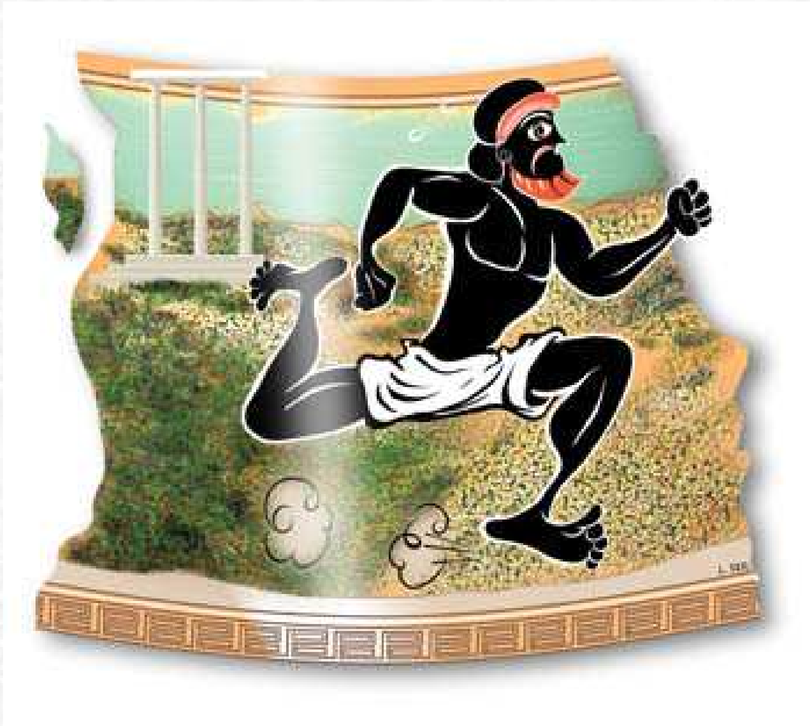
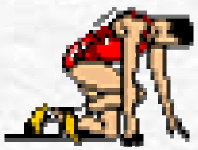
Exercise Physiology



Types of exercise

- Isometric (static) exercise

- Dynamic exercise



- **Aerobic exercise**
- **Anaerobic exercise**

Types of exercise

- **Anaerobic exercise** (sprinting, weight-lifting) – short duration, great intensity (fast-twitch muscle fibers); creatine phosphate + glycogen (glucose) from muscle

$\cancel{O_2}$

- WHITE MUSCLE FIBERS:
  - large in diameter
  - light in color (low myoglobin)
  - surrounded by few capillaries
  - relatively few mitochondria
  - high glycogen content (they have a ready supply of glucose for glycolysis)

Types of exercise

- **Aerobic exercise** (long-distance running, swimming)- prolonged but at lower intensity (slow-twitch mucle fibers) fuels stored in muscle, adipose tissue and liver

- the major fuels used vary with the intensity and duration of exercise (glucose – early, FFA – later)

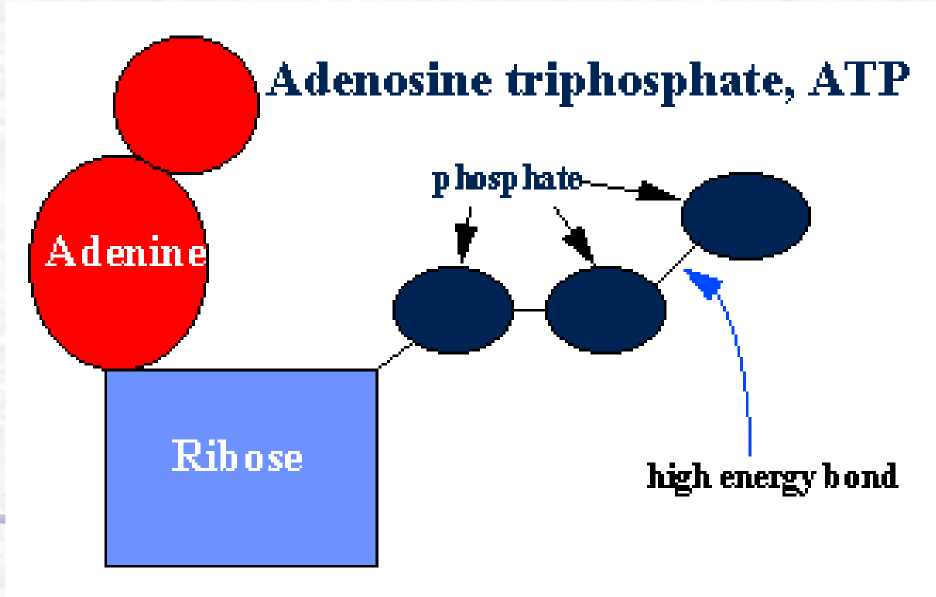
O_2

- RED MUSCLE FIBERS:

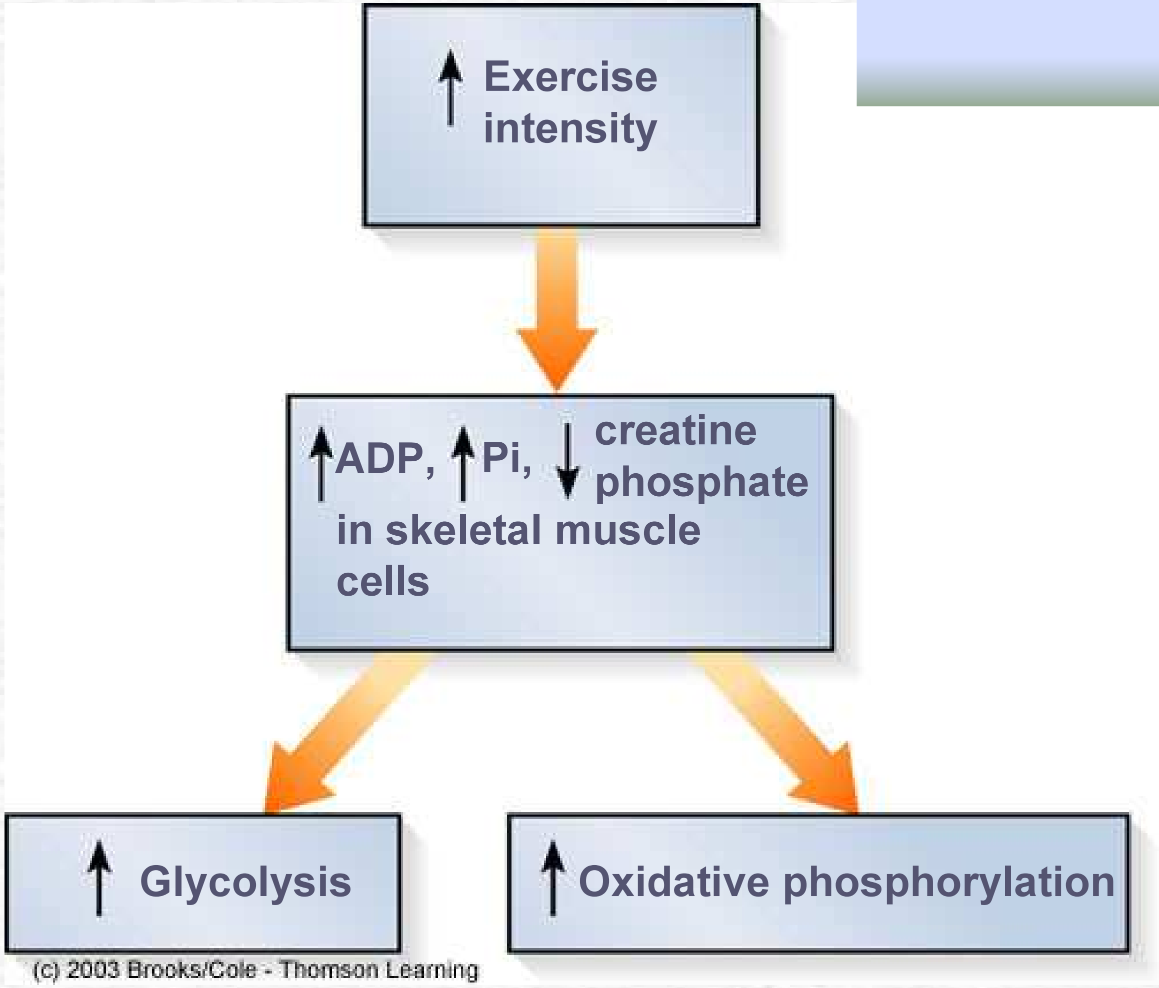
- red in colour (high myoglobin content)
- surrounded by many capillaries
- numerous mitochondria
- low glycogen content (they also metabolize fatty acids and proteins, which are broken down into the acetyl CoA that enters the Krebs cycle)

Why will a sprinter never win against a marathoner in a long distance run?

How do muscle cells obtain the energy to perform exercise?



Muscle metabolism



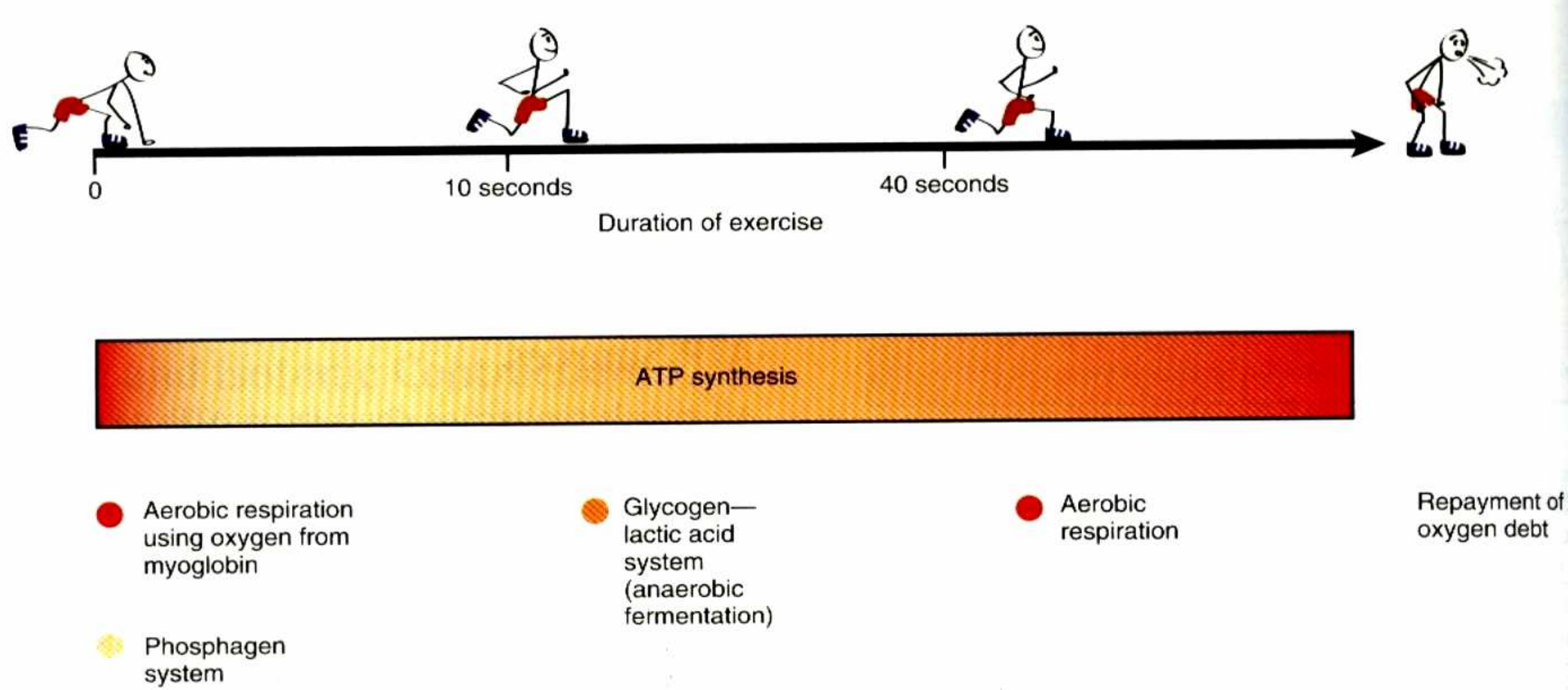
- Low ATP and creatine phosphate stimulate glycolysis and oxidative phosphorylation.
- Exercise can increase rates of ATP formation and breakdown more than tenfold

Creatine phosphate and stored ATP – first few seconds

Glycolysis – after approx. 8-10 seconds

Aerobic respiration – maximum rate after 2-4 min of exercise

Repayment of oxygen debt – lactic acid converted back to pyruvic acid, rephosphorylation of creatine (using ATP from oxidative phosphorylation), glycogen synthesis, O_2 re-binds to myoglobin and Hb)

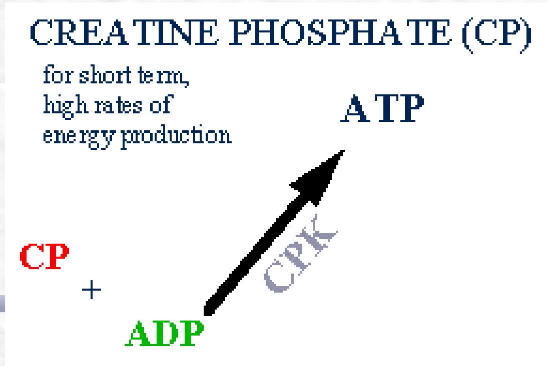


Energy sources during exercise

- ATP and CP – alactic anaerobic source
- Glucose from stored glycogen in the absence of oxygen – lactic anaerobic source
- Glucose, lipids, proteins in the presence of oxygen – aerobic source

Alactic anaerobic source

(for "explosive" sports: *weightlifting, jumping, throwing, 100m running, 50m swimming*)



- immediately available and can't generally be maintained more than 8-10 s
- ATP stored in the muscle is sufficient for about 3 s of maximal effort
- ATP and CP regeneration needs the energy from oxygen source

A quickest man in the world

- **Usain Bolt** (born 21 August 1986) is a Jamaican sprinter who currently holds the **100m** world record with a time of 9.58 sec. *(Berlin 2009)*

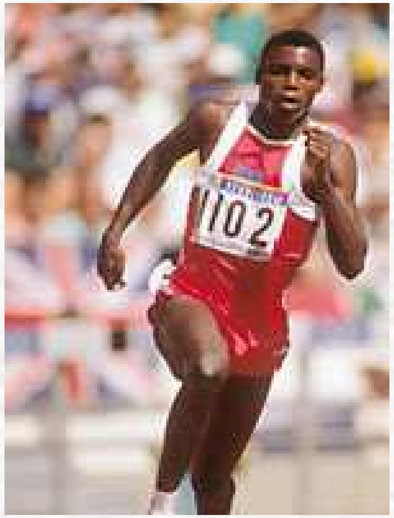
Women's world record 100m

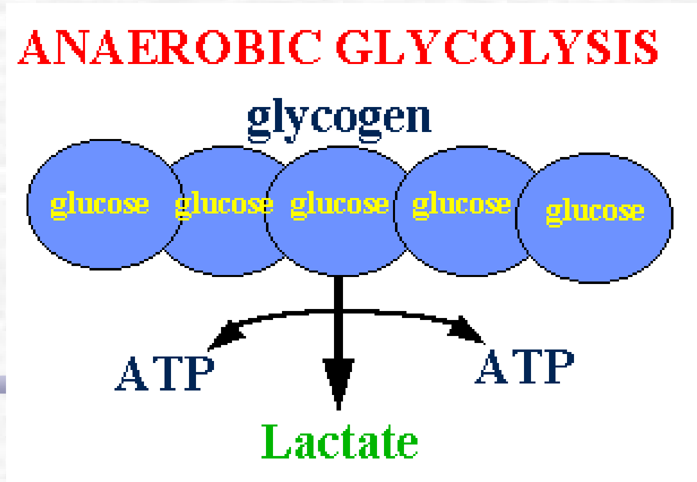
- **Florence Griffith-Joyner** (1959-1998), also known as **Flo-Jo** is world champion in 100m (10.49sec) and 200m (21.34 sec), which still stand as of 2009

The direct cause of death was that she had suffocated in her pillow during a severe epileptic seizure. She was 38 years old.

Lactic anaerobic source

(for "short" intense sports: *gymnastic, 200 to 1000 m running, 100 to 300 m swimming*)





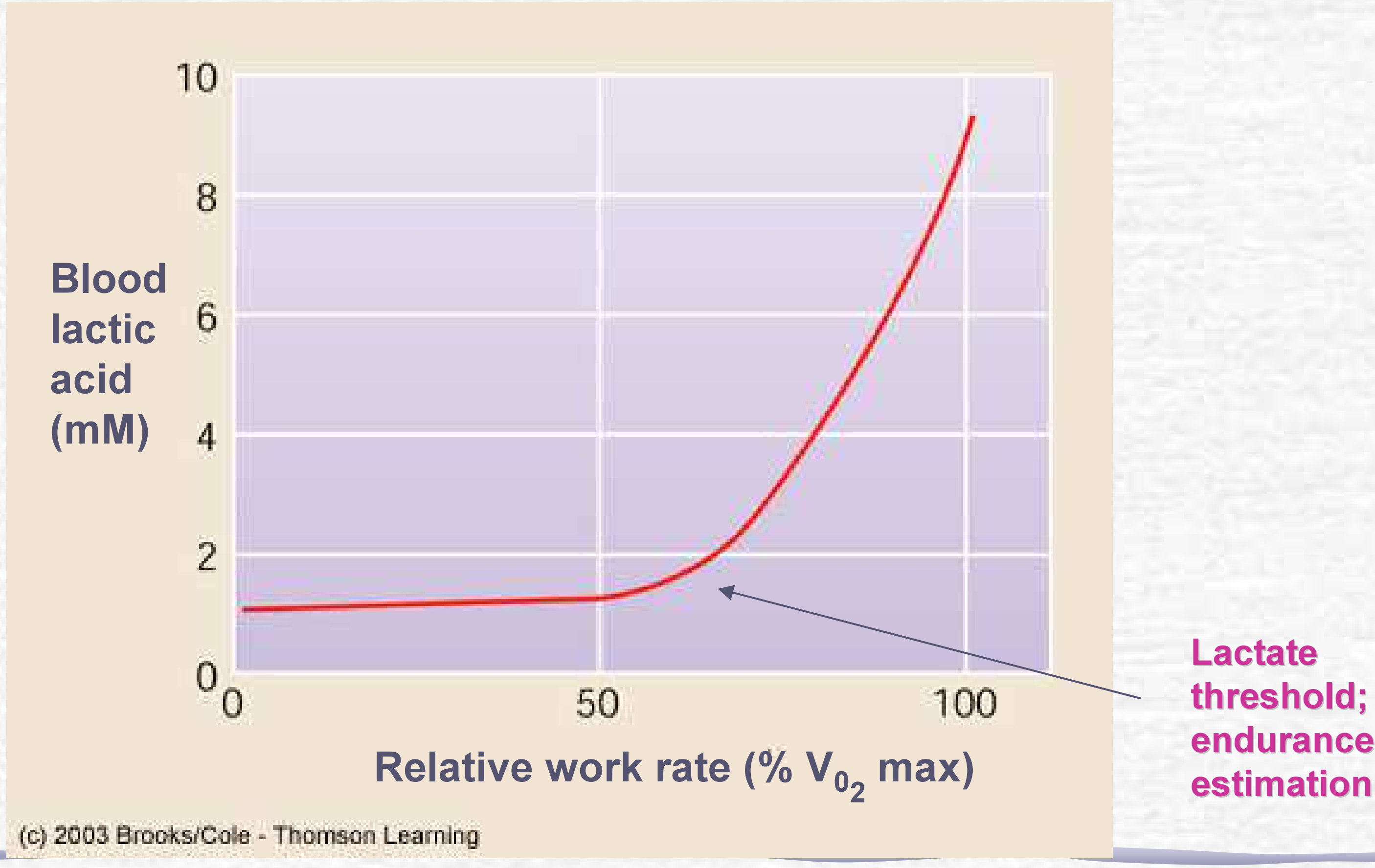
- for less than 2 min of effort
- recovery time after a maximal effort is 1 to 2 h
- medium effort (active recovery) better than passive recovery
- recovery: lactate used for oxidation (muscle) and gluconeogenesis in the liver

Fast exhaustic exercise (eg. sprint)

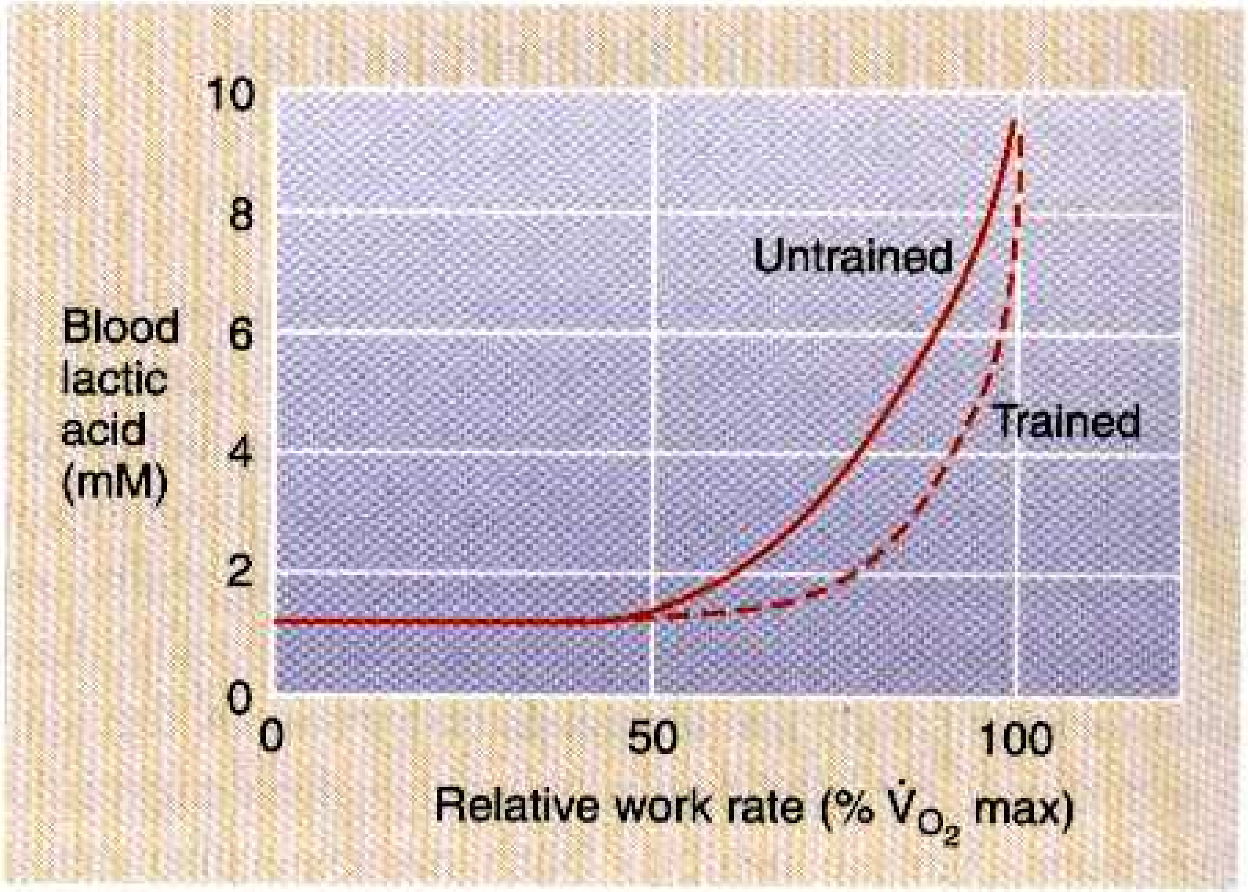
- ↑ in anaerobic glycolysis rate (role of Ca^{2+})
- In the absence of oxygen (anaerobic conditions) muscle is able to work for about 1-2 minutes because of H^+ accumulation and ↓pH;
- Sprinter can resynthesize ATP at the maximum speed of the anaerobic pathway for less than about 60s

\- **Lactic acid** accumulates and one of the rate-controlling enzymes of the glycolytic pathway is strongly inhibited by this acidity

Intense exercise → Glycolysis>aerobic metabolism → ↑ blood lactate (other organs use some)



Training reduces blood lactic acid levels at work rates between approx. 50% and 100% of VO_2max



Muscle fatigue

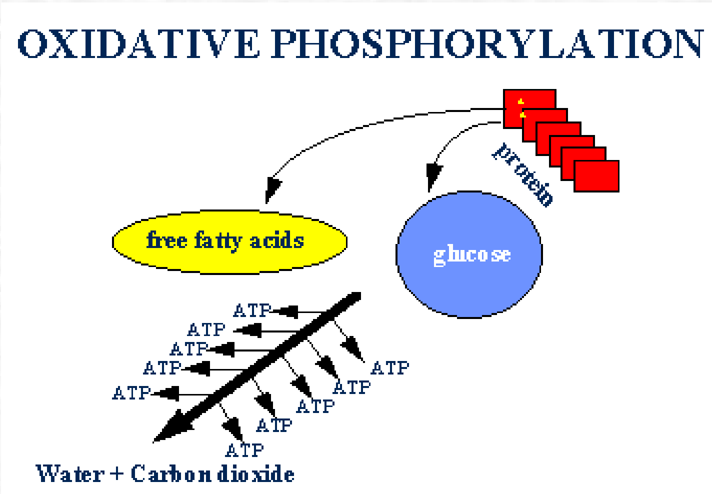
- Lactic acid
- ↓ATP (accumulation of ADP and P_i, and reduction of creatine phosphate) → → ↓ Ca^{++} pumping and release to and from SR→↓ contraction and relaxation
- Ionic imbalances →muscle cell is less responsive to motor neuron stimulation

Lactic acid

- ↓ the rate of ATP hydrolysis,
- ↓ efficiency of glycolytic enzymes,
- ↓Ca^{2+} binding to troponin,
- ↓ interaction between actin and myosin (muscle fatigue)
- during rest is converted back to pyruvic acid and oxidized by skeletal muscle, or converted into glucose (in the liver)

Aerobic source

(for "long" sports;
after 2-4min of exercise)



- recovery time after a maximal effort is 24 to 48 hrs
- carbohydrates (early), lipids (later), and possibly proteins
- *the chief fuel utilization gradually shifts from carbohydrate to fat*
- the key to this adjustment is hormonal (increase in fat-mobilizing hormones)

Which of the energy sources is required for tennis and soccer players?

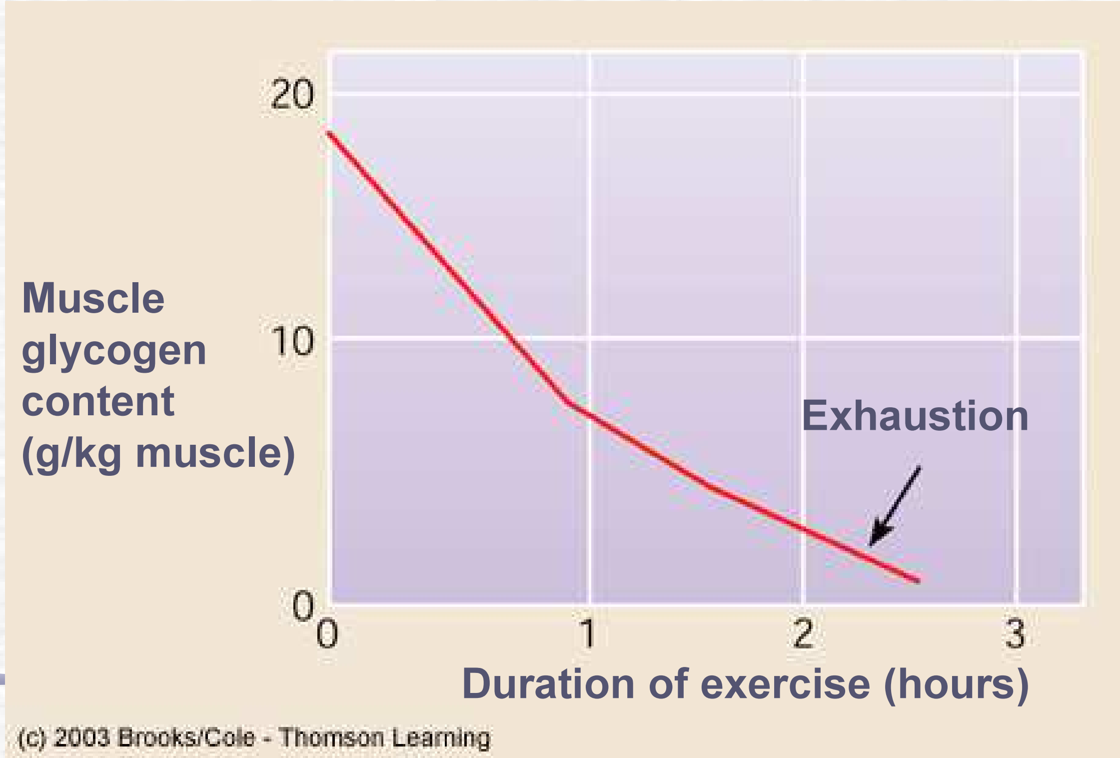
Why oxidation of glucose is so important in an endurance exercise?

The rate of FFA utilization by muscle is limited

- **Oxidation of fat can only support around 60% of the maximal aerobic power output**
- restricted blood flow through adipose tissue
- insufficient albumin to carry FFA
- glucose oxidation limits muscles’ ability to oxidize lipids
- *perhaps the ability to run at high intensity for long periods was not important in terms of the evolution of Homo sapiens (maybe the ability to sprint, to escape from a predator was more important)?*

Prolonged intense work →↑ glycogenolysis → ↑ glycolysis →glycogen depletion →exercise ends (marathon runners describe this as „hitting the wall”)

- circulating glucose cannot be sufficient for high intensity rate of glycolysis
- fat can only support around 60% of maximal aerobic power output

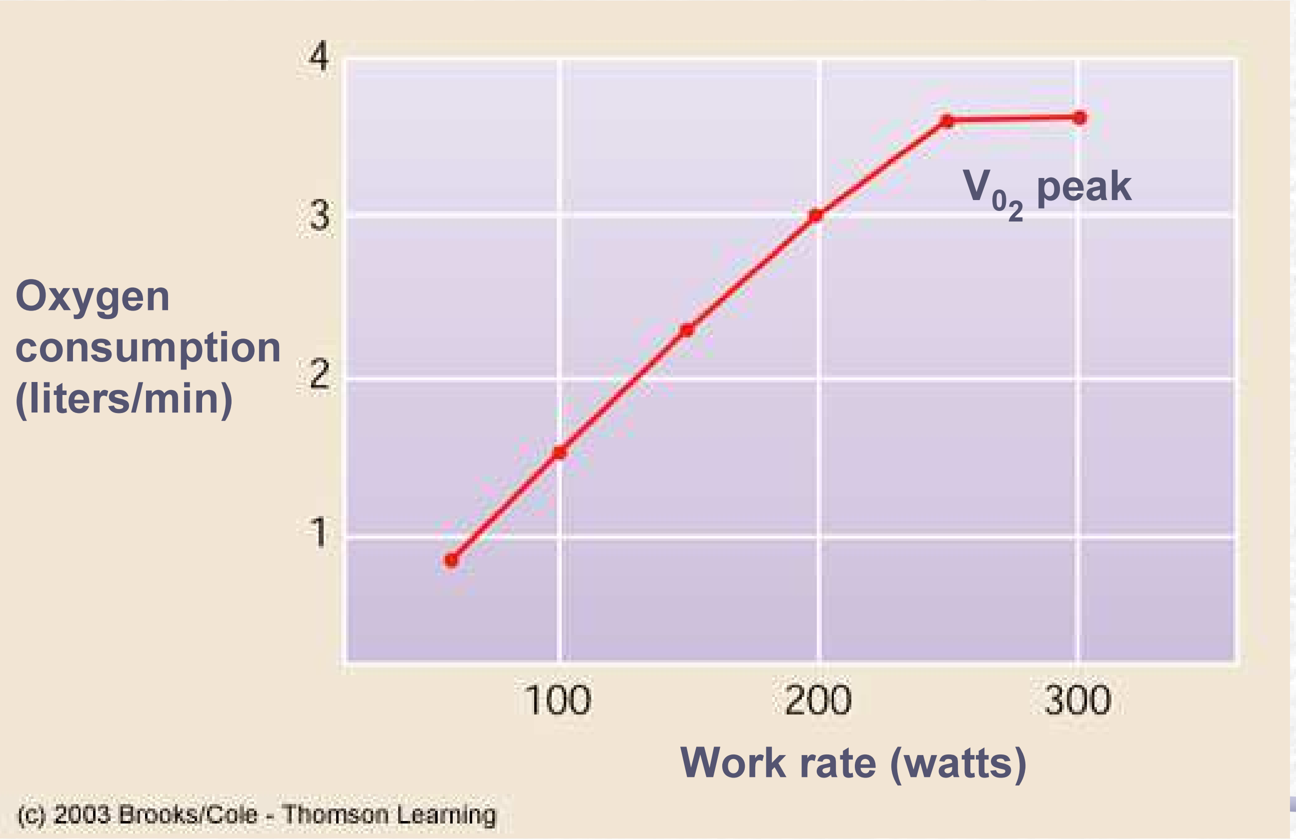


Often the intensity of exercise performed is defined as a percentage of VO_{2max}

- **$\leq$ 50% of Vo_{2max}** – glycogen use less than 50%, FFA use predominate + small amounts of blood glucose
- **>50% of Vo_{2max}** – carbohydrate use increases → glycogen depletion → exhaustion
- **70-80% of Vo_{2max}** – glygogen depletion after 1.5-2 hrs
- **90-100% of Vo_{2max}** – glycogen use is the highest, but depletion does not occur with exhaustion *(↓pH and ↑ of metabolites limit performance)*

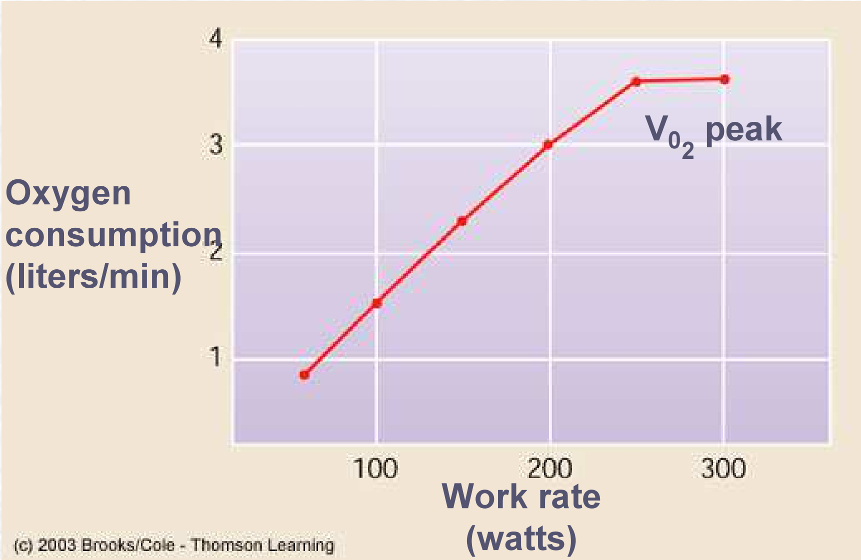
Oxygen consumption during exercise

↑ exercise work → ↑ O_2 usage → Person's max. O_2 consumption (V_{O2max}) reached



- The peak oxygen consumption is influenced by the age, sex, and training level of the person performing the exercise

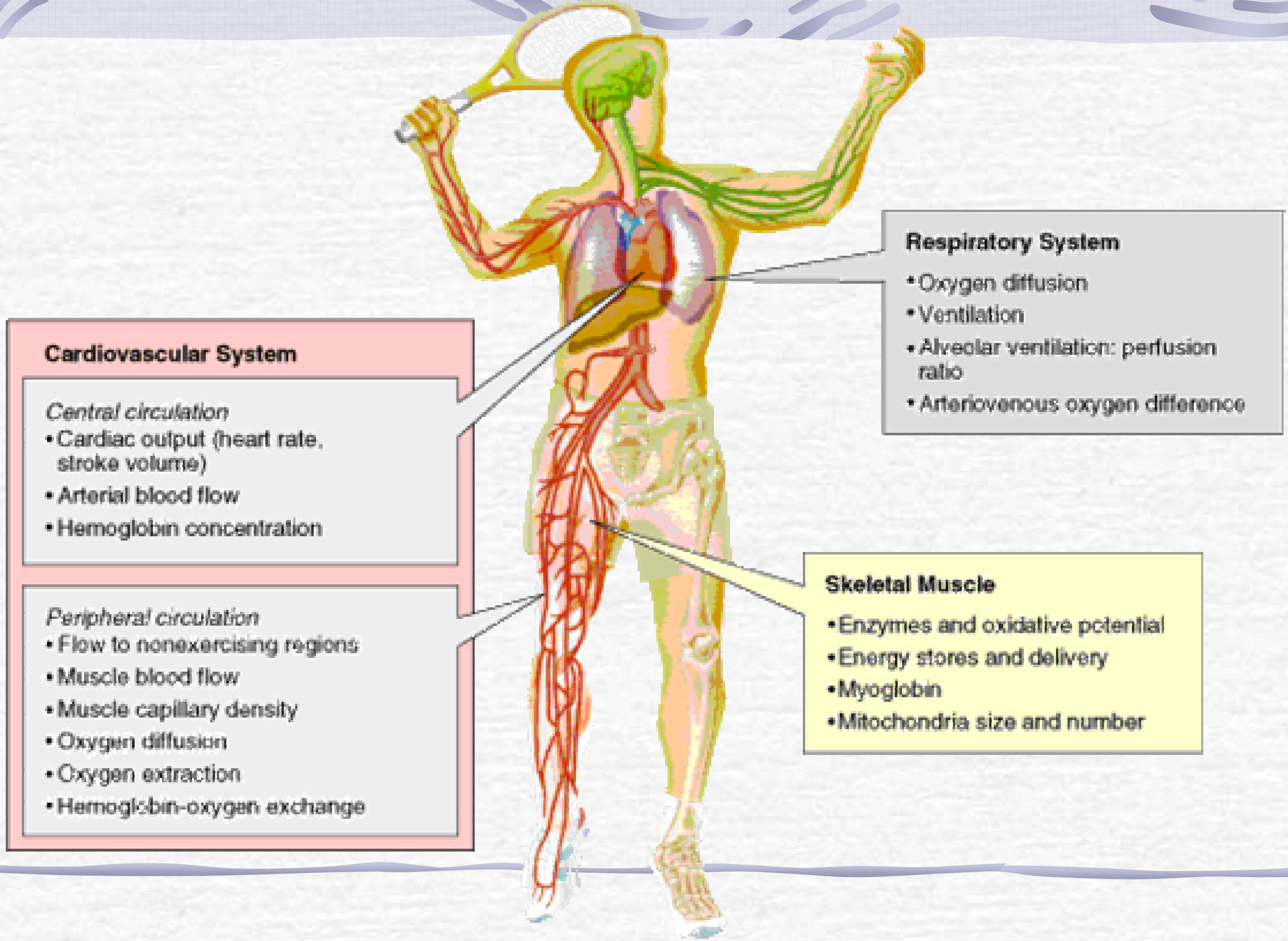
(V_{O2max})



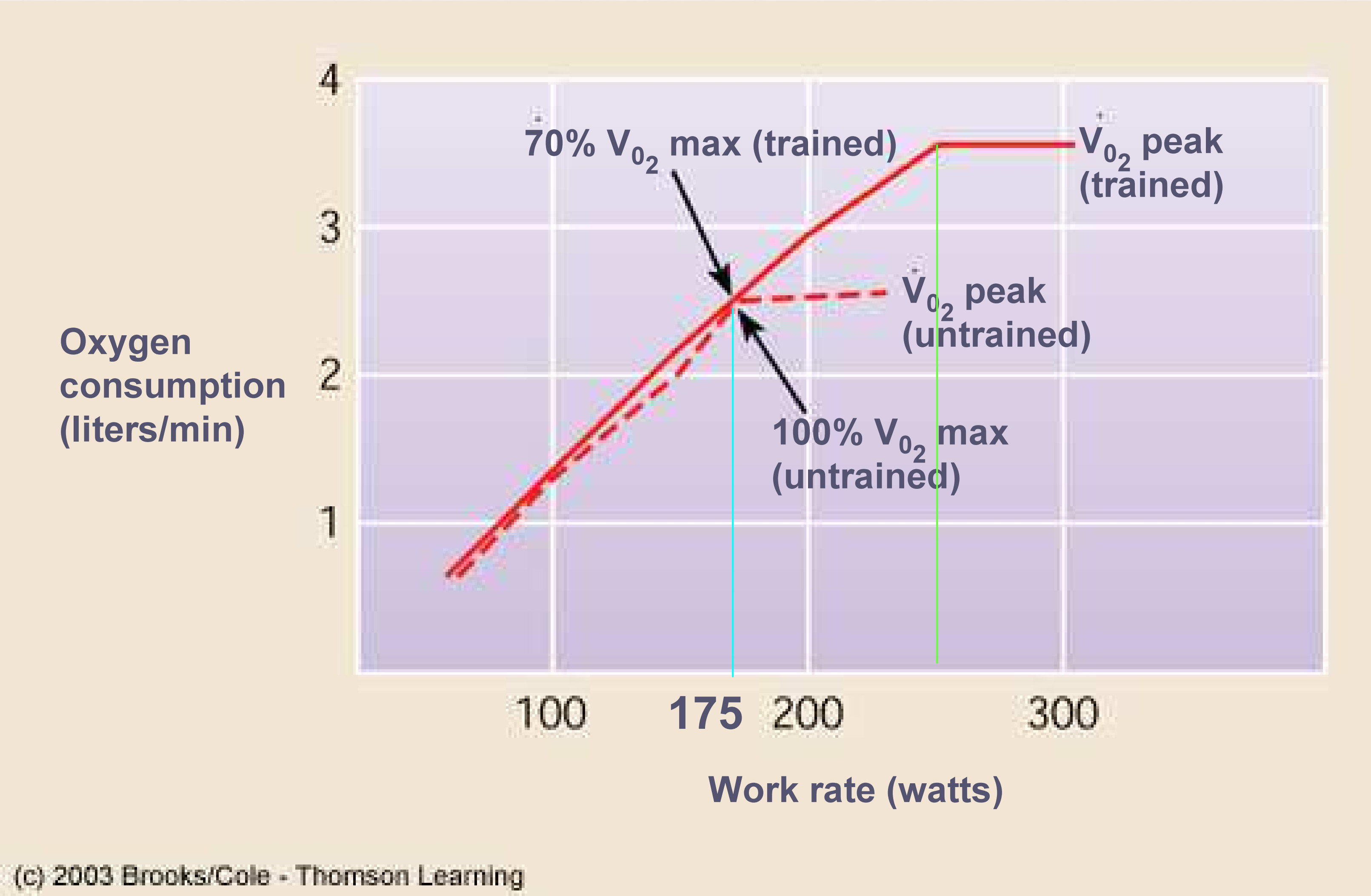
- The plateau in peak oxygen consumption, reached during exercise involving a sufficiently large muscle mass, represents the maximal oxygen consumption

- Maximal oxygen consumption is limited by the ability to deliver O_2 to skeletal muscles and muscle oxidative capacity (mucle mass and mitochondirial enzymes activity).

► Possible Limitation to Maximal Oxygen Consumption



The ability to deliver O_2 to muscles and muscle's oxidative capacity limit a person's V_{O2max}. Training → ↑ V_{O2max}



Cardiorespiratory endurance

- the ability of the heart, lungs and blood vessels to deliver adequate amounts of oxygen to the cells to meet the demands of **prolonged** physical activity
- the greater cardiorespiratory endurance → the greater the amount of work that can be performed without undue fatigue

- the best indicator of the cardiorespiratory endurance is **VO_{2max}** - the maximal amount of oxygen that the human body is able to utilize per minute of strenuous physical activity

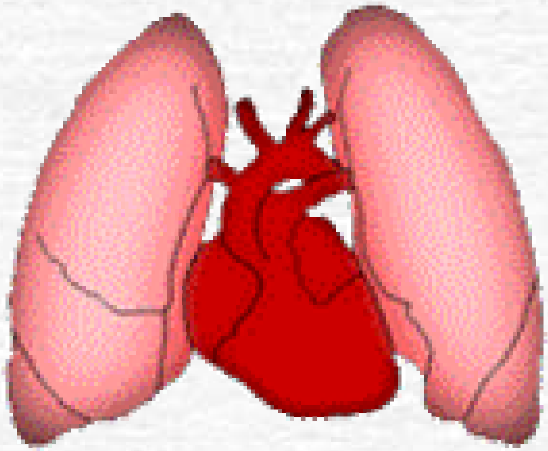
Methods for determination of VO2max

- Direct measuring of volume of air expired and the oxygen and carbon dioxide concentrations of inspired or expired air with computerized instruments

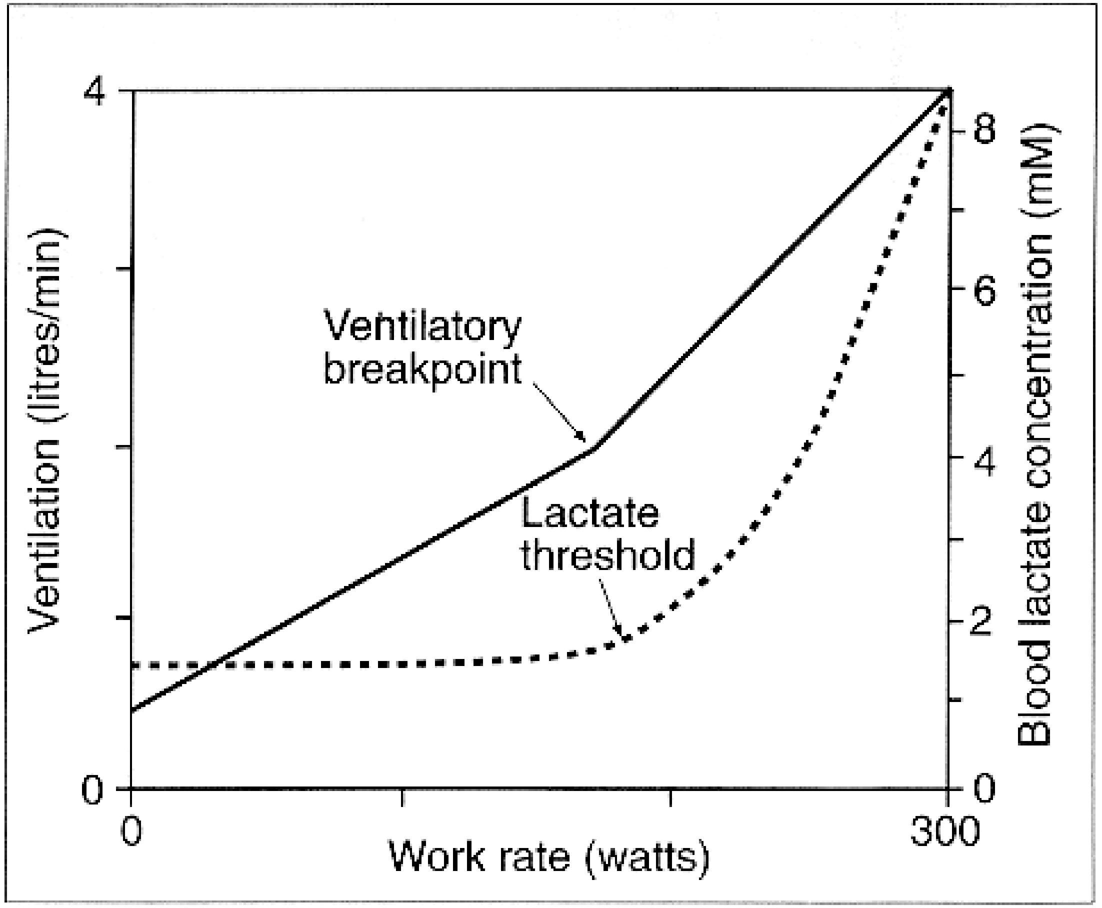
- Submaximal tests (samples):

- step tests, run tests
- stationary bicycle ergometer (Astrand-Ryhming test)
- Physical Work Capacity (PWC 170/150) test

How does the respiratory system respond to exercise?



Respiration during exercise

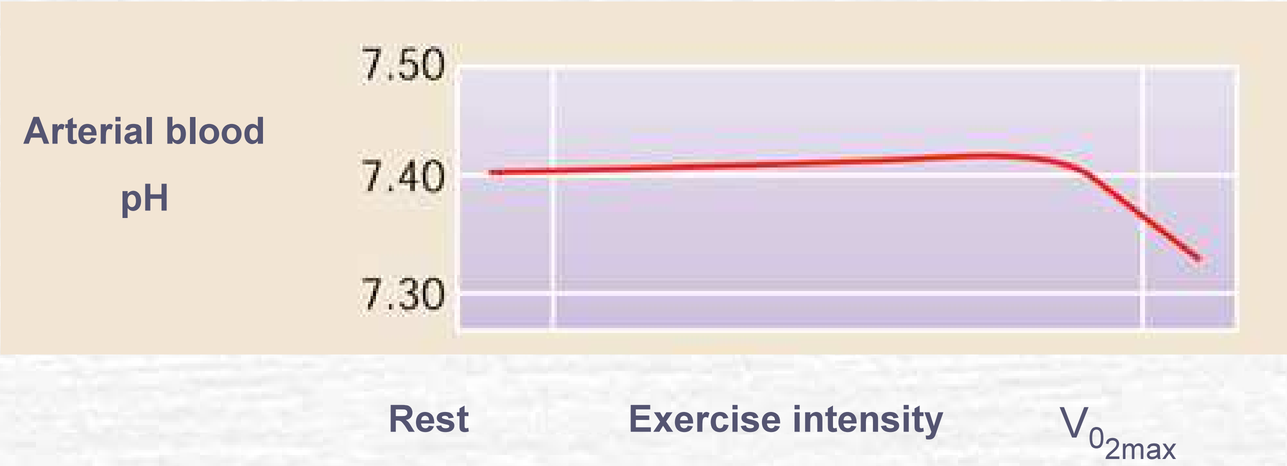


- during dynamic exercise of increasing intensity, ventilation increases linearly over the mild to moderate range, then more rapidly in intense exercise
- the workload at which rapid ventilation occures is called the ventilatory breakpoint (together with lactate threshold)

Lactate acidifies the blood, driving off CO2 and increasing ventilatory rate

Major factors which stimulate increased ventilation during exercise include:

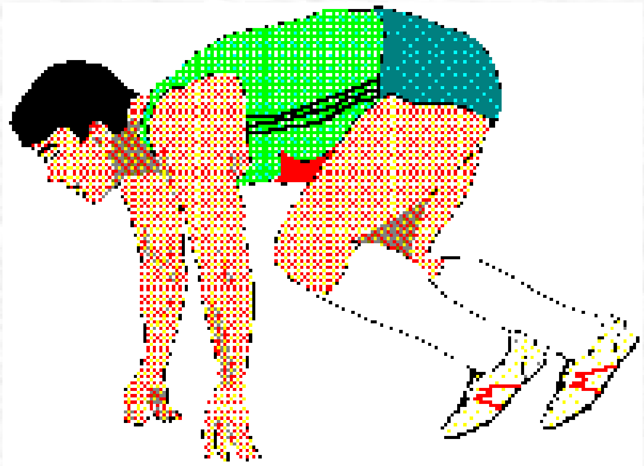
- neural input from the motor areas of the cerebral cortex
- proprioceptors in the muscles and joints
- ↑ body temperature
- circulating NE and E
- pH changes due to lactic acid



It appears that changes in pCO_2 and O_2 **do not** play significant role during exercise

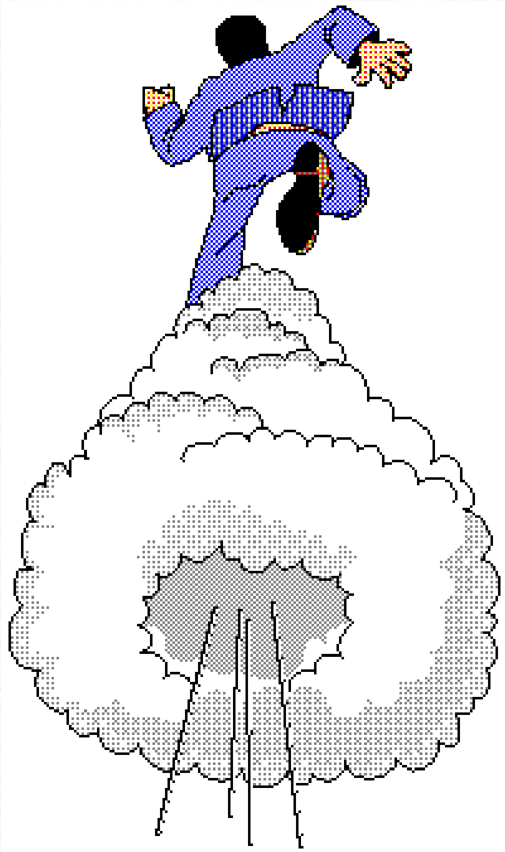
Before expected exercise begins, ventilation rises

- 'emotional hyperventilation'
- at any rate, impulses descending from the **cerebral cortex** are responsible



During the exercise, **stimuli** from the muscles, joints and perhaps such sensory receptors as pressure endings in the feet, contribute to the elevation of ventilation

- so do **chemicals**, originating in the active muscles.
- in **dynamic** exercise, they are carried in the blood to the arterial and medullary **chemoreceptors**, and probably have their main effects there
- in **isometric** efforts the ventilatory drive originates in *chemically sensitive nerve endings*



Recovery and ventilation

- Cessation of muscular effort
- Normal blood K^+ and CO_2 oscillations (2-3 min)
- Decreased acidity (several minutes)
- High temperature

How does the cardiovascular system respond to exercise?

Resting cardiac output is typically ~ 5 l/min.

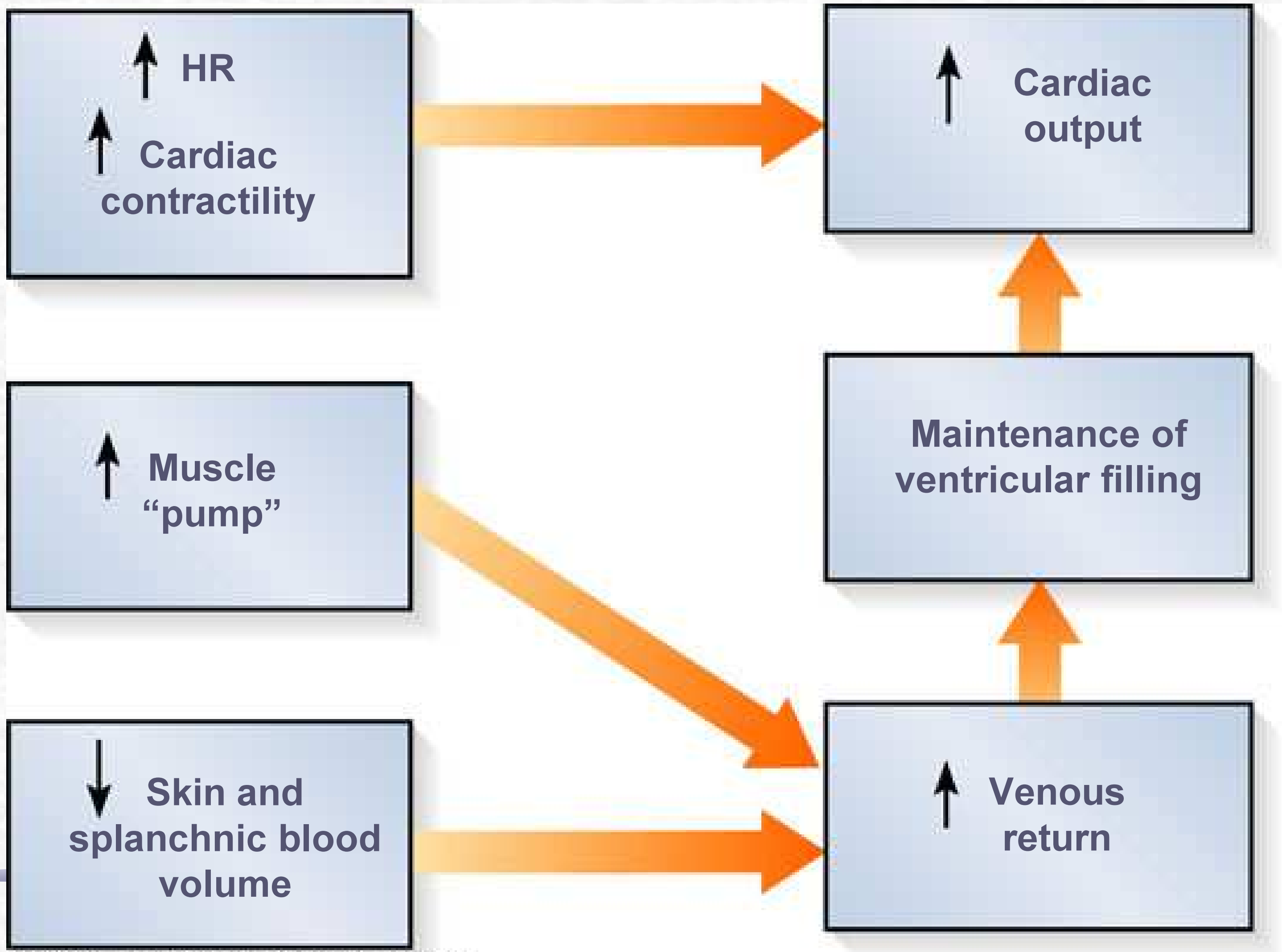
At VO_2max it will be ~ 25 l/min in a healthy but not especially trained young man

~ 35 l/min in a well-trained aerobic athlete, and up to 45 l/min in a ultra-elite performers

Dynamic exercise →

↑ Muscle pump + ↑ symp. vasocon. →

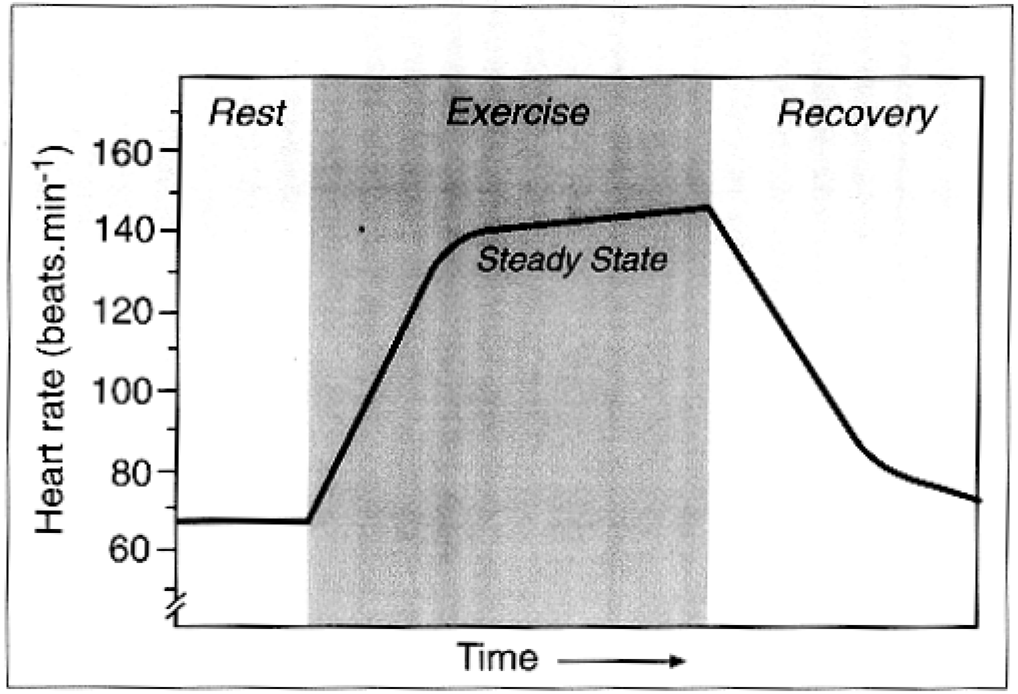
↑ Venous return → ↑ stroke volume → ↑ cardiac output



Cardiac output (CO) increase

- *Increased CO* can be achieved by raising either **stroke volume (SV)** or **heart rate (HR)**
- steady-state **HR rises** essentially linearly with work rate over the whole range from rest to VO_2max :

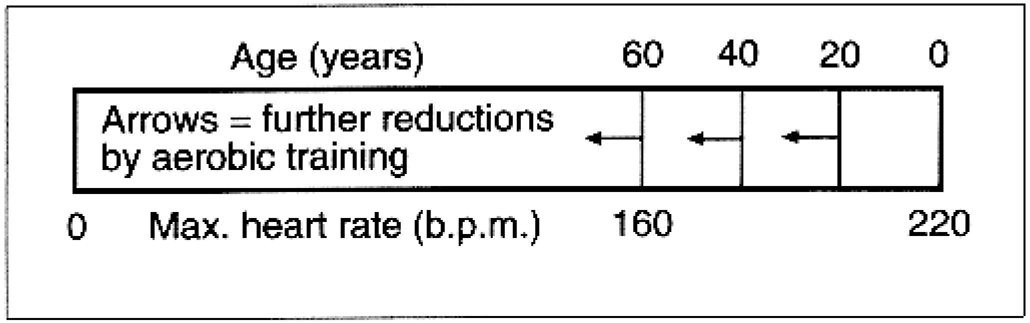
- *increased **sympathetic** and decreased parasympathetic discharge to the cardiac pacemaker* + catecholamines
- *reflex signals from the active muscles*
- *blood-borne metabolites* from these muscles
- *temperature rise*



Heart rate

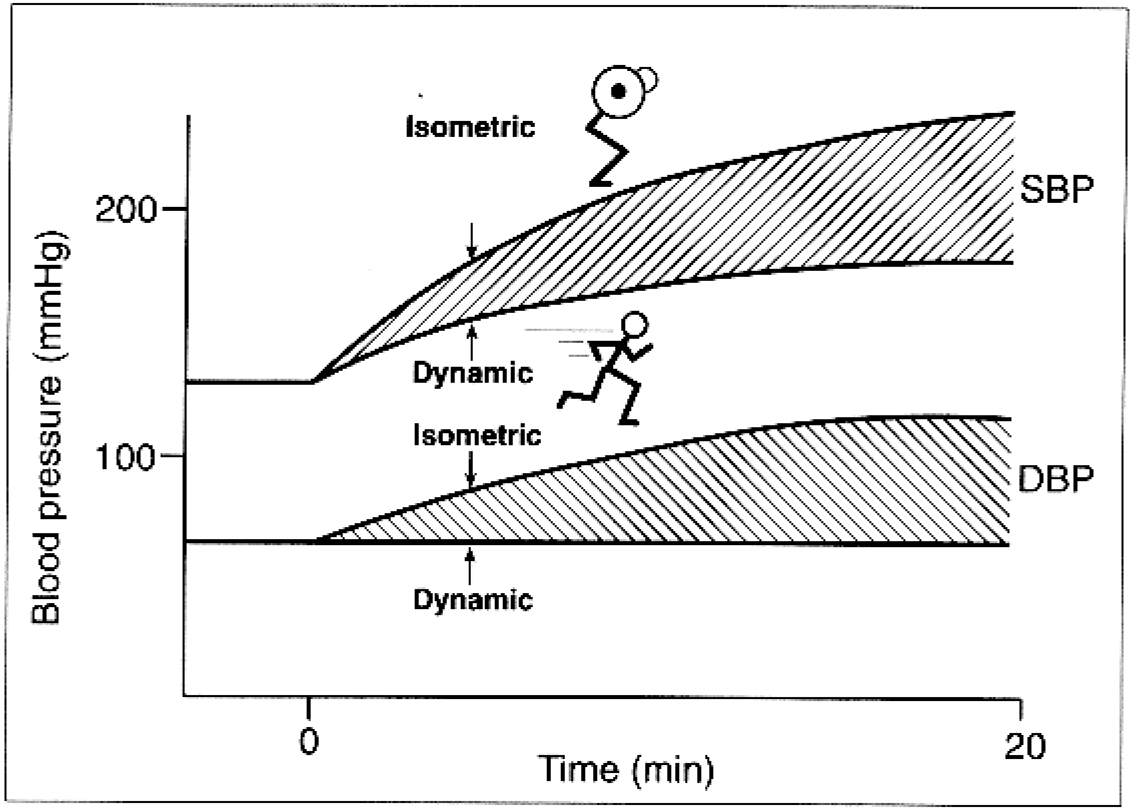
- *Maximum HR* is predicted to within 10 b.p.m., in normal people who are not endurance trained, by the rule:

HR (b.p.m.) = 220 - age



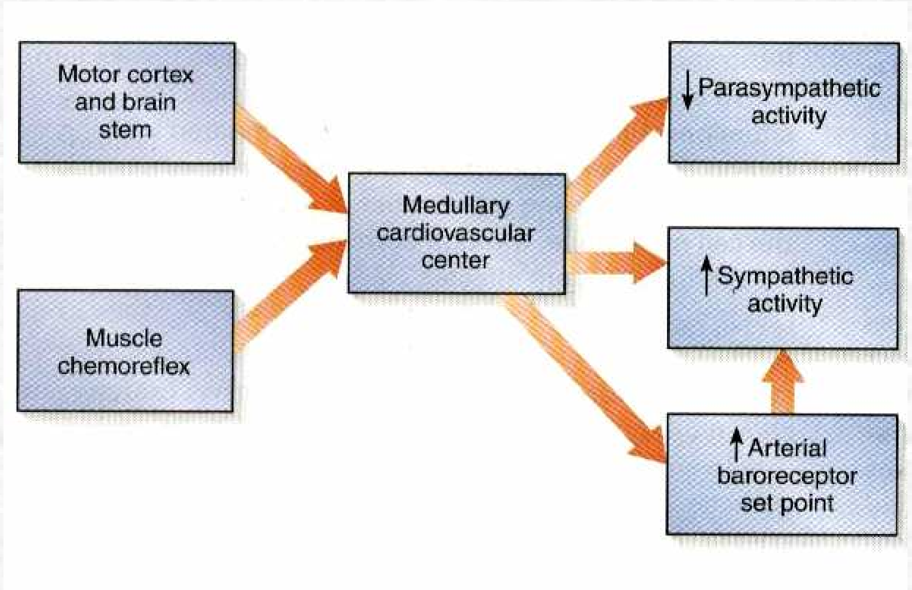
- endurance training, especially if maintained over many years, lowers this maximum by up to 15 b.p.m.
- it also, of course, lowers resting HR

Blood Pressure (BP) also rises in exercise



- systolic pressure **(SBP) goes up to 150-170 mm Hg** during **dynamic exercise**; diastolic scarcely alters
- in **isometric** *(heavy static) exercise, SBP may exceed* ***250*** *mmHg,* and **diastolic** (DBP) *can itself reach* ***180***

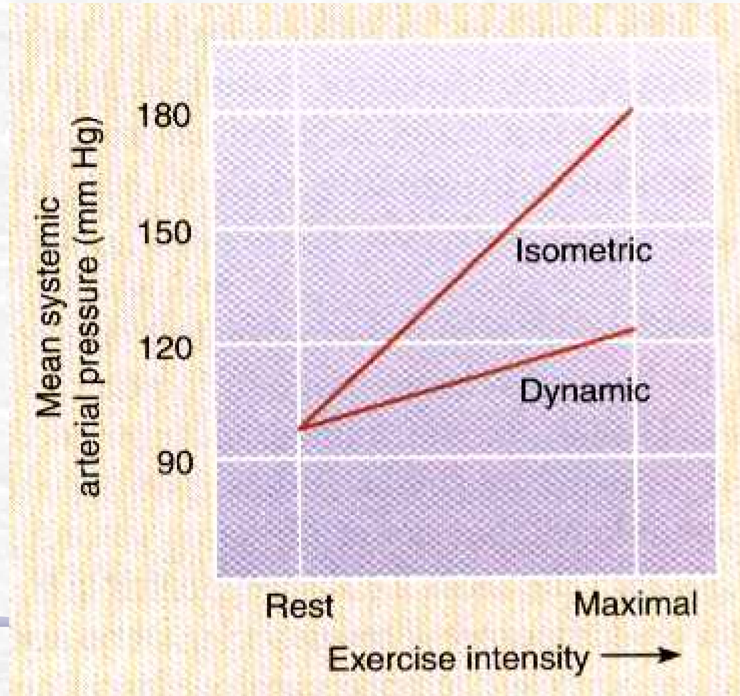
Muscle chemoreflex



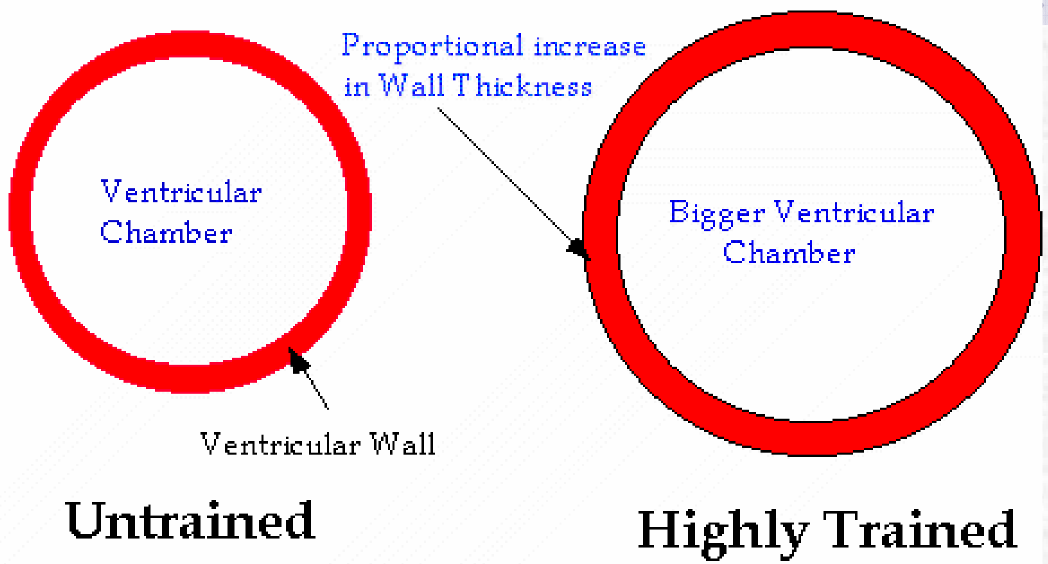
- Heavy exercise →↑ muscle lactate → muscle chemorec. and afferent nerves →medullary cardiovascular center →↑ sympathetic neural outflow→ ↑ HR and cardiac output per minute + vasoconstriction (viscera, kidneys, skeletal muscles) + vasodilation in working skeletal muscles

Cardiovascular response in **isometric** exercise

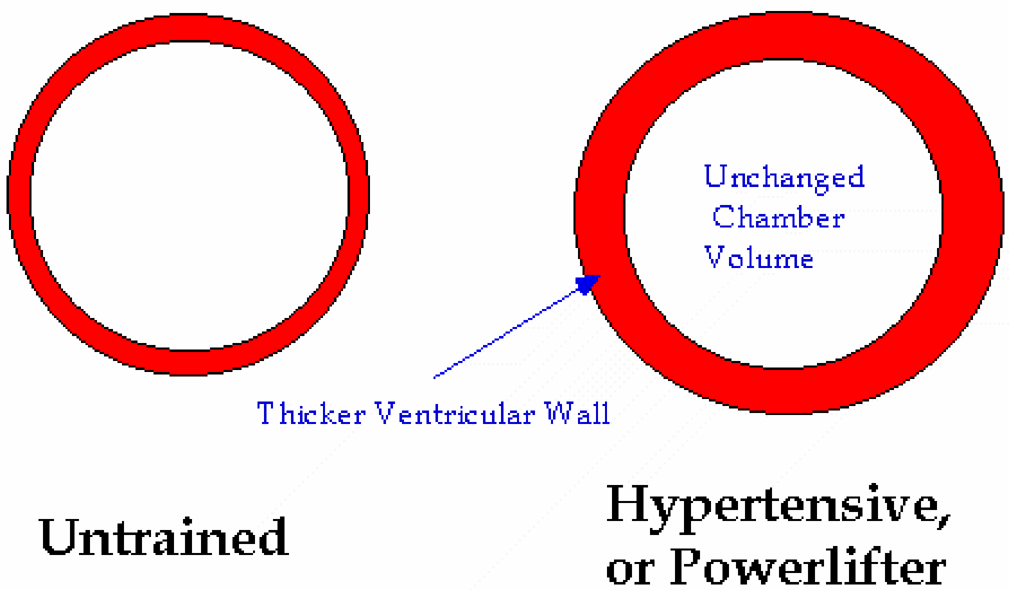
- Compression of intramuscular arteries and veins prevents muscle vasodilation and increased blood flow
- ↓ oxygen delivery causes rapid accumulation of lactic acid – stimulation of muscle chemoreceptors – elevation of baroreceptor set point and sympathetic drive (**muscle chemoreflex**)
- As a result: mean BP is higher (as compared with dynamic exercise)
- **↑ systolic and ↑ diastolic BP**



Heart Dimensions and Training

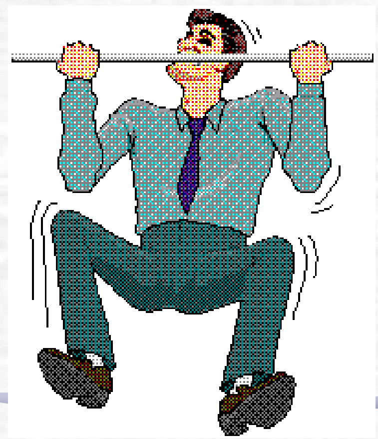


Changes due to Hypertension, or intense strength training



Endurance training

Strength training

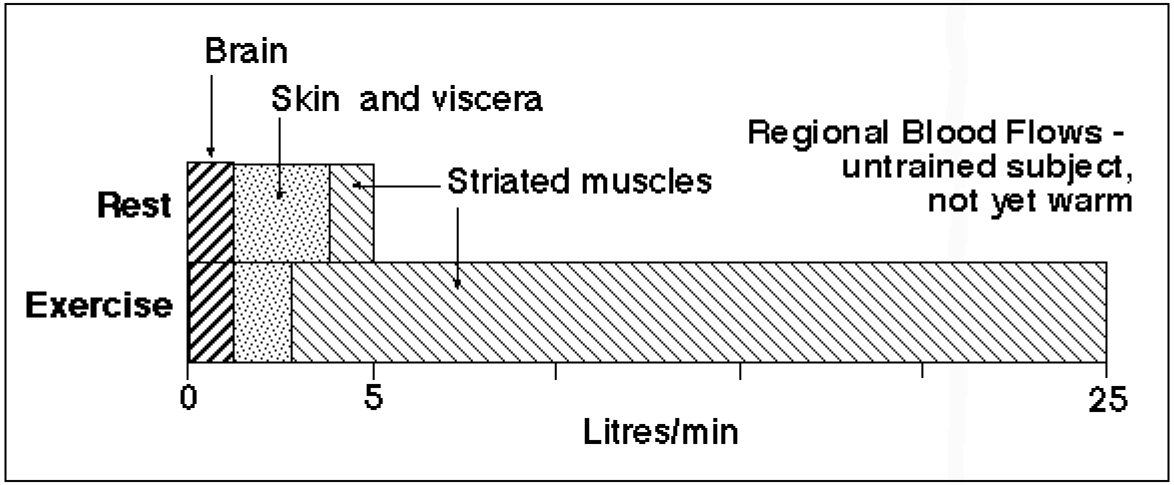


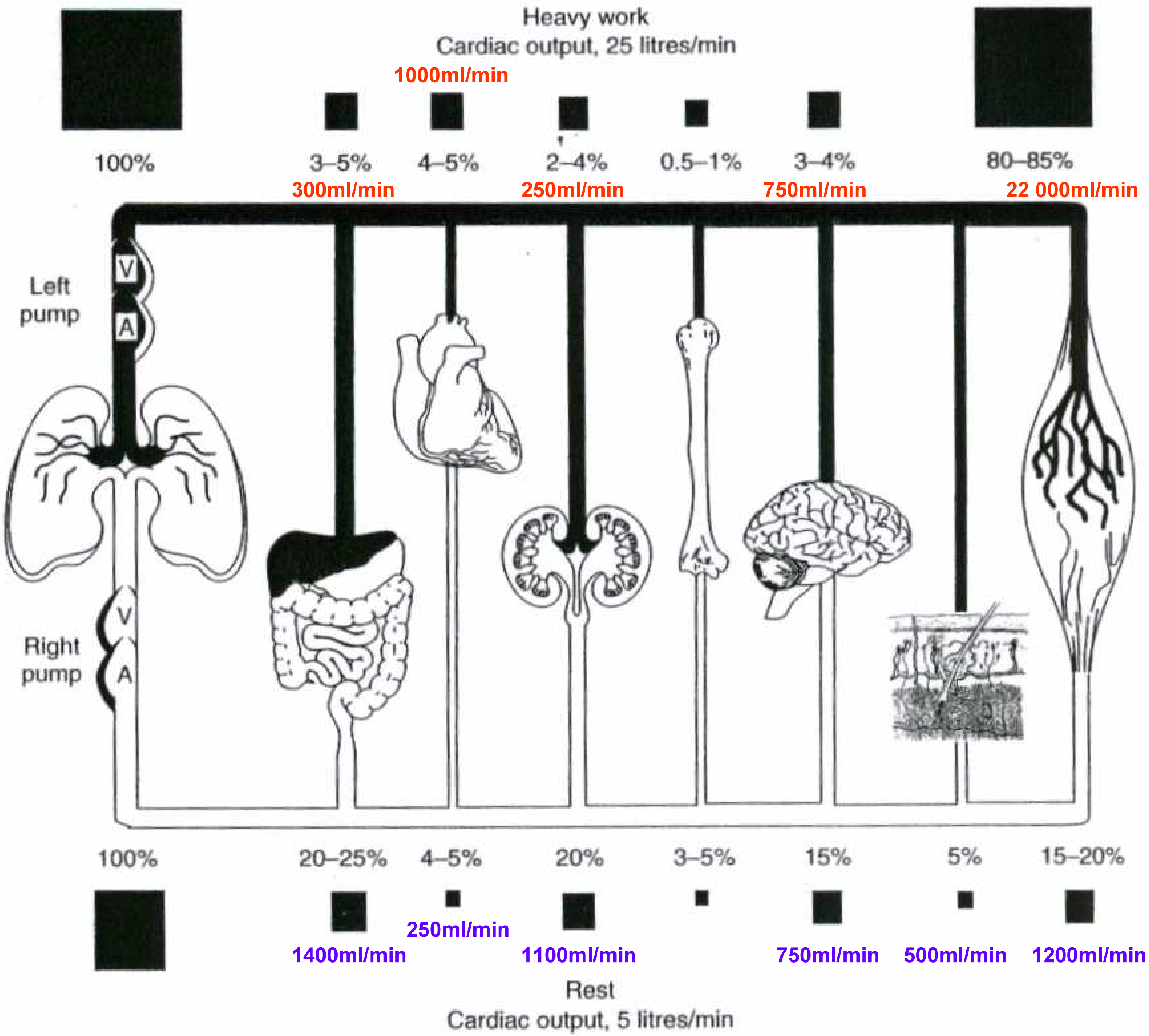
Chronic Effects of Dynamic Exercise

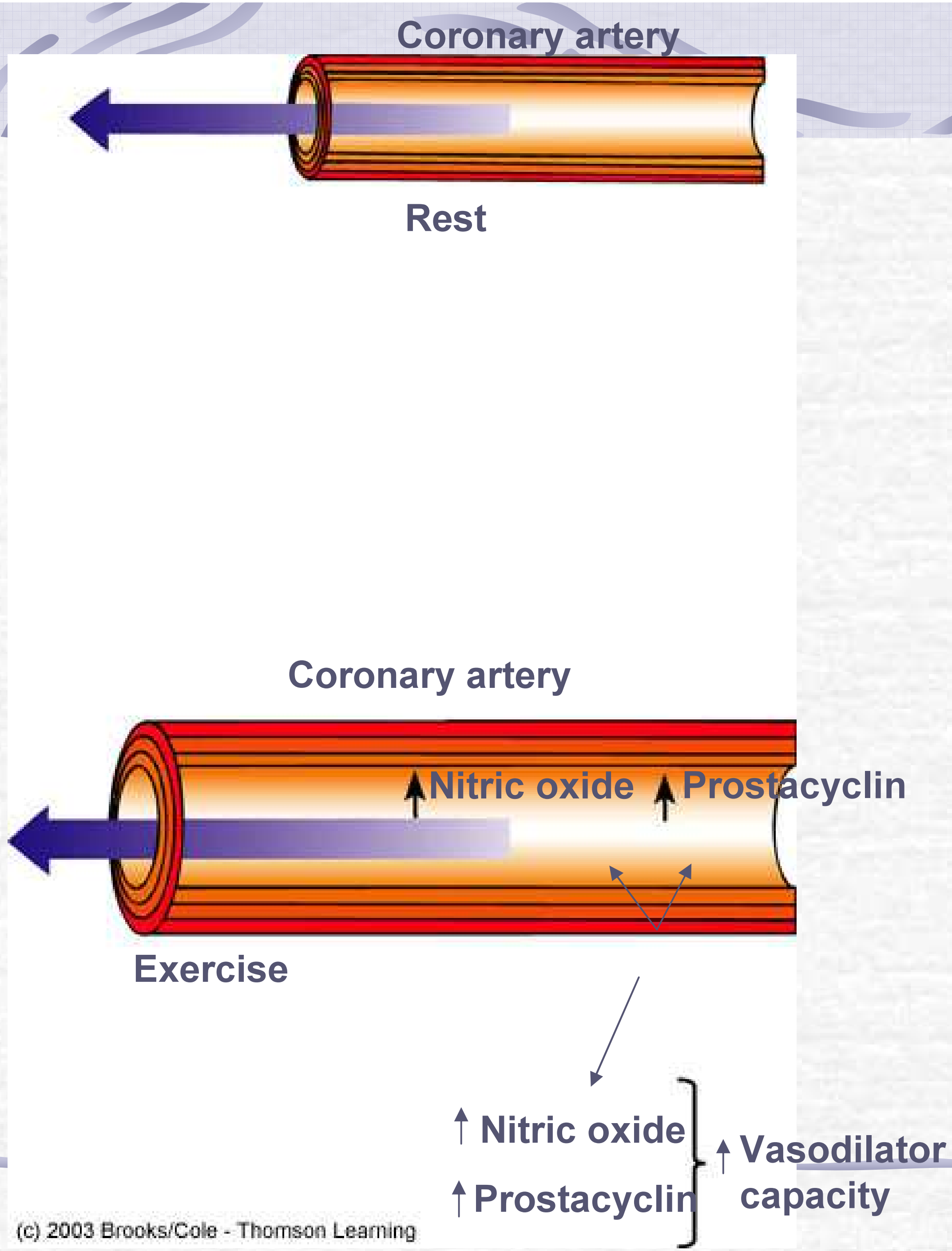
(cardiovascular adaptations to dynamic exercise training)

- Adaptations that increase muscle oxidative capacity and delay lactate production → ↓ muscle chemoreflex influence on cardiovascular system
- As a result sympathetic activity is decreased, which lowers BP and HR (trained people)

Blood flow **redistribution** is achieved partly by sympathetic nerve activity, and partly chemically




Heavy work
Cardiac output, 25 litres/min
1000ml/min
100%
3–5%
4–5%
2–4%
0.5–1%
3–4%
80–85%
300ml/min
250ml/min
750ml/min
22 000ml/min
Left
pump
V
A
Right
pump
V
A
100%
20–25%
4–5%
20%
3–5%
15%
5%
15–20%
250ml/min
1400ml/min
1100ml/min
750ml/min
500ml/min
1200ml/min
Rest
Cardiac output, 5 litres/min



Coronary blood flow

↑ Cardiac output →
↑ Coronary flow (fivefold) →↑ Endothelial cell shear stress →
↑ Endothelial-dependent vasodilation + cholinergic fibers stimulation (sympathetic system)

How do muscle respond to exercise?

Response to chronic moderate exercise

- Increased fatigue resistance is mediated by:

- ↑ muscle capillary density
- ↑ myoglobin content,
- ↑ activity of enzymes (oxidative pathways)
- ↑ oxidative capacity linked to ↑ numbers of mitochondria

- Increased capacity to oxidize FFA shifts the energy source from glucose to fat (to spare glucose)

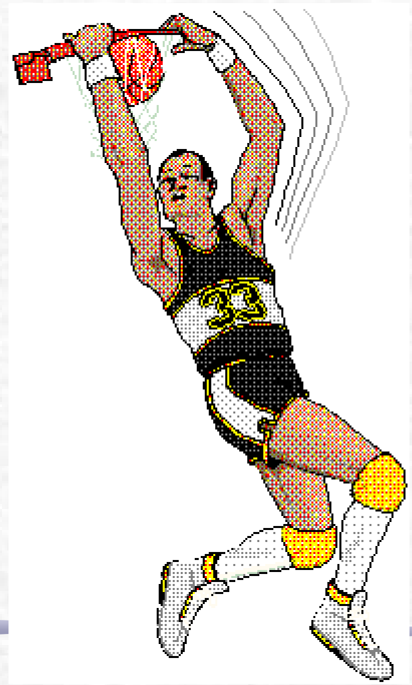
Chronic Effects of Dynamic Exercise

Moderate exercise →

↑ oxidative capacity and fat usage →

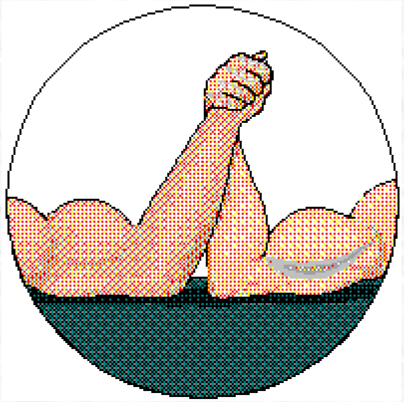
↑ VO_{2max} and endurance →

↓ lactate



Response to high intensity muscle contraction

- ↑ in muscle strength via improvement of motor units recruitment (1-2 weeks of training)
- muscle hypertrophy (↑ of muscle contractile elements)
- no change in oxidative capacity



Hormonal responses during aerobic exercise

Our endocrine system and hormones are key players in managing the body's chemistry

During exercise

If we concentrate on efforts of significant intensity – e.g. 70% VO_2max - lasting not less than 30 min, there's a simple rule: *all hormones rise over time*, ***except insulin***

Norepinephrine rises again ('fight or flight'). *Increases glycogen breakdown and elevates free fatty acids; also cardiovascular effects as in anticipatory phase*

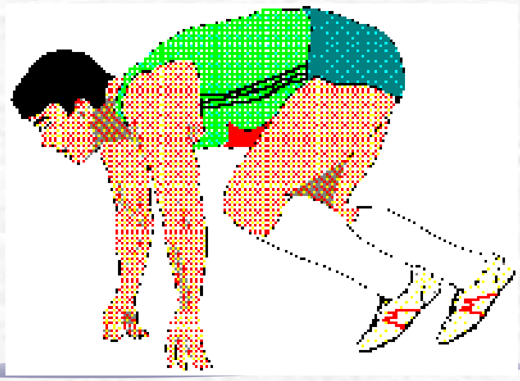
Glucagon rises (to keep up blood sugar). *Increases glucose release from liver*

Cortisol rises (response to the stress). *Increases use of fatty acids, reinforces glucose elevation*

Growth hormone begins to rise (damage repair). *Stimulates tissue repair, enhances fat use instead of glucose*

Anticipating exercise

- **Anticipation** principally involves the catecholamine hormones, particularly **epinephrine** + sympathetic activation



Systemic effects include:

• bronchodilation

• intra muscular vasodilatation

• visceral and skin vasoconstriction

•increased cardiac output

Metabolic effects include:

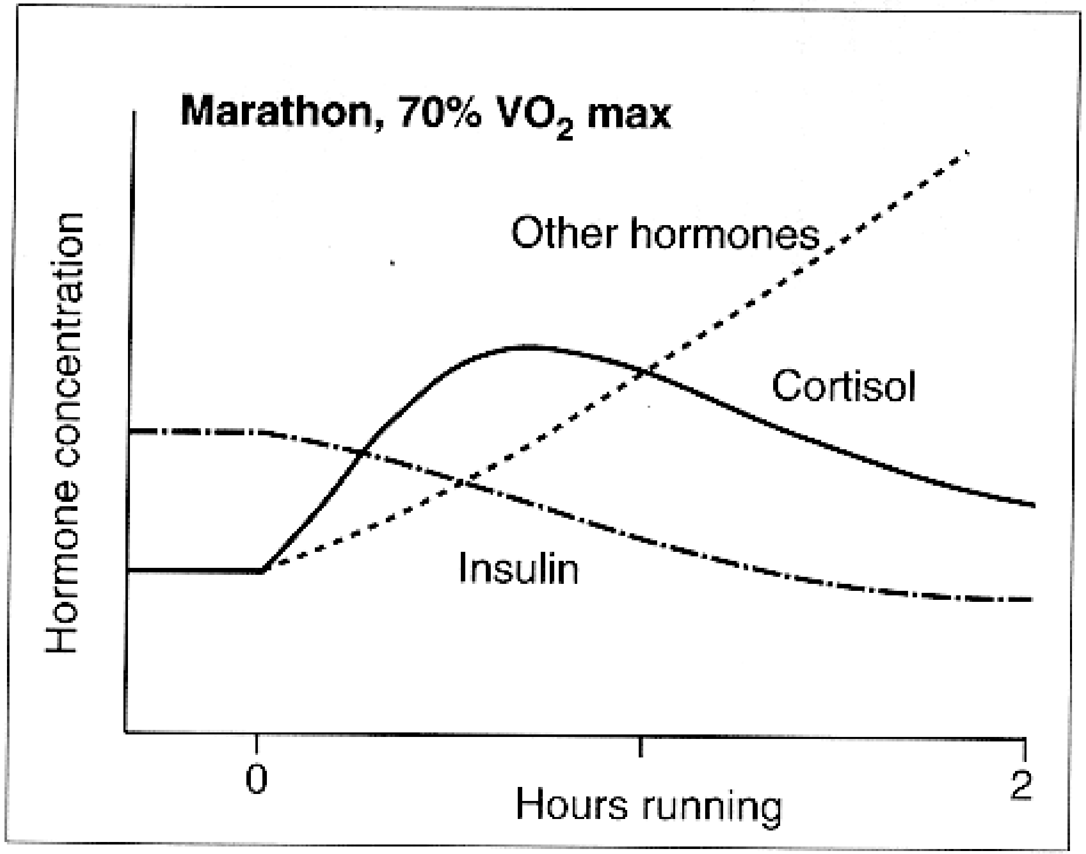
• promotion of glycogenolysis and glycolysis in muscle

• release of glucose from liver

• release of free fatty acids from adipose tissue.

Cortisol's behaviour is particularly complex. In exercise at low intensity (e.g.30% max - an easy jog) some reports indicate that its level falls (such gentle aerobic exercise relieves stress).

When it does rise,
at higher intensities,
it peaks after 30 min,
then falls off again



Other hormones involved in exercise

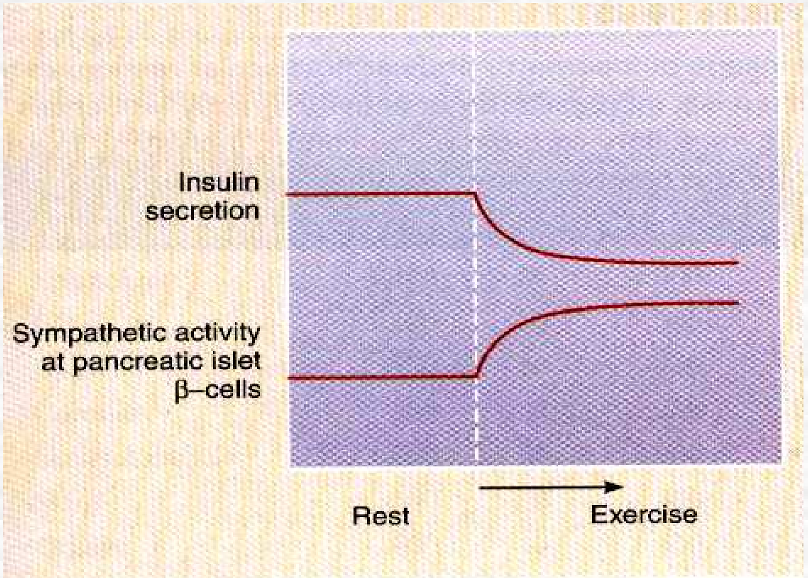
- **Thyroxine/T3** usually rise somewhat, but less than one might expect.
- **Epinephrine** requires more intense effort than norepinephrine to raise it significantly in this phase. 70% max may be barely sufficient.
- **ADH** is released in considerable quantities. It's not just socially inconvenient to have to urinate during exercise - it's a waste of fluid which will probably be needed as sweat.
- **Testosterone/estrogen** increase with exercise - probably, over many repetitions, promoting increased muscle bulk
- **Aldosterone** also rises, reducing Na+ loss in sweat (and in such urine as is still produced).

Insulin concentration **falls** significantly after 20-30 min exercise, and goes on falling (at a lower rate) if the exercise continues 2-3 hours

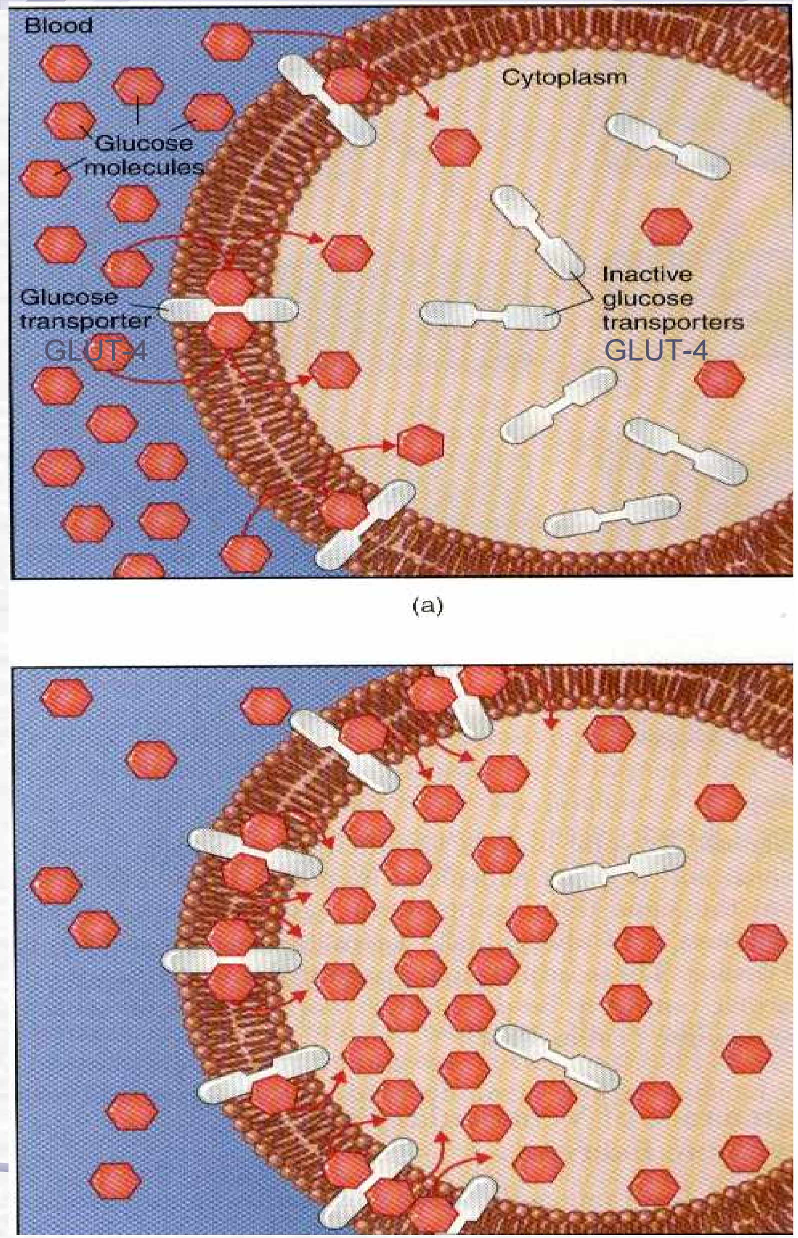
Why insulin falls?

How is glucose transport into skeletal muscle affected by exercise?

Exercise increases insulin sensitivity



- ↑symp. → ↓insulin release (α rec)
- ↑ glucose uptake (insulin-dependent and independent)
- ↑ in insulin sensitivity

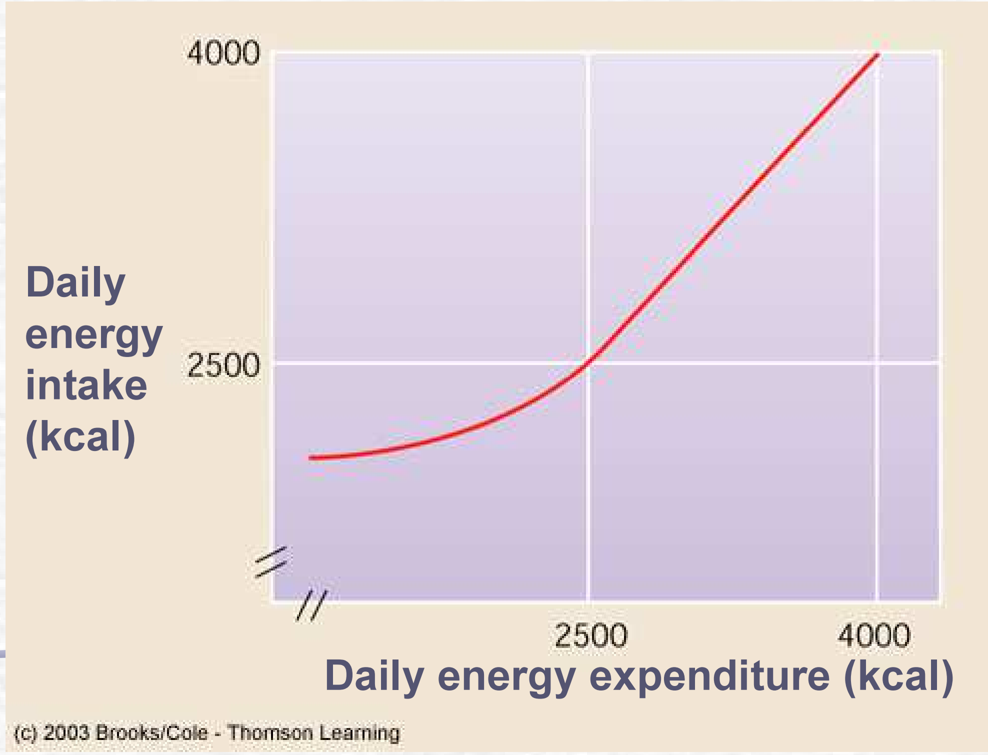


Increase in GLUT-4 number

How does physical activity affect appetite?

↑ Energy expenditure → ↓ blood glucose + ↑ digestion rate + ↑ hypothalamic stimulation → ↑ appetite

Appetite Control



Sport is health

True or false?

If the type of exercise

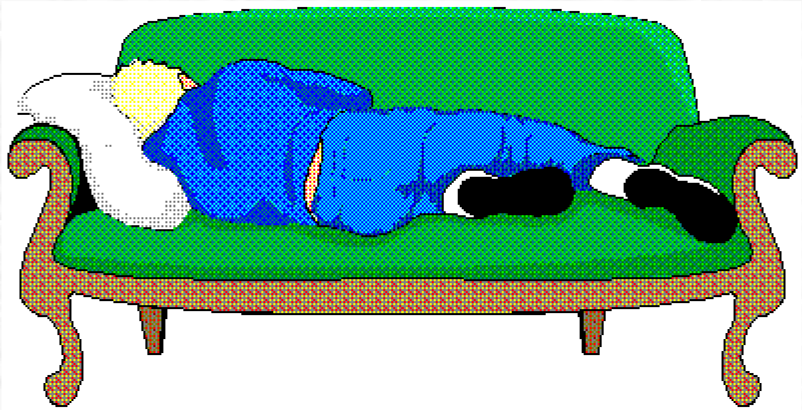
-involves **large muscle groups** (e.g. cycling, walking, running)

-in **continuous activity** at an **intensity** which **elevates oxygen consumption/heart rate** to an appropriate training level, and

-if this exercise is performed **three to five times per week**, between **20 and 60 minutes per day**,

→ **the aerobic fitness of most people is likely to improve**

The choice is yours...



If the individual becomes *sedentary or significantly reduces* the amount of training, the effects of training are lost.

The body also adapts to inactivity