

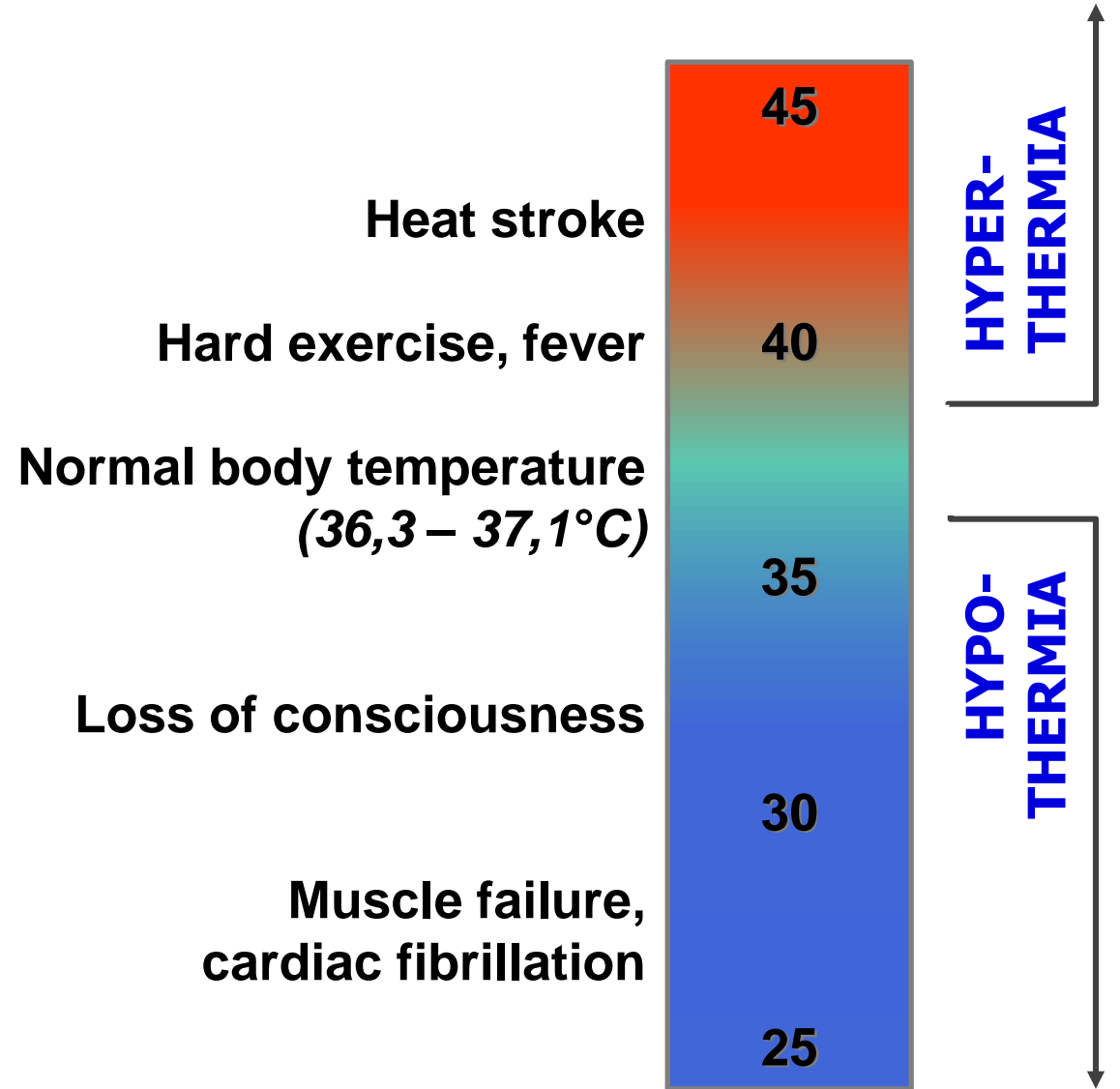
Thermoregulation

Physiology II lecture (aVLFY0422p)

Tibor Stračina

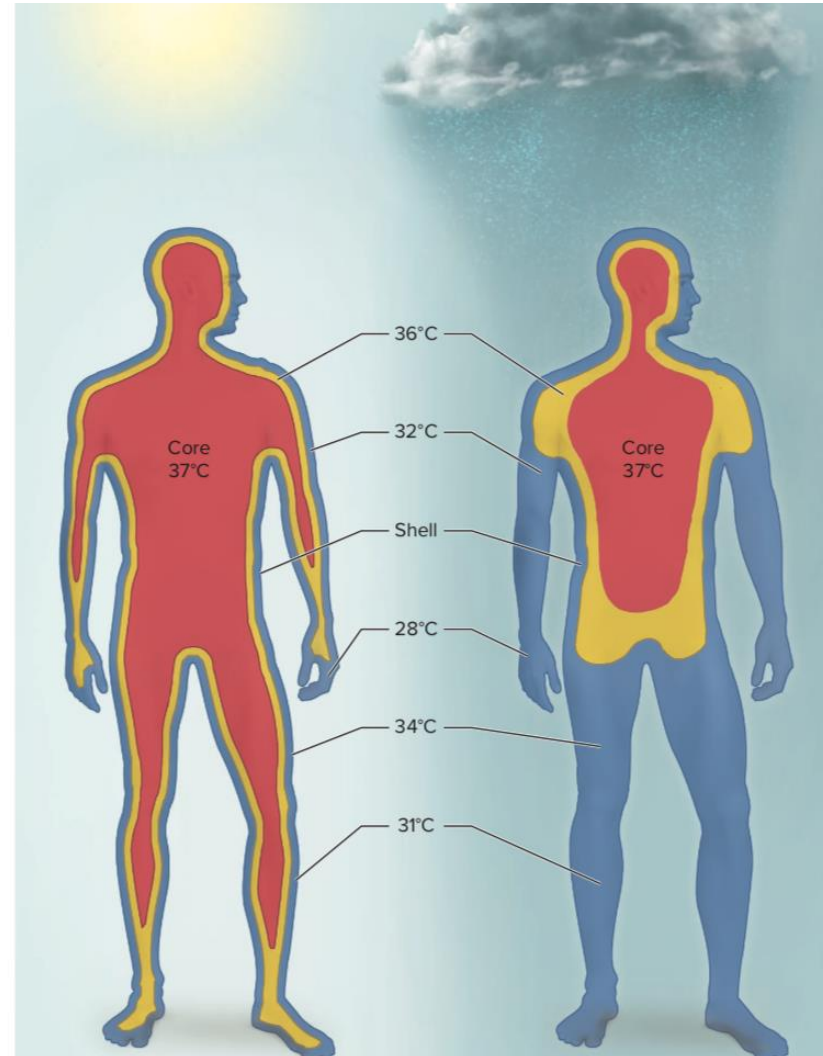
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Body temperature – homeostatic parameter



Body core vs. shell

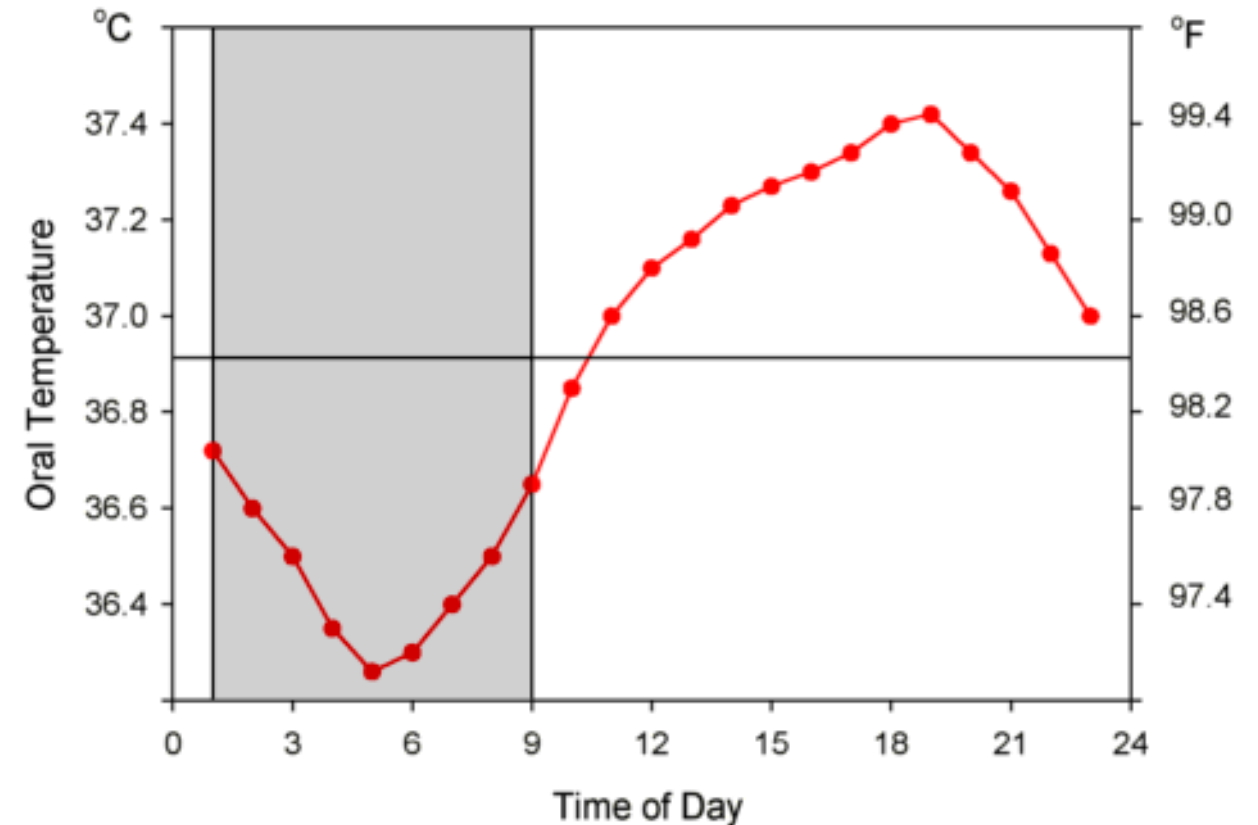
- homeotherms vs. poikilotherms
- Body core temperature – regulated within certain (narrow) range
- Skin temperature (shell) – more variable (ambient t., core body t.)



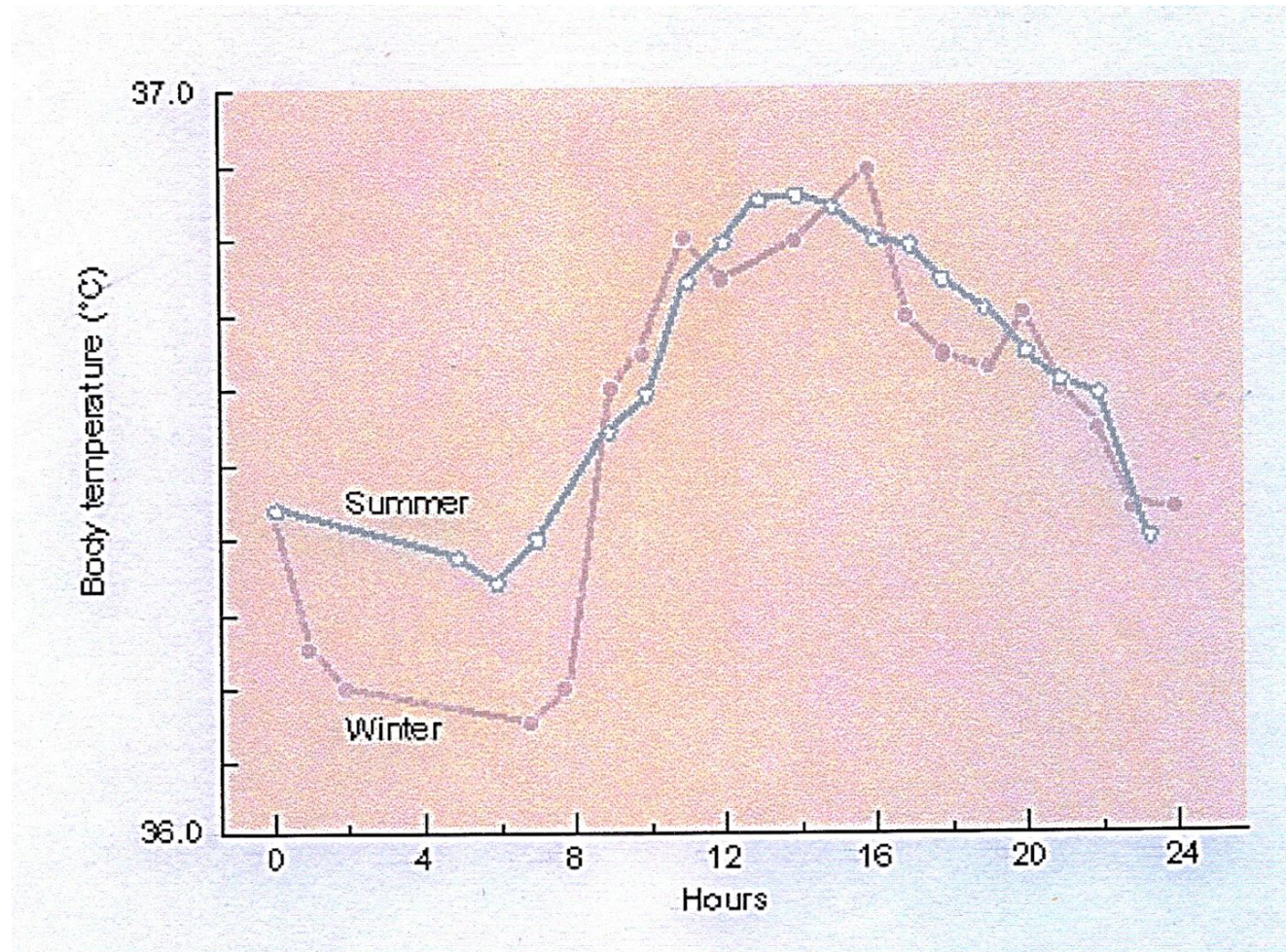
Adopted from: K.S. Saladin, *Anatomy & Physiology—The Unity of Form and Function*, 8th ed. (McGraw-Hill, 2018)

Variations of body core temperature

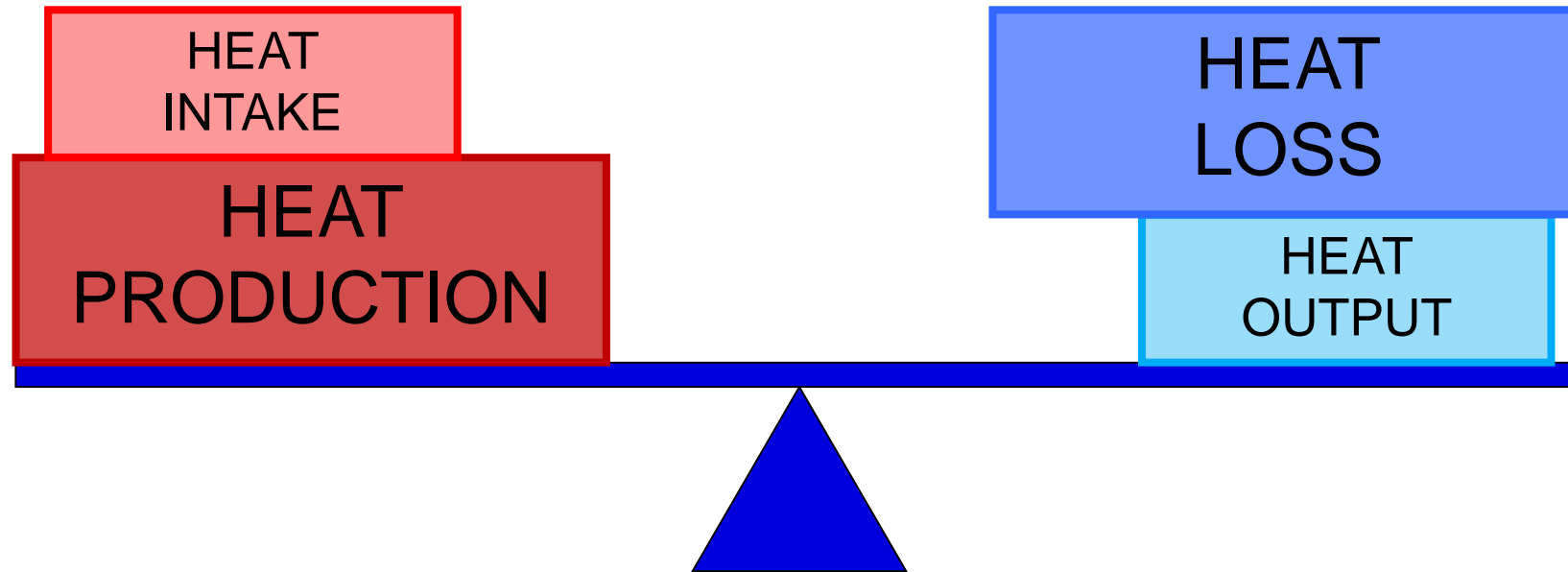
- Circadian rhythm
- Circamensal rhythm (women between puberty and menopause)
- Seasonal variations (circannul rhythm)
- Ageing



Variations of body core temperature



A fine balance of body core temperature



Heat vs. temperature

- **Heat [J]** – energy transferred to or from the system; measure of the internal energy state
- **Temperature [K, °C, °F]** – a measure of heat content; mean kinetic energy of the particles (molecules, ions)

Transfer of heat within the body

- primarily by **CONVECTION**
- medium = blood

- minor amount by **CONDUCTION**
- direct contact of organs/tissues

Heat production

- Metabolism: metabolic rate \approx heat production
- Physical activity (active muscle contraction) – rest vs. exercise
- Postprandial thermogenesis (food intake)
- Shivering thermogenesis
- Non-shivering thermogenesis (brown adipose tissue)

Heat intake and loss

- passive processes

- RADIATION
- CONVECTION
- CONDUCTION

- skin-environment temperature gradient

Heat output (active loss)

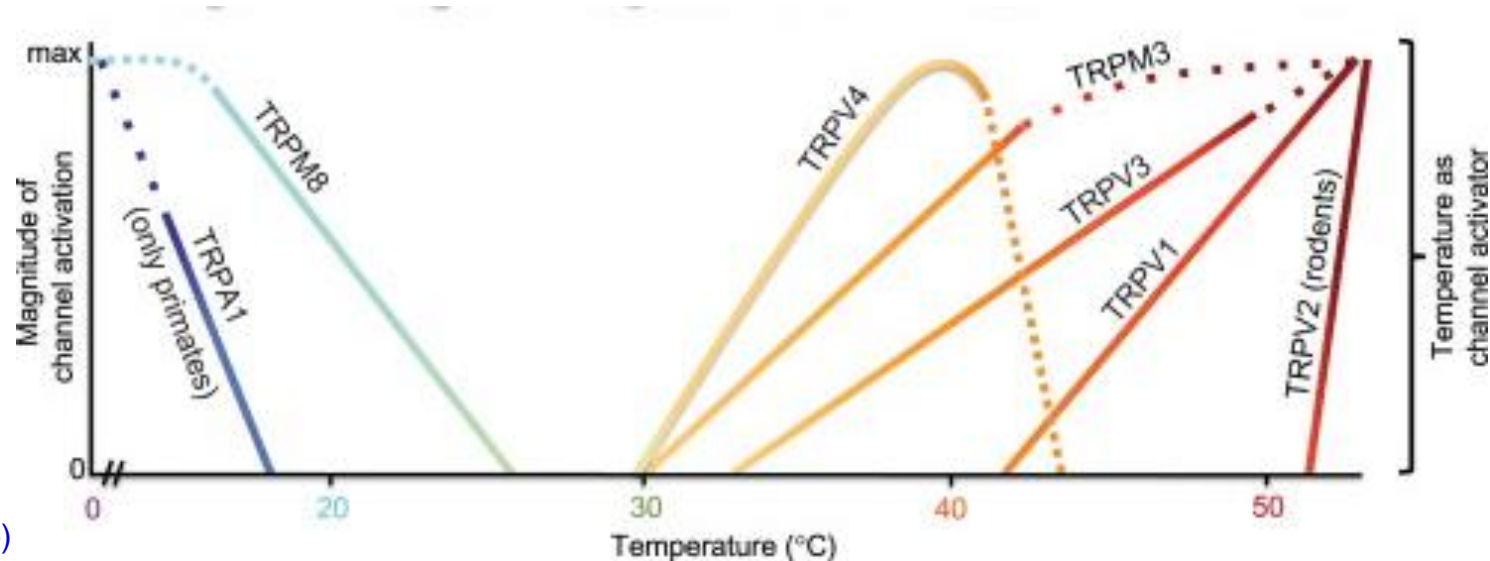
- EVAPORATION
 - sensible perspiration = sweat production (1 L of evaporated s. = 2 428 kJ)
 - Insensible perspiration = diffusion of water through skin and mucosae
- from the skin to the environment
 - (RADIATION)
 - (CONDUCTION)
 - (CONVECTION)

Thermoregulation

- All processes involved in keeping the body core temperature within the range
- Thermoregulatory behaviour
- Social thermoregulation

Afferentation

- Central thermoreceptors – deep brain temperature
- temperature-sensitive neurons in anterior preoptic hypothalamus
- Peripheral thermoreceptors – skin temperature
- TRP channels



Thermoregulatory centre

- anterior preoptic HYPOTHALAMUS
- integration of afferent information
- modifying the efferent pathways (vegetative, somatic) to the thermal effectors
- „set-point“ vs. threshold temperature for the effector(s)

Thermal effectors

- Behaviour
- Cutaneous circulation
- Sweat glands
- Skeletal muscles (shivering)
- Horripilation
- Brown adipose tissue (nonshivering thermogenesis)

Cold-induced thermoregulatory mechanisms

- Decrease of heat loss
 - Behaviour: Decrease of body surface, taking warm clothes
 - Vasoconstriction in the skin. Horripilation
 - Inhibition of sweating
- Increase of heat production
 - Skeletal muscles: Intentional movements (behaviour). Shivering
 - Nonshivering thermogenesis (brown adipose tissue, NA, β 3R, UCP1)
 - Hunger (increas of food intake)

Warm-induced thermoregulatory mechanisms

- Increase of heat loss/output
 - Skin vasodilatation
 - Increase of sweating (evaporation)
 - Increase of ventilation
- Decrease of heat production/intake
 - Behaviour: Moving out of the sun, taking light clothes. Inactiveness (decrease of intentional movements), apathy
 - Loss of appetite

Physiology of Exercise

Physiology II lecture (aVLFY0422p)

Tibor Stračina

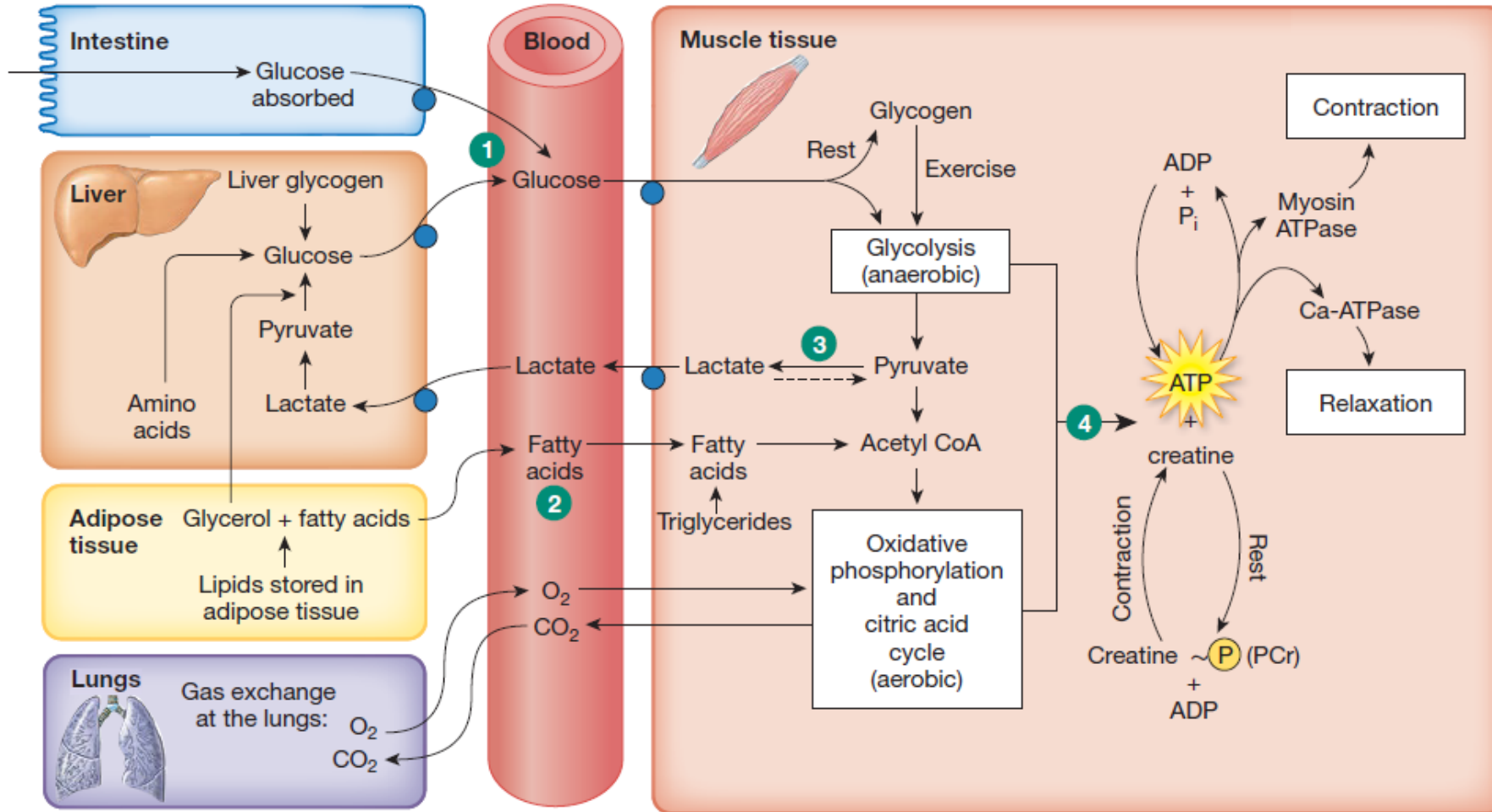
Work (physical activity, exercise)



Skeletal muscle

- Contraction: isometric (static work) vs. isotonic (dynamic work)
- Blood flow depends on muscle tension
- Metabolic autoregulation: $\downarrow pO_2$; $\uparrow pCO_2$; $\downarrow pH$; $\uparrow K^+$; \uparrow local temperature
- Metabolism: aerobic vs. anaerobic
- Muscle spindles – muscle tension – afferentation of exercise pressor reflex

Skeletal muscle metabolism



Reaction of the body to exercise

- Sympathetic NS (ergotropic system)
- Cardiovascular changes
- Respiratory changes
- Metabolic changes

- HOMEOSTASIS

Anticipation of exercise

- Reaction of the body (cardiovascular system)
- Prepare the body for the increased metabolism of the exercising skeletal muscles

- Same as the early response to exercise
- Resembling fight-or-flight reaction

Cardiovascular response to exercise

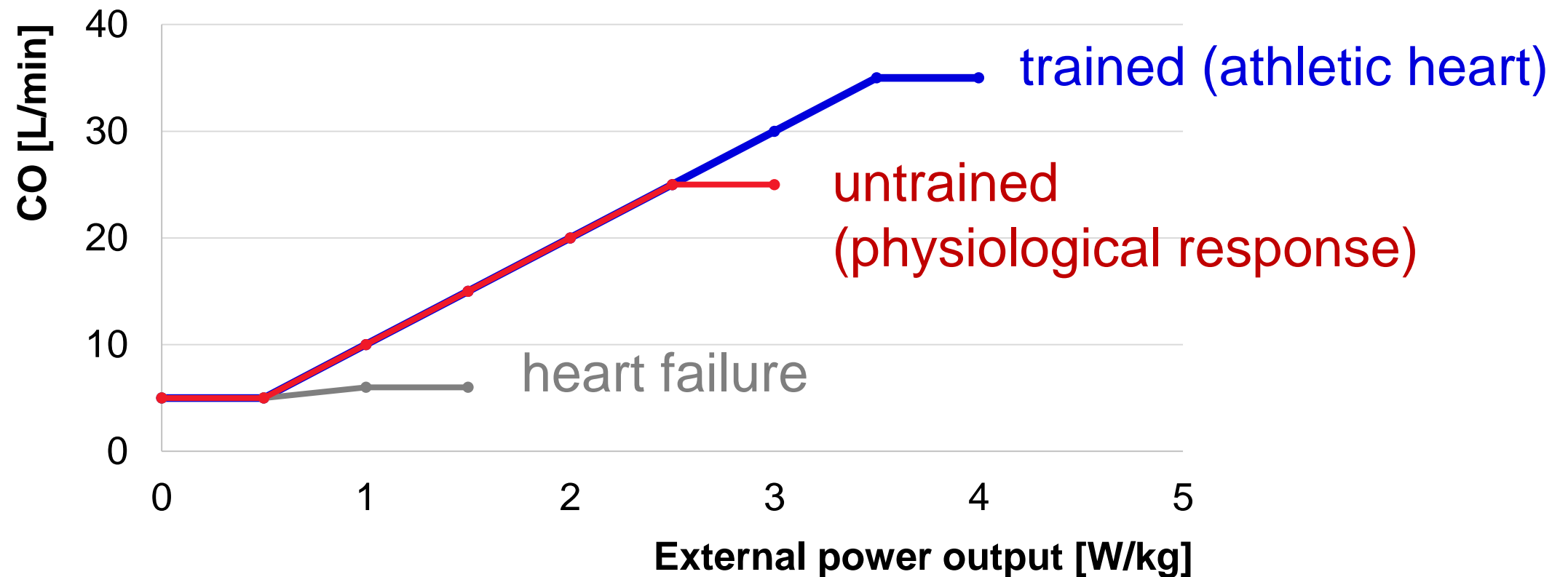
- Increased cardiac output
- Vasoconstriction in inactive skeletal muscles, the GIT, skin, (kidneys)
- Vasodilation in active muscles (metabolic autoregulation)
- Increased venous return
- Histamine release
- Epinephrine release (adrenal medulla)
- Thermoregulation

Increase of cardiac output. Cardiac reserve

- $CO = SV \times HR$ (SNS: positive inotropic and chronotropic effect)
- **Cardiac reserve = maximal CO / resting CO** (4 – 7)
- Coronary reserve = maximal CF / resting CF (~3.5)
- Chronotropic reserve = maximal HR / resting HR (3 – 5)
- Volume reserve = maximal SV / resting SV (~1.5)

CO – cardiac output; CF – coronary flow; HR – heart rate; SV – stroke volume

Cardiac reserve in healthy and failing heart



Changes of arterial blood pressure

PARAMETER	AT REST	DURING EXERCISE	INCREASE (x)
Cardiac output [L/min]	5 – 6	25 (35)	4 – 5 (7) <i>cardiac reserve</i>
Heart rate [1/min]	(45) 60-90	190 – 200 (220) <i>age-dependent</i>	3 – 5 <i>chronotropic reserve</i>
Stroke volume [mL]	75	115	~1.5 <i>volume reserve</i>
Systolic BP [mmHg]	120	<i>static work</i> ↑ <i>dynamic work</i> ↑↑	
Diastolic BP [mmHg]	70	<i>static work</i> ↑↑↑ <i>dynamic work</i> – / ↓	
Mean arterial P (MAP) [mmHg]	~90	<i>static work</i> ↑ <i>dynamic work</i> – / ↑	
Muscle persufion [mL/min/100g]	2 – 4	60 – 120 (180) <i>static vs. dynamic work</i>	30 (10% CO _{max})

Respiratory response to exercise

- Respiratory centre - \uparrow ventilation
 - chemoreceptors: \uparrow pCO₂ + \downarrow pH
 - proprioceptors in lungs
- Sympathetic stimulation (stress – anticipation)

Respiratory response to exercise

PARAMETER	AT REST	DURING EXERCISE	INCREASE (x)
Ventilation [L/min]	6 – 12	90 – 120	15 – 20 <i>respiratory reserve</i>
Breathing frequency [1/min]	12 – 16	40 – 60	4 – 5
Tidal volume (V_T) [mL]	0.5 – 0.75	~2	3 – 4
Pulmonary artery blood flow [mL/min]	5 – 6	25 – 35	4 – 6
O₂ uptake (V_{O_2}) [mL/min]	250 – 300	~3000	10 – 12 (25)
CO₂ production [mL/min]	~200	~8000	~40

Oxygen uptake by lungs

– Spiroergometry

– Resting \dot{V}_{O_2} : **~3.6** mL O₂ / (min x kg)

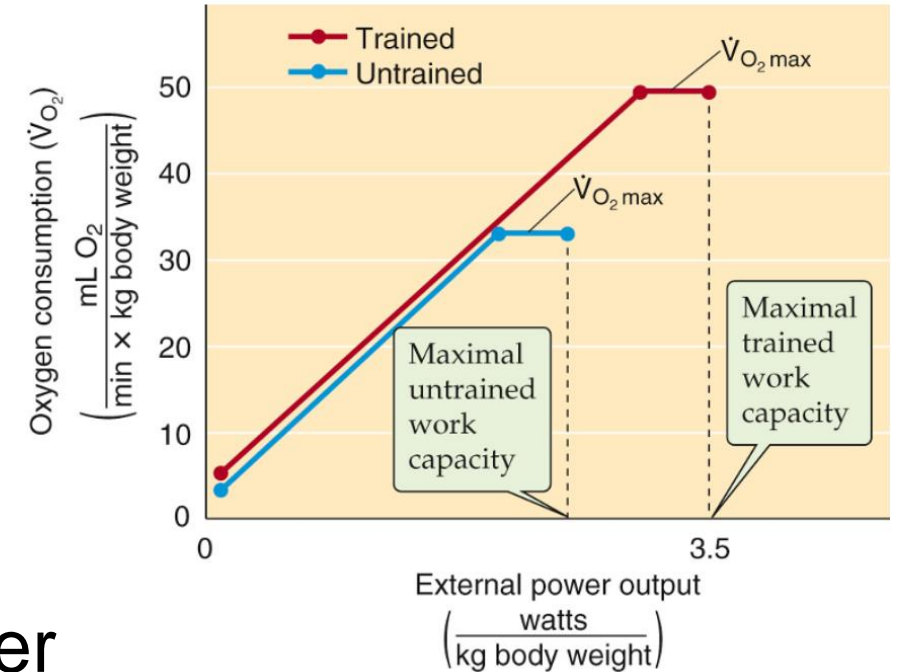
– $\dot{V}_{O_2 \max}$ – objective index for aerobic power

– untrained middle age person: **30 – 40** mL O₂ / (min x kg)

– elite endurance athletes: **80 – 90** mL O₂ / (min x kg)

– HF / COPD patients: **10 – 20** mL O₂ / (min x kg)

Adopted from:
<https://studentconsult.inkling.com/read/boron-medical-physiology-3e/chapter-60/figure-60-6>



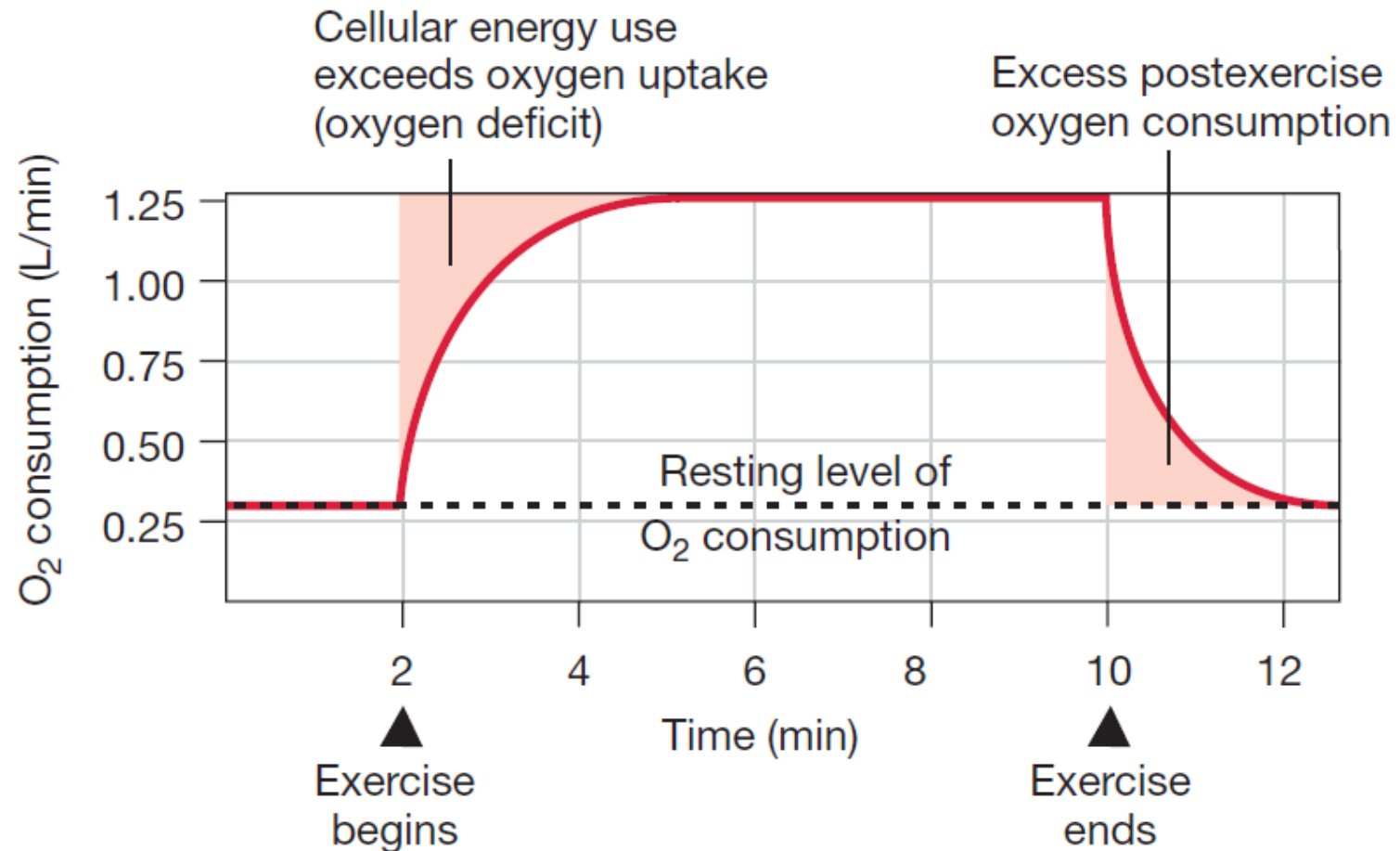
Determinants of $V_{O_2 \max}$

1. Uptake of O_2 by the lungs
 - pulmonary ventilation
2. O_2 delivery to the muscles
 - blood flow (pressure gradient – cardiac output x resistance)
 - haemoglobin concentration
3. Extraction of O_2 from blood by muscle
 - pO_2 gradient: blood-mitochondria

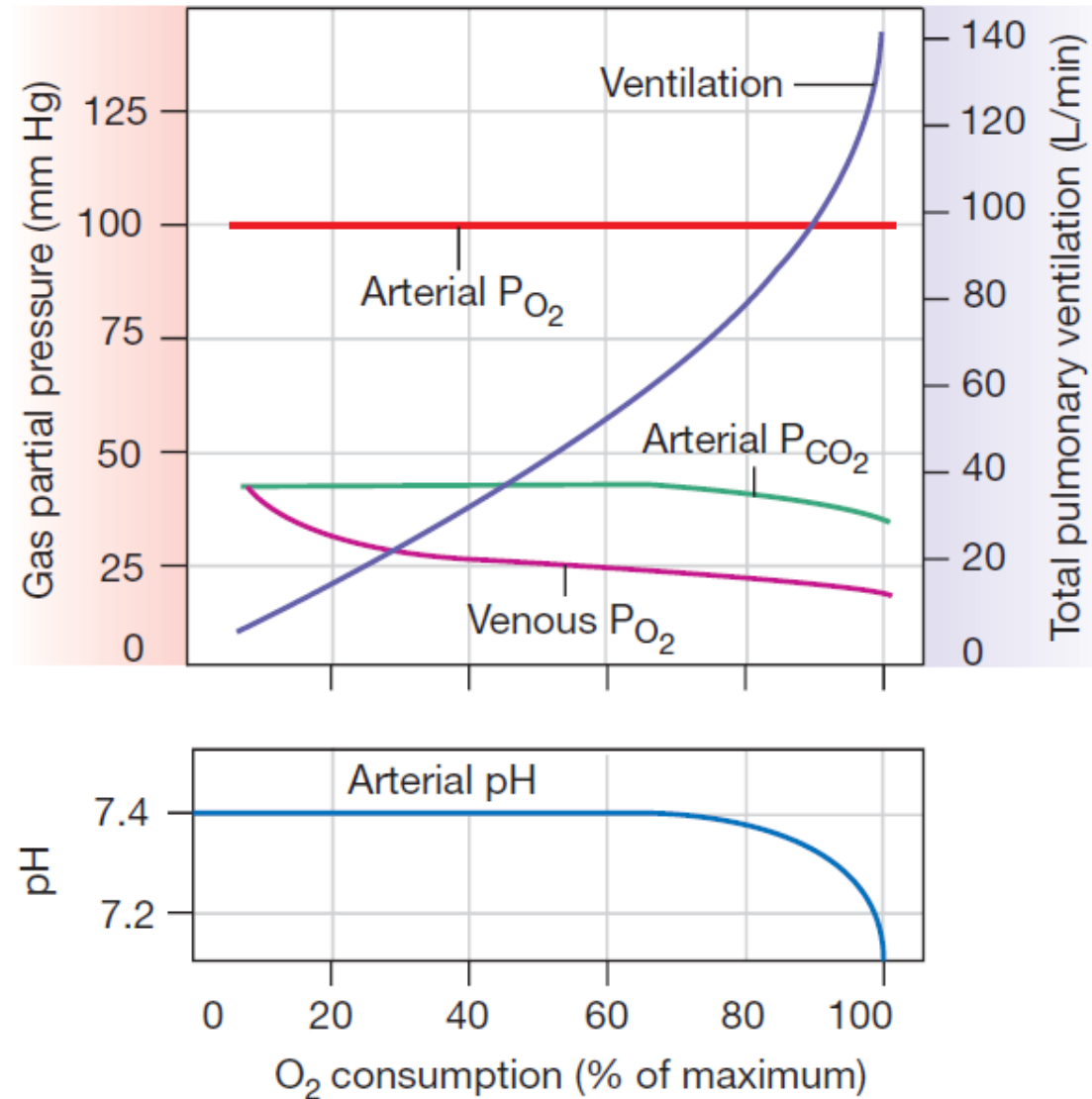
Oxygen consumption during exercise

Adopted from: D.U.Silverthorn:
Human Physiology (An Integrated
Approach)

– Oxygen debt



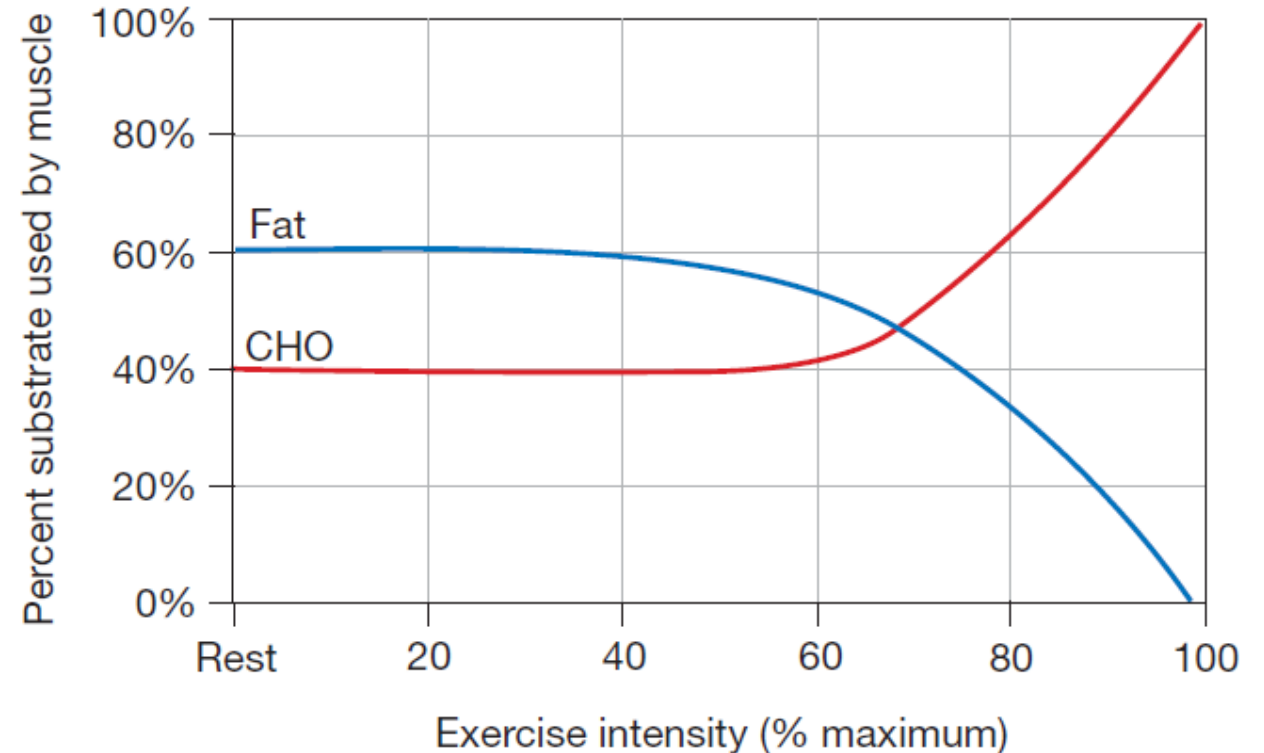
Blood gases during exercise



Adopted from: D.U.Silverthorn:
Human Physiology (An Integrated
Approach)

Energy substrate used by skeletal muscle during exercise

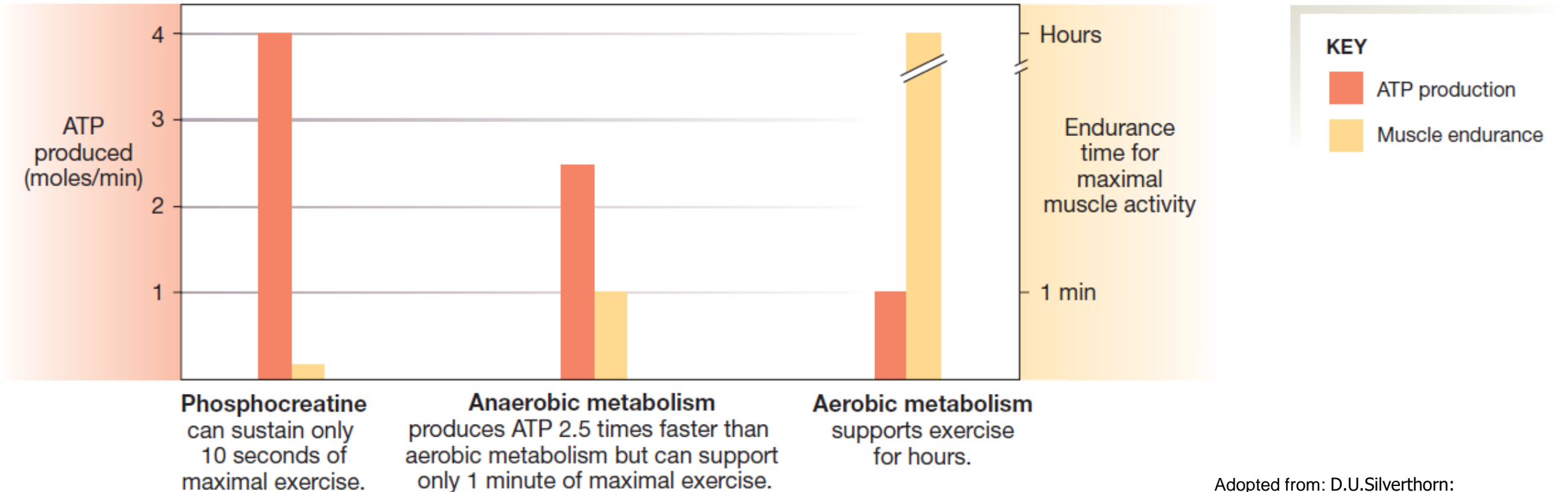
- Low-intensity e.: fats
- High-intensity e.: glucose



Data from G. A. Brooks and J. Mercier, *J App Physiol* 76: 2253–2261, 1994

Adopted from: D.U.Silverthorn:
Human Physiology (An Integrated
Approach)

Energy substrate use – aerobic vs. anaerobic



Adopted from: D.U.Silverthorn:
Human Physiology (An Integrated
Approach)

Testing of fitness

- Spiroergometry
- Standardised workload
 - accurate: in W/kg
 - comparative (simple, inaccurate): in MET
 - metabolic equivalent (actual MR / resting MR)
 - 1 MET = uptake of 3.5 ml O₂/kg.min ≈ 4.31 kJ/kg.h
 - sleeping ≈ 0.9 MET; slow walking ≈ 3-4 MET; fast running ≈ 16 MET

Indexes of fitness

- W_{170} [W/kg]
- $V_{O_2 \max}$ [mL O_2 / (min x kg)]
- Aerobic / anaerobic threshold

- Fatigue
- Training
- Adaptation to exercise

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