pull/strengthen the breathing as close to race pace as possible, without trying to mimic the race, and pair that stimulus with race+ coordination stimuli.

(6) Consider routine overdistance sessions we did of 3.5 to 4.0 hrs., divided into two sessions of roughly equal duration, with an 1:30 break for lunch. In the morning we did 2 hrs. with 4x10 min@threshold in the middle; in the afternoon we did the rest with 2 10-15 periods of 30/30s or 30/15s, divided by 15-20 minutes of easy skiing, you have a distance session with 55+/- minutes of threshold speed in it. Throughout the winter we routinely did 45 -55 minutes of long threshold intervals on a Tuesday or Wednesday and paired them with 30/30s on the other mid-week day. (7) This would seem at first glance to be excessive, until you re-define what you are doing: the variant loading is more precisely simply a change in stimulus character, which in fact has a refreshing effect on both body and mind. It also assures that the skier is constantly changing pace, skiing at all speeds. The body experiences more complete training, is stretched and stimulated and finishes still awake. This is the second thing the Germans, and doubtless others, learned from studying triathletes. Not only were triathletes training more, they were able to do it because they not only took on greater loading but precisely because the varying stimuli made it possible. It was therefore not just *more* work but *better* work. (8) The same variant stimulus patterns can be achieved in other workouts, say 100s to 200s or more, so long as the skier's speed does not exceed threshold(+2-3) heart rates. The only way that can be assured is by measuring roller ski sections and timing. (S. later)

Is there any basis in sports science for these contentions and practices? I go back to Viru's original title article.

What about so-called maxVO2 intervals, the highlighted area. How do we understand them?

Viru: “Exercise intensity at VO2max does not indicate maximal performance on the basis of aerobic resynthesis of ATP. Actually, it was found that there is no close coupling between the whole body VO2max and the oxidative capacity of a local muscle group in elite road cyclists during a session.There is a close relationship of these variables over the first 3 to 4 weeks of training. Thereafter, the increase in VO2max levels off, but the activity of the mitochondrial enzymes continues to rise. The VO2max of athletes may be twice that of untrained persons, whereas the activity of mitochondrial enzymes of the muscle is three- to fourfold higher than that of sedentary individuals. When training was discontinued, the activity of the oxidative enzymes dropped to the initial level within 2 to 4 weeks. However, VO2max remained high for 6 weeks.”(159)

For rowers “Power output data indicated that 72% of total power is generated at the anaerobic threshold. In topclass distance-runners the anaerobic threshold is as high as 85 to 90% VO2max and in skiers 75 to 80% VO2max. The difference is related to the higher VO2max in skiers. However, in predicting the endurance performance level, exercise intensity at the anaerobic threshold in more important than the percent of VO2max at this intensity..... Aerobic training is most effective at intensities of exercise corresponding to the anaerobic threshold or at an intensity slightly higher than anaerobic threshold.” (160)(S. Also 265 and references in Crowther, “Training to improve the Big Three,” http.//faculty.washington.edu/Misc?RBC/model2,html)

“VO2max was found to be a good interpreter of endurance performance when a heterogeneous group of persons with quite different athletic abilities were[sic] studied. However, it is a relatively poor predictor when athletes of similar ability are evaluated. When two athletes with the same VO2max were compared, the runner with the higher running economy was faster.”(161)

One considers these findings and remembers: (1) VO2max intervals are just that, as Jan Helgerud's study calls them, “**aerobic** high-intensity intervals,” that is, threshold level training (to just over), and what the Germans call Base Endurance II or Entwicklingsbereich – Development Zone. No attention is drawn particularly to anaerobic or mixed aerobic-anaerobic intervals. (2) The emphasis seems on developing not further VO2max* but on (a) continuing to elevate the levels of mitochondrial enzyme activity, with the stimulus being of significant duration to equate with racing, not once but more often in a rather dense series (a view also noted by Rolas (2000) in Finn, *Sportscience* 5(1) 2001). This emphasis fits with the goal of maintaining the adaptation process of the IIa muscle fibers to aerobic metabolism.

Finn also cites Acevedo and Goldfarb's finding that (a) increases in training intensity can improve performance without changes in VO2max.); and (b) on movement economy, which extends metabolic efficiency to neuromuscular efficiency. This also requires training of significant duration and explains the motives behind German athletes reporting in mid-season leading up to a major series or championships of 7 days of high-intensity (= highest level aerobic) training, followed by another week at mid-altitude, with high-velocity distance training. Base II is thus not only the next step up from Base I, it is the short step down from racing in the training “holding pattern” throughout the season. Without it, the body loses contact with its optimum levels of performance. The key may well be in Viru's reporting that the oxidative enzyme activity drops off after 2 to 4 weeks, unless adequate continuous high-level threshold work is maintained cyclically within the racing season. I think of Germany's Head Coach Jochen Behle reporting that his team's “day off” during this winter's Tour de Ski was 20km easy for the women, 30km easy for the men. I also remember Tobias Angerer's reporting some 100 km days in Muonio just prior to the start of the World Cup season in last November.

Another factor to be considered: if too much anaerobic training is done, the longer recovery times required would shift the emphasis away from maintaining the high level of aerobic fitness, another reason anaerobic and mixed aerobic-anaerobic intervals must combine with greater rest, with the result than special endurance fitness soon begins to drop. This is a mistake often made when the blanket assumption is made that greater effort = greater improvement. My favorite image for this is piano practice: a practice at all is 2 hours; it cannot be accomplished in 1 hour by playing twice as hard. Seldom did we train less than 2 hours, and then only in the easier third week of a period.

A final point: I believe in the 30/30s even if they are theoretically mixed, and a batch of them does bring the heart rate up. But they need to be seen not as sprint work but pace work, a pace that is only very slightly over race speed. In that way they become threshold sessions metabolically. And the only way to assure the proper pace is by measuring sections accurately, road or snow or track, and timing. If a skier is comfortable with 36s for 200m(3 min/km on roller skis, try 72 for 400m. If that succeeds, try 600m. That will surely slow, so go back to 100 or 200 and get the 36s back. Once that is assured, extend again. In the middle go to 1 km, 1.5 or even 2 km to change the stimulus and check the speed. Then return once again to the 200s. This sort of training trains for the speed you want rather than just waiting for whatever speed you get.

But this is a another discussion.

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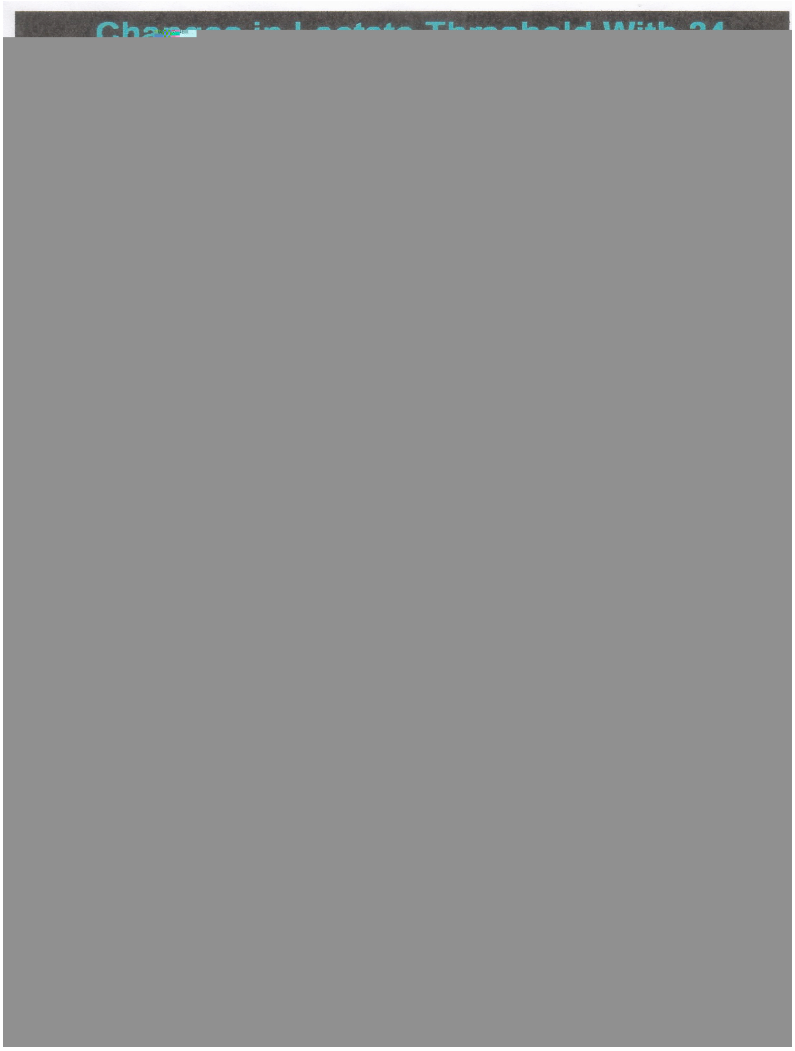
*This is not Helgerud's conclusion, of course. But consider two things:(1) his test group is comprised of "moderately trained university students doing endurance training at least 3 times a week." That is a group whose initial primary development would be improvement of VO2max, in accordance with the research Viru reports (quoted above), after which it would level off. (2) A 4 minute interval may be in the area of oxidative phosphorylation, but at very high threshold, at 90-95% of max heart rate, at which point there is (usually) already a substantial anaerobic contribution. (3) It is worth noting that Helgerud also stays away from the middle anaerobic or mixed intervals. The most effective were either the 4x4minues or the 15/15s. (4) Adjustments have to be made for skiing, for Helgerud is testing runners, usually in lengthening the interval time to accommodate slower rates of acceleration. Jack Sassville describes block intervals as being a combination of 4x4s and 30/30s, one week out of every four. I prefer much longer threshold intervals, particularly in a skier's development stage, where adaptation to anaerobic stimuli is not yet available. My belief in long intervals is gut feeling, however, since that has not been researched. (As Crowther points out. Heiki Rusko, on the other hand, among others, has found continuous long slow distance training to be as effective at raising anaerobic threshold as a percentage of VO2max. That was 1987, a notable consideration.)

Tim Gibbons therefore , sounds a wise caution when he remarks: "The trend in the U.S. Toward intensity periods of 4-6 high-intensity sessions a week as recommended by Jan Helgerud certainly overlooks the long-term view of development in skiing. Junior and master skiers alike, fitted with relatively low level of fitness and/or years of low training volume suffered greatly after attempting to duplicate the two to three week Helgerud intensity period. Why do we bring an unproven training protocol to the masses to try on unsuspecting athletes? Becky Scott claims the Helgerud protocol was responsible for her success the last three or four years of her career. I suspect she was able to respond favorably to this kind of training because of years of high volume training." (e-mail of 11 May, 2007) Tim adds the following graphs, supplied by Steve Gaskill at a 1997 coaches symposium in Minnesota.



Data by Rusko/Kantala

It will be interesting to see if Marit Bjoergen, who has trained with the Helgerud protocol, returns next winter in better form than this (2007), or if the blocks created a rise but also a fall off, as Marty Hall has speculated. (As of March, 2010 her change away from that protocol, or block intervals, seems to have proven positive. But I am waiting for further information about changes she might have made.)

This question has now been rather emphatically answered with Bjoergen's stellar 2010 results, following her switch away from the hard 4x4min intervals to more of the high-level threshold level training we have discussed here.

The following discussion expand on these ideas and is a response to an athlete's questions about the role, timing, and execution of longer threshold intervals, and how the three muscle fiber types work in training and racing.

Longer threshold sections (up to 30+ minutes), or LFD (**l**ong **f**ast **d**istance)

They are appropriate anytime as a variation from other, usually somewhat shorter (closer to 10 minutes). Two things to remember: a fairly drastic variation in stimulus has a productive "waking up" effect on your physiology; it is important when you do them to pay attention to the speed/pace you are going and maintaining. Thus, particularly when you go long, be looking for easy terrain where the speed you want at that pace, for that length of time is available. Another decision you make (as you seem to have done Sunday) is letting up when you sense your pace dropping off, even a little. Recover well and go on with whatever pace/length seems right (fits your plan) next.

That question leads right into a little more explanation of the roles of fast twitch fiber types, FOG (fast oxidative glycolytic)(IIa) and FG (fast glycolytic)(IIb).

Quoting from the German study from which I derived our 6x10, 4x20, 1x40 protocol: "In most endurance sports the capacity of energy resource readying by way of using oxidative metabolism dominates, that is, the the oxidative features of the muscle determine performance. Adaptation phenomena in the muscle manifest themselves in its metabolic differentiation. For power endurance performances the development of the fast-twitch oxidative muscle fibers is particularly important. Muscle fibers of this type can achieve high energy turn-over rates over a longer time period. The operation of this fiber type is connected to middle to high stimulus intensities."

If we consider all we have said about lots of ant- and ant training (Base 1-2 and Base 2 (Development Zone), it becomes clear how the two types of fast-twitch fibers fit in.

The pure fast-twitch fibers (FG, IIb) are solely anaerobic/glycolytic, able to generate great force but with very short duration. They exhaust their fuel quickly and recover it slowly. That is because they do not respond to the presence of oxygen.

The fast-twitch oxidative fibers can adapt/respond to **both** anaerobic and aerobic environments. They have all the power potential of the other fast-twitch fibers, but they are the power hybrids. If you keep them in a predominantly aerobic environment, at a high-enough speed/load for them to be stimulated, then they will transform themselves into more oxidative fibers. The specific stimulus/load environment in which they can accomplish that transformation is precisely our threshold zone, if you spend enough training time there . That is where power-endurance is developed, from ant-(10-15bpm below threshold) to ant (just below threshold to just over- 3-5mmols of lactate). It is this latter spectrum, in which 4mmol is considered actual threshold, that the discovery that a slight(!) anaerobic stimulus also stimulates aerobic responses makes practical sense. It is also, as we have said (in "In-Season Training"), where the activity of the various critical oxidative enzymes is enhanced.

What happened to our FG (IIb)fibers? If you push the intensity much higher than 5mmols of lactate, then for certain the anaerobic environment will quickly dominate, with the specific responses of the muscle fibers. You want these responses to be available for certain **short-term** race situations, but if you were to train too much there, or race too often at maximal intensities, then the FOG fibers will start to think that it what you want of them and transform to being more like the FG fibers. That is not how high speed/power endurance is built.

It is built by just the variety, longer and shorter, of threshold work you have been doing.