The Causes of Fatigue in Distance Events and How to Combat Them

What is Fatigue?
The inability to maintain or repeat a given level of muscle force production, resulting in an acute impairment of performance.

Causes of Fatigue
- inadequate ATP resynthesis via aerobic metabolism
- acidosis & accumulation of metabolites
- CNS/neuromuscular?
- glycogen depletion/hypoglycemia
- dehydration
  - causes decrease in plasma volume of blood, decreasing stroke volume & cardiac output
- muscle fiber damage
  - results in fewer functioning actin-myosin cross-bridges
- hyperthermia
  - Decreases blood flow to active muscles
  - reduces mitochondrial respiration & ATP regeneration

Inadequate ATP Resynthesis
Improve cardiac performance to increase blood flow to muscles and improve characteristics of aerobic metabolism so that reliance on O2-independent ATP regeneration is delayed.

The 3 Players of Distance Running
Running Economy
O2 cost of maintaining a given pace
VO2 max
maximum volume of O2 consumed per minute
Lactate Threshold
speed above which lactate accumulates & acidosis occurs

VO2 max
- Maximum volume of oxygen muscles consume per minute (maximum rate of oxygen consumption).
- Most often measured variable in exercise physiology.
- Expressed as liters/min or ml/kg/min.
- Although a high VO2 max alone is not enough to attain elite-level performance, it gains one access into the club. An athlete simply cannot attain a high level of performance without a high VO2 max.
- Largely genetically determined.
- Males have higher VO2 max than females, primarily due to differences in cardiac output and blood hemoglobin concentration.
What Determines VO2max?

- **Cardiac output & blood flow (central factors)**
  - Cardiac output dependent on:
    - stroke volume
    - heart rate
  - Stroke volume determined by:
    - venous return
    - heart contractility
    - amount of pressure in left ventricle (preload)
    - amount of pressure in aorta (afterload)
    - size of left ventricle

- **Blood flow dependent on:**
  - redistribution of blood away from other tissues & to active muscles
  - resistance of blood flow through blood vessels
  - adequate dilation of blood vessels, which depends on interplay between sympathetic & parasympathetic nervous systems & associated hormones
  - O2 transport capacity of blood, which is determined by red blood cell volume & amount of hemoglobin, which transports O2 in blood
  - amount of myoglobin, which transports O2 in muscles
  - density & volume of capillaries that perfuse muscle fibers, which determines time available for diffusion into muscle mitochondria

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Fick Equation

\[ \text{VO2} = \text{SV} \times \text{HR} \times (\text{a-v O2 difference}) \]
\[ \text{VO2} = \text{CO} \times (\text{a-v O2 difference}) \]

VO2max occurs when SV, HR (and therefore cardiac output), & a-v O2 difference are at maximum.

Central vs. Peripheral Limitation?

- Unfit people seem to be equally limited by central & peripheral factors (they lack both high blood flow & abundant metabolic machinery)
- Highly trained endurance athletes are more centrally limited.
- Training causes a shift of limitation on sliding scale—the more fit you become, the more you move away from a metabolic limitation to VO2max and the closer you move to an O2 supply limitation.
- Progressive increases in mileage improve VO2max by increasing muscles' metabolic capacity. Once you have achieved a high level of mileage, intensity of training becomes more important to increase cardiac factors responsible for maximizing O2 supply to muscles.

VO2max Intervals

Provides greatest cardiovascular load because you repeatedly reach & sustain maximum stroke volume, cardiac output, & VO2max during work periods.

**Purposes:**
- Increase max SV, max CO, & VO2max
  - the higher the VO2max, the higher the aerobic ceiling

**Recommendations:**
- 3-5 min work periods with 1:≤1 work-to-rest ratio
- (short intervals with very short, active recovery periods)
**Work Periods**

VO2max (HRmax)

**Recovery Periods**

Reps

**VO2max Pace**

- Running velocity that elicits VO2max (vVO2max)
- Fastest speed that can be maintained for ~7-10 min
- 95-100% max HR
- Slower/recreational runners:
  - 1- to 1½-mile race pace
- Highly-trained/competitive runners:
  - 3K (2-mile) race pace

**Training VO2max**

- While short intervals can improve VO2max, long intervals run at 95-100% VO2max are most potent stimulus.
- The more highly-trained the athlete, the more important intensity becomes to improve VO2max.
- The more aerobically fit the athlete, the faster the recovery both within & between interval workouts, which 1) allows athlete to complete more reps during each workout, thus enabling him/her to spend more time at vVO2max, & 2) allows athlete to run interval workouts more often.

**VO2max Interval Workouts**

- 4 x 1,000 meters @ vVO2max with a 1:≤1 work:rest ratio
- 6 x 800 meters @ vVO2max with a 1:≤1 work:rest ratio
- 16 x 400 meters @ vVO2max with a 1:<1 work:rest ratio

If you can run 1½ miles in 10:00 (= 6:40 mile pace):
- 4 x 1,000 meters in 4:10 with 3:00 jog recovery
- 6 x 800 meters in 3:20 with 2:30-3:00 jog recovery
- 16 x 400 meters in 1:40 with :50 jog recovery

Although tempting to run faster when intervals are shorter, pace should be same for all 3 workouts since goal is same—to improve VO2max. As you progress, make workouts harder by adding more reps or decreasing recovery period rather than by running faster. Only increase speed of intervals once races have shown that you are indeed faster.

**LT Pace**

- Slower/recreational runners:
  - 10-15 sec/mile slower than 5K race pace (or ~10K race pace)
  - 75-80% max HR
- Highly-trained/competitive runners:
  - 25-30 sec/mile slower than 5K race pace (or 15-20 sec/mile slower than 10K race pace)
  - 85-90% max HR
- Subjectively feel “comfortably hard”

**LT Workouts**

**Continuous LT Runs**

3-4 miles up to 7-8 miles (or ~45 min)

**LT Intervals**

intervals @ LT pace with short rest periods
- 4 x 1 mile @ LT pace w/ 1 min rest

**LT+ Intervals**

short intervals @ slightly faster than LT pace with very short rest periods
- 2 sets of 4 x 1,000 meters @ 10 sec/mile faster than LT pace w/ 45 sec rest & 2 min rest between sets

**LT/LSD Combo Run**

medium-long runs with portion @ LT pace
- 12-16 miles w/ last 2-4 miles @ LT pace
- 2 miles + 3 miles @ LT pace + 6 miles + 3 miles @ LT pace
Training Lactate Threshold

- Best stimulus to improve LT is continuous or interval-type training performed at, or slightly faster than, current LT pace.
- Among hardest types of workouts for runners to do correctly, so monitoring by coach is essential.
- LT training is the best aerobic bang for your buck.
- LT training makes what was an anaerobic intensity before now high aerobic.
- The longer the race, the more important it is to train LT.

Training Running Economy

- High mileage (>70 miles per week) seems to improve running economy.
- Optimized biomechanics
- Hypertrophy of Type I skeletal muscle fibers
- Greater skeletal muscle mitochondrial & capillary volumes
- Greater ability for tendons to store & utilize elastic energy
- Lower body mass
- Optimized motor unit recruitment patterns gained from countless repetitions of running movements

Training Running Economy

- Higher intensity training (e.g., intervals & tempo runs) has been shown to improve economy.

Franch et al. (1998):
- 3.1% sig. improvement following tempo running (20-30 min @ 90% max HR, 3 x wk for 6 wks)
- 3.0% sig. improvement following long intervals (4-6 x 4:00 w/2:00 rest)
- 0.9% non-sig. improvement following short intervals (30-40 x 15 sec. w/15 sec. rest)

Training Running Economy

- Improved economy may be most significant attribute gained from running high mileage.
- Adding long intervals to baseline mileage can improve economy.
- Because runners are most economical at speed at which they train the most, they should spend time training at race pace to improve economy at race pace.
- Heavy strength training & plyometrics improve economy, possibly by neural mechanism.
Muscle Morphology

**Fiber Type**

<table>
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<tr>
<th>Type I</th>
<th>Type IIA</th>
<th>Type IIB</th>
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<tbody>
<tr>
<td>Slow-Twitch</td>
<td>Fast-Twitch A</td>
<td>Fast-Twitch B</td>
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1. Change characteristics of each fiber type
2. Change area taken up by fiber type
3. Conversion of fiber types?
   - Increasing % of ST fibers would increase aerobic power & capacity because ST fibers contain more mitochondria & aerobic enzymes.

We combat fatigue by making muscles act as much like ST fibers as we can by causing 1, 2, &/or 3.

**Acidosis/Metabolite Accumulation**

Workouts that use anaerobic glycolysis as predominant energy system and repeatedly cause acidosis to improve acidosis tolerance, muscle buffering capacity, and anaerobic capacity.

**Training Anaerobic Capacity**

**Examples of Workouts**

- Intervals from 45 seconds to ~2 min (300-800 meters) w/ either short or long recovery
  - short recovery keeps acidosis level high throughout workout
  - long recovery allows for even greater degree of acidosis
  - 6-8 x 400 meters @ mile race pace w/1:1 work:rest ratio
  - 2 sets of 5 x 300 meters @ 800m race pace w/1:2 work:rest ratio & 5:00 between sets

\[
\text{H}^+ + \text{HCO}_3^- \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{CO}_2 + \text{H}_2\text{O}
\]

**CNS/Neuromuscular Fatigue**

Power training with weights, sprints, & plyometrics to increase motor unit recruitment & rate of force development.

**Sample Plyometric Program**

To get the most out of plyometric training, try to spend as little time on the ground as possible between Reps/sets/jumps. Perform on a soft surface (grass, track, or gymnastic mat). Begin with two sessions per week of two sets of two repetitions (2 x 2) with full recovery between sets.

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<th>Double leg bound</th>
<th>Alternate leg bound</th>
<th>Squat jumps</th>
<th>Depth jumps</th>
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**Marathon Fatigue**

- **Glycogen Depletion**
  - long runs (>2 hrs) & LT/LSD combo runs to deplete muscle glycogen
  - causes greater synthesis & storage
  - causes greater reliance on fat
  - stimulates liver gluconeogenesis

- Since recovery is closely linked to replenishment of carbohydrates, consume carbs immediately afterward.
Marathon Fatigue

- **Dehydration**
  - drink fluids w/sodium during marathon
- **Muscle Fiber Damage**
  - do long runs on pavement
- **Hyperthermia**
  - acclimatize (~14 days) by running in heat