**Definitions**

Applied physiology (earlier, today); Work circumstances, conditions

**Load:** the externally imposed task

**Performance:** work, depending on the person.

**Performance capacity:** The maximal limit of ability to perform a work. 
2.3 Watts/kg for women and 2.8 Watts/kg men

**Efficiency:** Mechanical power output for a given energy consumption:

- Mechanical work / chemical energy expended
- Output/Input
**Strain:** is reflected in the alteration of various physiological functions. It depends: performance capacity, and economy/efficiency.

**Adaptation:** The long-term changes that occur as a result of repeated bouts of exercise.
**Types of work**

**Physical**

1.a. **Dynamic**

\[ W = \text{power} \times \text{distance} \]

- light: 500 ml/min O₂ consumption
- middle: 500-2000 ml/min
- hard: >2000 ml/min

1.b. **static**

- isometric contraction
- hard

\[ W = \text{power} / \text{time} \]

**Psychological**

- mental
- emotional

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**Ergometry**

is a procedure for determining physical performance capacity

- **Stair-step ergometer**
- **Cycling ergometer**
- **Treadmill ergometer**
Physiological mechanisms in the adjustment to physical work

Energy, oxygen consumption and muscle activity

Prompt => strain

Slow => adaptation (training)

Intra- and interindividual differences
Prompt changes
A. Muscle circulation in dynamic work

<table>
<thead>
<tr>
<th></th>
<th>Resting</th>
<th>Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle of cardiac output</td>
<td></td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>15-20</td>
<td>80</td>
</tr>
<tr>
<td>Muscle circulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ml/kg/min</td>
<td>20-40</td>
<td>1300 (1800)</td>
</tr>
<tr>
<td>Opened capillaries</td>
<td>x</td>
<td>50x</td>
</tr>
<tr>
<td>filtration</td>
<td></td>
<td>↑</td>
</tr>
<tr>
<td>permeability</td>
<td></td>
<td>No changes</td>
</tr>
</tbody>
</table>

TPR ↓, venous return ↑; redistribution

Distribution/Redistribution

<table>
<thead>
<tr>
<th>Organ</th>
<th>Resting CO</th>
<th>Resting $O_2$</th>
<th>Work CO</th>
<th>Max vasodil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg</td>
<td>%</td>
<td>ml</td>
<td>%</td>
</tr>
<tr>
<td>Sum</td>
<td>70</td>
<td>100</td>
<td>5000</td>
<td>100</td>
</tr>
<tr>
<td>Brain</td>
<td>1.4</td>
<td>2</td>
<td>750</td>
<td>15</td>
</tr>
<tr>
<td>Heart</td>
<td>0.3</td>
<td>0.4</td>
<td>250</td>
<td>5</td>
</tr>
<tr>
<td>Splanch</td>
<td>4</td>
<td>5.7</td>
<td>1000</td>
<td>20</td>
</tr>
<tr>
<td>Liver</td>
<td>1.5</td>
<td>2.1</td>
<td>500</td>
<td>10</td>
</tr>
<tr>
<td>Kidney</td>
<td>0.3</td>
<td>0.4</td>
<td>1000</td>
<td>20</td>
</tr>
<tr>
<td>Muscle</td>
<td>35</td>
<td>50</td>
<td>800</td>
<td>16</td>
</tr>
<tr>
<td>Skin</td>
<td>2</td>
<td>2.9</td>
<td>250</td>
<td>5</td>
</tr>
<tr>
<td>Fat</td>
<td>9</td>
<td>13</td>
<td>250</td>
<td>5</td>
</tr>
<tr>
<td>Bone etc</td>
<td>18</td>
<td>25.6</td>
<td>200</td>
<td>4</td>
</tr>
</tbody>
</table>

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B. Muscle metabolism in dynamic work

Resting: fat, glycogen, aminoacid

Light work:
  Start:
    ATP: 1-2 s,
    Phosphocreatine breakdown: 20-30 s,
    Anaerobic glycolysis: 30-120 s
  Later:
    Aerobic => glucose, fatty acid, glycerin

Hard work: anaerobic, lactic acid production
Changes in cardiovascular parameters during dynamic work

HR ↑
max: 180-200/min (old: 160/min)
sympathetic effects ↑
vagal tone ↓

Contractility ↑
(20-60 %)
sympathetic effects + Frank-Starling law =>

Stroke volume ↑: 100-190 ml

TPR ↓
resting 1 PRU (Hgmm*s/ml)
work: 0.38 PRU

Blood pressure ↑
SAP: 200-220 mmHg
DAP: slight changes

CO ↑
max: 30-40 l/min

Contractility ↑
(20-60 %)
sympathetic effects + Frank-Starling law =>

Stroke volume ↑: 100-190 ml

Blood pressure ↑
SAP: 200-220 mmHg
DAP: slight changes

Stroke volume

Heart rate

Cardiac output (liters/minute)
$O_2$ transport to the muscles

Depends on the circulation (not from lung)

Dynamic work:
  systemic circulation
Static work:
  Local circulation
ECG changes
- R-R ↓
- P-Q ↓
- ST depression

Lung circulation ↑
- volumen ↑
- velocity ↑

Regulation of circulation during work
- Sy adrenergic activation ↑
- Sy cholinergic activation ↑
- Vagal tone ↓ (heart)
- Local metabolites

Sweat glands = bradykinin = vasodilation
Hypothalamus => decreased sy. tone in skin vessels = vasodilation

Baroreceptor sensitivity ↓
Respiration during work

Breathing frequency: 40-50/min
Tidal volume: 3000 ml
Minute volume: 100 l/min

Energy requirement for respiration: max 5%

Nasal/oral breathing

Oxygen diffusion constant:
- Resting: 20 ml/min*mmHg
- Work, non-trained: 50 ml/min*mmHg
- Work, trained: 70-80 ml/min*mmHg
Mechanism of hyperventilation

Condition reflex in preparative phase too; origin: cerebral cortex
Muscle receptors; CO₂, lactic acid

Oxygen consumption:
250 ml/min => max: 3500-4000 ml/min
Anaerobic capacity: work without oxygen.
Oxygen dept.
Oxygen dept is the volume of extra oxygen consumption after the end of work
Causes:
Replacement of ATP, creatinin phosphate
Replacement of O₂ in myoglobin
Metabolism of lactic acid

Light work: 1-2 min adaptation phase => equilibrium in O₂ uptake/consumption (a small O₂ dept)
Hard work: no balance => large O₂ dept

Close connection between O₂ consumption and HR
Anaerobic threshold: RQ >1
**Blood parameters**

**Gases:**
- **Light work:** slight changes!
  - $pCO_2$ ↑
  - $pO_2$ ↓
- **Hard work:**
  - $pCO_2$ ↑ (10%)
  - $pO_2$ ↓ (8%)

**A-V $O_2$ difference** ↑ (in working muscle: temperature, pH, $pCO_2$)

**pH**
- **Light work:** slight changes! ↓
- **Hard work:** ↓ ↓ metabolic acidosis

**Blood cells**
- $HTK$ ↑ => viscosity ↑
- Granulocyte ↑, Ly ↓
Other substances in blood

Glucose: ↓ (fatigue)
Lactic acid: 1=>15 mmol/l
Se K⁺ ↑
transaminase ↑
triglyceride ↓
Fatty acid ↑
Se Na⁺ ↓ (sweating)
Thermoregulation

heat production $\uparrow$ (max 15x)
set-point $\uparrow$
heat-loss $\uparrow$ (sweating, vasodilation in skin $\Rightarrow$ decreased preload $\Rightarrow$ water homeostasis disturbance)

Body temperature $\uparrow$

above 39 $^\circ$C: collapse
41 $^\circ$C (marathon runner) heat stroke/coma
**Endocrine system**

- Activation of sympatho-adenergic system => Circulation; Mobilisation of glycogen
- Pituitary-adrenocortical system => Mobilisation of glycogen; Permissive effects of cortisol
- Insulin-glucagon system
  - Insulin level: ↑ => inhibits the excessive protein metabolism
  - Glucagon ↑↓

- GH ↑ => fat mobilisation
- ADH ↑ => decreased volume of urine
- Prolactin ↑ => fat mobilisation; antidiuretic effect
- T3, T4 ↑ (during training) => blood glucose ↑, beta receptor ↑
- Calcitonin ↑ => inhibition of bone reabsorption
- Testosterone ↑ (during training) => protein anabolism, muscle hypertrophy

**Immunology**

light work ↑
hard work ↓
**Metabolism**

RQ:
- (↓) (fat metabolism)
- ↑ Lactic acid production

Digestion:
- light work: ↑
- hard work: ↓

**Changes during static work**

Posture, weight lifting, etc.

Muscle circulation:
- ↑ up to 30% of max strength, then ↓
- 0: at 70% of max strength (max 1 min)

CVR:
- HR ↑ ↑
- SAP ↑ ↑
- DAP ↑ ↑

Respiration ↑ ↑ (lactic acid)
Changes during psychological work

Sympathetic activity $\uparrow \Rightarrow$ metabolism $\uparrow$
Muscle tone $\uparrow \Rightarrow$ metabolism $\uparrow$

Limits of Performance Capacity

2.3 Watts/kg for women and 2.8 Watts/kg for men

Factors:
Primarily cardiovascular system
   Energy store in muscle
   $O_2$ transport capacity
   Thermoregulation
Fatigue

**Definition:** It is a state induced by (heavy) work and associated with a decrease in performance capacity.

**Recovery:** frequent, short resting periods

**Light work** can be performed for more than 8 hours without fatigue.

Equilibrium between muscle metabolism and circulation.

- HR: < 130, recovery time < 5 min
- O₂ uptake: constant
- O₂ < 500 ml/min
- Lactic acid < 2 mmol/l

**Fatigue limit in static work:**
- 15% of maximal strength

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**Physical fatigue:**
- Causes: lactic acid ↑, storage ↓
- Dynamic light work: recovery during relaxation
- Hard work: continuous lactic acid ↑, storage ↓

**Psychological fatigue:**
- Irritability, depression, emotional lability
- Causes: long-term concentration
  - hard physical work
  - noise, dark, temperature
  - anxiety, conflict, boring
  - diseases, pain, malnutrition

Prompt recovery might be!
**Overload - exhaustion**

Overload appears when load tolerance is exceeded. 
**Exhaustion:** It occurs when physical or mental performance is not interrupted soon enough or no enough time for recovery or overt hard work.

**Consequences:**
- Performance capacity ↓
- Metabolic acidosis
- Adrenal cortex hypertrophy
- Permanent impairments => bone fracture, muscle, tendon tearing, hernia disci, meniscus injury etc.
Factors influencing performance capacity

Age
Sex
Health conditions
Training/experience
Talent
Environment
  Circadian rhythm
    6-12: high
    22-4 low
Weather
Noise
Temperature
Mental-, emotional conditions
Automatic tasks
Nutrition
Maintenance and enhancement of performance capacity

Resting periods

Sleeping

Food

TRAINING
Training Results depend on doses and repetition

Plato

 Regression Age + training

Long-lasting changes in muscle

Structural:
- Hypertrophy (30-60%)
- Number of myofibrils ↑
- Number of myochoondria ↑
- Sarcoplasma ↑
- Myoglobin ↑ = oxygen storage ↑

Biochemical:
- Aerobic enzyme activity ↑
- Glycogen ↑
- Fat metabolism ↑
- Glucose metabolism ↓
- Protein metabolism ↓

Functional:
- Tone ↑
- Strength ↑
- Speed ↑
- Flexibility ↑
- Duration ↑
Nutrition

Long-lasting, hard work:
untrained:
  more eating for 2-3 days
trained:
  more eating for 1 day
trained:
  increased fat metabolism =>
higher blood glucose level; more protein; decreased fat

Heart hypertrophy
Stroke volume ↑
HR ↓
Respiration:
Vital capacity ↑
Minute volume ↑↑
Compliance ↑
Oxygen diffusion constant (64 => 80 ml/min*mmHg)
Oxygen dept ↓
Oral respiration => later

Minor changes in blood parameters
Stronger tendon, bone
Immune system activity ↑
### Resting

<table>
<thead>
<tr>
<th></th>
<th>Nonathlete</th>
<th>Marathoner</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO (ml/min)</td>
<td>5625</td>
<td>5250</td>
</tr>
<tr>
<td>Stroke Volume (ml)</td>
<td>75</td>
<td>105</td>
</tr>
<tr>
<td>Heart Rate (beats/min)</td>
<td>75</td>
<td>50</td>
</tr>
</tbody>
</table>

### Maximum

<table>
<thead>
<tr>
<th></th>
<th>Nonathlete</th>
<th>Marathoner</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO (ml/min)</td>
<td>16450</td>
<td>29970</td>
</tr>
<tr>
<td>Stroke Volume (ml)</td>
<td>110</td>
<td>162</td>
</tr>
<tr>
<td>Heart Rate (beats/min)</td>
<td>195</td>
<td>185</td>
</tr>
</tbody>
</table>

### Parameter Variation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Untrained</th>
<th>Trained</th>
</tr>
</thead>
<tbody>
<tr>
<td>pulse rate at rest, recumbent (l/min)</td>
<td>80</td>
<td>40</td>
</tr>
<tr>
<td>pulse rate, maximal (l/min)</td>
<td>180</td>
<td>180</td>
</tr>
<tr>
<td>stroke volume at rest (ml)</td>
<td>70</td>
<td>140</td>
</tr>
<tr>
<td>stroke volume, maximal (ml)</td>
<td>100</td>
<td>190</td>
</tr>
<tr>
<td>cardiac output at rest (l/min)</td>
<td>5.6</td>
<td>5.6</td>
</tr>
<tr>
<td>cardiac output, maximal (l/min)</td>
<td>18</td>
<td>35</td>
</tr>
<tr>
<td>heart volume (ml)</td>
<td>700</td>
<td>1400</td>
</tr>
<tr>
<td>heart weight (g)</td>
<td>300</td>
<td>500</td>
</tr>
<tr>
<td>respiratory minute volume, maximal (l/min)</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>oxygen uptake, maximal (l/min)</td>
<td>2.8</td>
<td>5.2</td>
</tr>
<tr>
<td>blood volume (l)</td>
<td>5.6</td>
<td>5.9</td>
</tr>
</tbody>
</table>
Dopings

Mobilisation of autonomic protective storage
Adrenaline-like effects

Amphetamine (ecstasy: 3,4-Methylenedioxymethamphetamine): Tom Simpson
1967 cyclist

Dopings
Anabolic steroids
Increased protein synthesis, hormonal side effects
tearing of tendons or bone-fracture
Androgenic hormones

Testosterone

Growth hormone

Yao Ming
Erythropoietin (EPO)

Making EPO from Hamster ovaries

(CERA)
Mircera™

• Blood doping