There are a ton of endurance training resources out there, mostly focused on running, cycling, and swimming. For mountaineering, there is less as most information deals with mostly the technical aspects and less with fitness and physical training.

Of the set of information available from all these sources, there are often conflicting protocols and rationale – i.e. the Uphill Athlete book recommends lots of “Zone 1” and “Zone 2” work. In running, weekly “long runs” and regular regimen of “tempo runs” are recommended, along with increasing weekly mileage.

What’s the reason behind these recommendations? A lot of these protocols are derived from experiences. Athletes differ in their starting fitness level, age, available time to train, and goals. For example, if a recreational or former college athlete starts training for mountaineering, most likely he can skip the first several weeks of long “Zone 1” and “Zone 2” work. If his goal is going up Mt. Whitney the fastest he can, the training protocol will most likely be different from training for the fastest marathon on flatland.

Here I try to compile training protocols from physiologically based principles – when the underlying principles are clear, and the training goals are clear, then we can derive the most time-efficient training protocols.

Goal

Our goal as mountaineers is to go higher, faster, for longer, while carrying more weight. This differs from runners’ objective – go faster for longer. The weighted requirement thus introduces more strength requirements to our training.

Specificity

Note that training for any endurance sport, such as mountaineering, specificity is very important. Hiking/running for a very long time, for example, means tens of thousands of reps are taken. This means movement efficiency and movement patterns will have a huge impact on performance. In practice, someone that trains primarily in cycling is not expected to be able to run an ultra-marathon. This is in contrast with general strength training, where training squats or deadlifts will often reflect in relatively strong performance gains in the others (assuming one’s proficiency in both movement’s techniques).

Of course, any endurance training can result in general improvements in energy systems (VO2 max and lactate threshold) and aerobic fitness, resulting in gains in other endurance sports. But training with specificity is the most time-efficient method.

Protocol-wise, for mountaineering, training with upright spine loading activities (i.e. running, hiking, skinning) are preferable to others (e.g. cycling, swimming, rowing).

Energy Systems or Why do we get tired?
References:
- Andy Galpin science of physiology
- Andy Galpin lactic acid
- Training peaks lactate threshold
- Uphill athlete: what enables endurance

Important concepts include **VO2max**, **lactate threshold**, **aerobic** and **anaerobic respiration**.

VO2max is a measure of how much oxygen your tissue can utilize. In other words, given X-amount of oxygen in blood going into a volume of tissue per unit time, how much oxygen is in the blood that comes out of that same volume?

VO2max is calculated by the Fick equation as **Q * (oxygen_in - oxygen_out)**, where Q is the cardiac output, defined as **Stroke Volume (SV)** times **Heart rate (HR)**.

Lactate threshold describes how much of one's VO2max can be utilized, before anaerobic metabolism kicks in.

Factors influencing VO2Max

Heart-rate has a maximum ceiling as a function of age range. During rest, HR is depressed by the parasympathetic system (rest and digest) via the vagus nerve through the emitting of acetylcholine. During exercise, this suppression decreases, and as needed, adrenaline is released to stimulate heart rate. However, this is not a trainable parameter.

Stroke-volume is the amount of blood that the heart pumps per stroke. The heart is a muscle, and the bigger, the more powerful it is, the higher the stroke volume is. So how do you get a bigger, stronger heart? Looking at the biomechanics, the left ventricle of the heart contracts to pump blood, and then expand as blood rushes in. Note that at the maximum heart rate, the ventricle cannot expand in time to let the returning venous blood enter. As the heart pumps faster, blood rushes in quicker, impacting the surrounding ventricle walls. This impact also increases with the more total volume of blood per stroke, putting even more stress onto the ventricle walls.

This means the faster the heart pumps more blood, the stronger the heart walls become, the greater the stroke volume is, which in turn increases the stress. **This would indicate very high-intensity, near maximum HR exercise as most efficient for increasing the stroke volume. Since maximum HR cannot be maintained for long (see lactic threshold), this points toward HIIT as most effective in increasing stroke volume.** This is the principle behind this famous Joe Rogan clip on “heart stretching” endurance training – frankly that was a bad explanation and obscures a lot of important physiological principles. I was confused after first hearing it. As a result of higher stroke volume, one's resting heart rate would also decrease, assuming the same resting metabolic energy requirement.

The second part of the Fick's equation is the utilization of oxygen by a specific volume of tissue. Oxygen is utilized by cells via diffusion – blood vessels surround muscular tissues and the oxygen molecules move into the cells. This diffusion process is more efficient when there are more blood vessels – cell membrane exchange area, and if blood moves slower. This happens when the **capillary density** within the muscle tissue increases.

Increase of capillary density, or angiogenesis, is stimulated by vascular endothelial growth factor (VEGF) secreted from the muscle fibers to the muscle interstitium. This review points out that angiogenesis responds positively to high-volume, low-intensity exercise, while less or even negatively to high-intensity/low-volume exercise. One interesting proposed mechanism is that the amount of shear stress applied to blood vessels is important to angiogenesis, and this stress is higher during high-volume exercise. Further, during high-intensity exercise, anti-angiogenic factor secretion increases to possibly prevent angiogenesis from going "hay-wire". Whatever the mechanism, **long-duration, low-intensity exercise serves to increase capillary density.**

Aerobic Metabolism

Aerobic respiration is the process of cellular respiration that takes place in the presence of oxygen gas to produce energy from food, utilizing primarily mitochondria to produce ATP. The source of fuel for aerobic respiration can be glucose, lipid (fat) or protein. This happens mainly in slow-twitch muscles that have high density of mitochondria.

Anaerobic Metabolism

Anaerobic respiration is the process of producing ATP from primarily glucose, in the absence of oxygen, in the cytoplasm. This can happen in all types of muscle fibers, but predominantly in bigger/fast-twitch fibers which lack a high number of mitochondria. This process is much less efficient than aerobic respiration in that it produces much less ATP per glucose (2 vs. 32), and generates Pyruvate, which in the bloodstream combines with free H+ ions to form lactic acid.

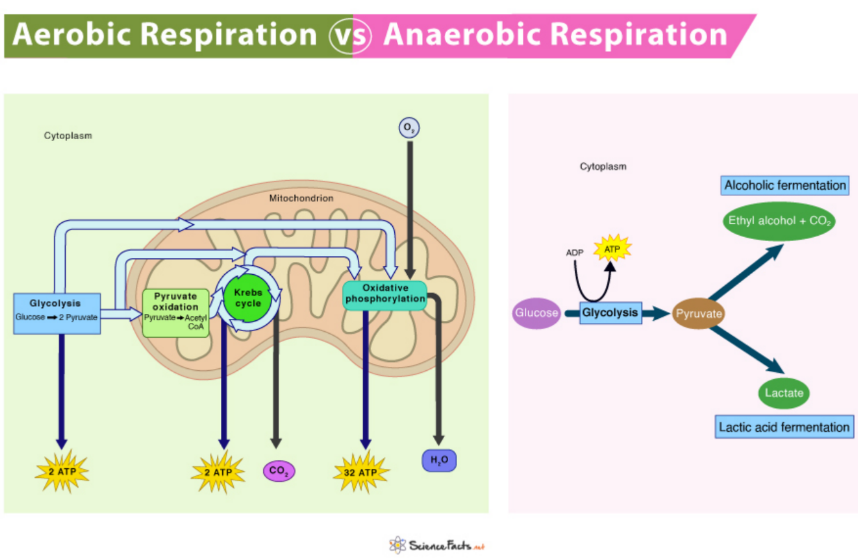
Lactic acid is not actually harmful and acts as a buffer for H+ ions to maintain pH level, during the absence of oxygen in the body. When too much lactic acid is present however, the pH lowers steadily, ATP production drops.

Good thing the slow-twitch mitochondria-packed muscles uptake this access of lactate, up to a certain degree (power output), at which point the production of lactic acid outpaces that of their intake, regardless of increased heart rate and breathing. At this level, the athlete can only sustain his effort for a fixed amount of time (traditional measurement is for less than 2 hours). This level of work is considered the **lactic threshold** (for x duration).

Note that while there is an upper limit to heart rate as a function of age, lactic threshold can occur before the maximal heart rate due to lack of oxygen and acid build up in a local region. At this point, the only way to restore energetic balance is for the athlete to slow down or work with less intensity.

Aerobic vs anaerobic respiration

	Aerobic	Anaerobic
Reactants	Glucose and oxygen	Glucose
Products	ATP, water, CO_2	ATP and lactic acid (animals); or ATP, ethanol, and CO_2 (yeast)
Location	Cytoplasm (glycolysis) and mitochondria	Cytoplasm
Stages	Glycolysis (anaerobic), Krebs cycle, oxidative phosphorylation	Glycolysis, fermentation
ATP produced	Large amount (36 ATP)	Small amount (2 ATP)



Training protocol from physiology

Now it would seem more apparent that to go longer, the key is to increase aerobic respiration. To go longer for faster, we want more muscles to be more capable during aerobic respiration, while delaying glycolysis (anaerobic respiration) for as long as possible to prevent gas-out.

This is the idea behind **long-run** in running, **zone-2** training, and **low-intensity long-duration** (**LD**) training. Very long duration, low-intensity training preferentially stresses the mitochondria-rich low-twitch fibers, resulting in increased mitochondria density and increased capillary density in the exercised muscles physiologically, and better running/walking economy biomechanically.

Low-intensity long-duration exercises also increase capillary density, and therefore VO2max. This is especially important for high-altitude mountaineering, where oxygen is less available and whatever oxygen is present in the body should be utilized maximally. This means **HIIT** would also be useful as it contributes directly to increasing stroke volume.

To summarize, to go faster for longer:

- We want to increase VO2max and lactate threshold – **aerobic capacity**. Note commonly aerobic capacity is simply VO2max, but defining it as a composite VO2max and lactate threshold is more informative of performance.
- LD training increases VO2max by increasing capillary density, increases lactate threshold by increasing mitochondria/aerobic capacity of the muscle fibers.
- HIIT increases VO2max by increasing stroke volume, but may have negative effects on angiogenesis.
- This would suggest a mostly LD-training protocol, with some HIIT.

What about interval training?

From a physiological point of view, interval training lies inbetween LD and HIIT, and shouldn't be as effective as the above combination. Indeed, Training for the new alpinism, Fellrnr, and Training Peaks shows recommendations against interval training, favoring a polarized LD-HIIT protocol.

So why are so many people fans of interval training (tempo runs, fartlek, maximal steady-state) and swear by it. Some articles suggest that tempo runs help increase lactate threshold. This is not incorrect as any exercise that stresses aerobic respiration will help with lactate threshold. The close to maximal (80-90%) heart rate also works to increase VO2max, though likely not as effective as HIIT, also stresses the heart enough. So in a way, **tempo run is a blend of LD and HIIT into a single exercise, that aims to get the physiological benefits of both.**

Is it the most effective? If you have limited time and are going for short enough distance, tempo run might be the most time-efficient method, instead of using tons of high-volume LD training. What's short distance/total work? This would be determined by one's lactate threshold and the amount of glycogen supply – if one is fast enough to finish a marathon before glycogen depletion, then tempo run may be the most efficient method. On the other hand, if glycogen depletion happens with 3 more hours to go and no re-fuel, it would be much better to work on LD. Therefore, physiologically tempo run **is a situationally effective training tool**. For mountaineering specifically, as oxygen decreases with altitude, lactate threshold also decreases, thus making tempo run at the same altitude less effective.

For running, tempo run does have the psychological benefit of understanding what it feels like to hold a pace for an extended amount of time, hence its wide use in competition runners.

Additional training protocol pieces

On top of the important aerobic base from LD and high VO2max from HIIT (though Uphill athlete would suggest LD exercise as maximally important before HIIT), more pieces can be added onto the training to improve performance.

Muscular Endurance

Muscular endurance refers to the ability of a muscle to consistently exert force for a long period of time. So how is this different from regular endurance?

Typical endurance trained with the polarized training protocol recruits primarily the weaker slow-twitch muscles. Mountaineers often need to carry heavy packs that require the recruitment of bigger fast-twitch muscles that are less efficient aerobically, which is not possible during low-intensity LD exercises.

So why not just do all LD with loaded backpacks, assuming the athlete has the max strength requirement (i.e. carrying 50lb pack should be easy for someone that squats 270lb)?

The key is endurance! Someone with a low aerobic capacity can carry the pack, but with a low lactic threshold will quickly have to take a break as the blood pH level drops. He won’t be able to do this for too long, because as glycogen level depletes, and aerobic respiration is not able to keep up with the energy demand, there is not enough energy available. As a result, carrying a heavy pack without a proper aerobic capacity will not provide enough training volume to properly develop the aerobic respiration pathways (i.e. mitochondria and capillary density increase).

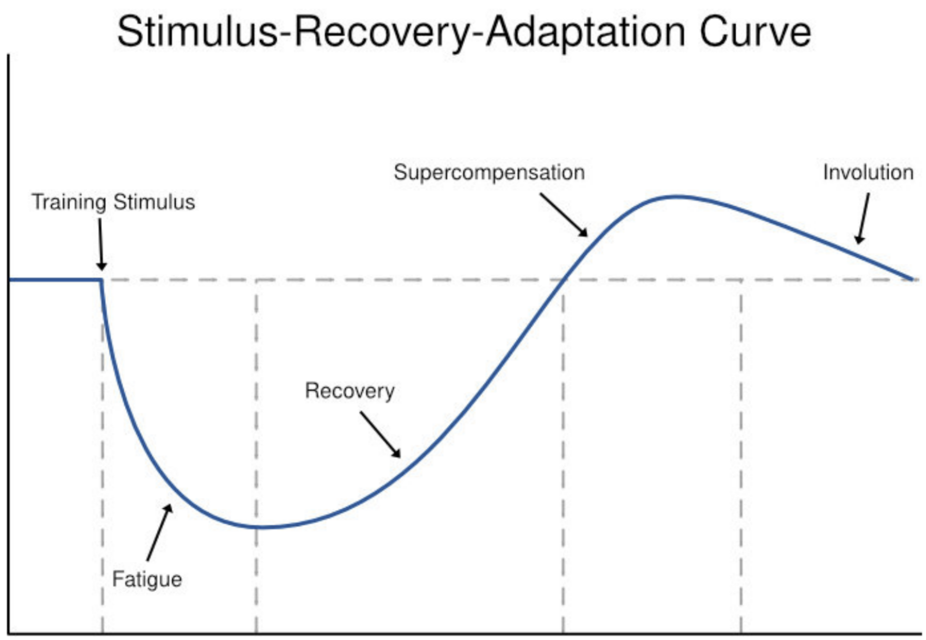
With proper aerobic capacity, one can then carry a heavy load for long enough to deplete the glycogen levels, recruit the bigger muscle fibers and stimulate their aerobic respiration. This then results in the bigger muscles to become more efficient aerobically, increasing muscular endurance.

Max strength training

General strength training is always great, and increases the force generation of ALL muscle fibers, especially the biggest fastest-twitch ones. In addition, tendons responds the best to resistance training, therefore combined with muscular endurance training this is a great protocol. Having stronger tendons makes one more injury proof, stronger, and more biomechanically efficient.

Deloading and rest

Our body gets stressed during training and adapt during rest, following the adaptation recovery curve.



This means that rest days/weeks are necessary, during which the training load is less or zero. Training weeks is necessary to allow the body to fully recover (unless one can overlap the supercompensation phases!!!), enabling even greater training stimulus to be used subsequently.

Overtraining happens at high frequency such that the body is constantly in the fatigue phase – when this happens and training stimulus increases, the body becomes unable to handle it and injuries usually happen.

How to monitor fatigue and prevent overtraining? Good article on this, specifically:

- Monitor resting HR: higher than normal means need of recovery. This was also covered in the Huberman-lab podcast.
- Sore during easy exercises, especially after rest days that used to be ok.