Exercise physiology and sports performance

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Factors influencing sports performance

Sports performance

- Flexibility
- Strength
- Endurance
- Agility
- Balance

Peak oxygen consumption / uptake
Cardiopulmonary exercise testing
Determinants of sports performance

Pulmonary circulation

Heart & Circulation

Peripheral circulation

Lung

Inhalation

Distribution

Utilization

Ventilation

Diffusion

Perfusion

Durchblutung

Muscle

Exhalation

Transport

CO

Mitochondrium

Energy

Muscle efficiency
Cardiac output in athletes

\[ \text{VO}_2 = \text{Cardiac output (CO)} \times \text{a-vO}_2\text{Diff} \]

\[ \text{CO} = \text{Stroke volume (SV)} \times \text{Heart rate (HR)} \]

Afterload (Pressure)

Preload (Volume)

Picture of strength athlete

Picture of endurance athlete

Morganroth J, Maron BJ, Ann NY Acad Sci 1977;301:931
Circulation in endurance athletes

Increased capillary density and surface → maintains oxygen utilization (a-vO₂Diff)

Schuler G et al, Eur Heart J 2013;34:1790-9
Circulation in strength athletes

Initial vasodilatation and slight increase in cardiac output

Muscle contraction compresses vessels with reduced blood flow

Increase in peripheral resistance and blood pressure

Dynamic / concentric (muscle contracts and shortens)

Eccentric (muscle contracts but lengthens)

Isometric (muscle contracts, no change in length)
Types of muscle fibers

Type I: S(low) fibers
Predominantly aerobic, “slowly twitching”,
High density of mitochondria, high activity of aerobic enzymes, fatigue-resistant
→ “red muscle”

Type IIa: F(ast resistant) fibers
Mainly anaerobic, “fast twitching“
Less mitochondria, rapid fatiguing, but
good response to exercise!
→ “white muscle”

Type IIb: F(ast fatigue) fibers
Anaerobic, “fast twitching“
Few mitochondria, strong, agile, but very rapid fatigue
→ “white muscle“
Determinants and limits of VO$_2$max

- Age
- Ethnicity
- Gender
- Training status
- Genetic disposition
- Capacity of energy-delivering systems
- Upper physiological limits of cardiac adaptation

85-90 ml/min/kg

Aerobic (O$_2$-Consumption)

Anaerobic-lactacid (anaerobic glycolysis)

Anaerobic-alactacid (creatine phosphate)
Energy supply during maximal exercise

Percentage of energy supply

Duration of exercise (time)

Decreasing performance

Picture of 100m sprinters
Testing anaerobic capacity

Workload (Watt)

Time (s)

A = Peak Power

\[
\frac{(A-B) \cdot 100}{A} = \text{Fatigue Index (FI)}
\]

B = Lowest Power
Energy supply during incremental exercise

[Graph showing energy supply over duration of exercise with labels for different metabolic processes and percentage of energy supply over time.]

- Increasing performance
- Duration of exercise (time)
- Percentage of energy supply
Indirect Calorimetry

RER

Fatty acids

Carbohydrates

Increasing lactate
Dickhuth: Increase of lactate over baseline + 1.5 mmol
Maximal lactate steady state

- Production and elimination of lactate are in equilibrium
- Determined by several constant load trials at increasing intensities with a maximum increase of 1 mmol/l
- Respiratory parameters remain constant, but respiratory and heart rate increase

## Lactate thresholds and performance

<table>
<thead>
<tr>
<th>Threshold</th>
<th>Short distance</th>
<th>Middle distance</th>
<th>Long-distance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Velocity</td>
<td>VO₂</td>
<td>Velocity</td>
</tr>
<tr>
<td>LT&lt;sub&gt;FIX&lt;/sub&gt;</td>
<td>0.85 (0.68-0.93)</td>
<td>0.73 (0.51-0.79)</td>
<td>0.91 (0.81-0.95)</td>
</tr>
<tr>
<td>LT&lt;sub&gt;AER&lt;/sub&gt;</td>
<td>0.74 (0.43-0.93)</td>
<td>0.66 (0.58-0.85)</td>
<td>0.84 (0.73-0.97)</td>
</tr>
<tr>
<td>LT&lt;sub&gt;AN&lt;/sub&gt;</td>
<td>0.88</td>
<td></td>
<td>0.91 (0.83-0.94)</td>
</tr>
</tbody>
</table>

**Above:** Correlation coefficients between different thresholds and running performance

**Below:** Mean bias for different threshold concepts as compared to MLSS

<table>
<thead>
<tr>
<th>Lactate threshold concept</th>
<th>Treadmill ergometry 3 min stages, +0.4 m/s</th>
<th>Treadmill ergometry 5 min stages, +0.4 m/s</th>
<th>Cycle ergometry 2 min stages, +25 W</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean bias (m/s)</td>
<td>mean bias (m/s)</td>
<td>mean bias (W)</td>
</tr>
<tr>
<td></td>
<td>LoA (m/s)</td>
<td>LoA (%)</td>
<td>LoA (%)</td>
</tr>
<tr>
<td>LT4</td>
<td>−0.13</td>
<td>0.02</td>
<td>−19.8</td>
</tr>
<tr>
<td></td>
<td>±0.35</td>
<td>±0.39</td>
<td>±28.4</td>
</tr>
<tr>
<td></td>
<td>±8</td>
<td>±9</td>
<td>±14</td>
</tr>
<tr>
<td>IAT (Keul et al.&lt;sup&gt;[96]&lt;/sup&gt;)</td>
<td>−0.20</td>
<td>0.06</td>
<td>−21.0</td>
</tr>
<tr>
<td></td>
<td>±0.39</td>
<td>±0.35</td>
<td>±22.4</td>
</tr>
<tr>
<td></td>
<td>±9</td>
<td>±8</td>
<td>±11</td>
</tr>
<tr>
<td>IAT (Stegmann et al.&lt;sup&gt;[88]&lt;/sup&gt;)</td>
<td>−0.03</td>
<td>−0.03</td>
<td>−15.0</td>
</tr>
<tr>
<td></td>
<td>±0.51</td>
<td>±0.37</td>
<td>±35.0</td>
</tr>
<tr>
<td></td>
<td>±12</td>
<td>±9</td>
<td>±18</td>
</tr>
<tr>
<td>IAT (Bunc et al.&lt;sup&gt;[143]&lt;/sup&gt;)</td>
<td>−0.33</td>
<td>−0.14</td>
<td>−71.4</td>
</tr>
<tr>
<td></td>
<td>±0.33</td>
<td>±0.37</td>
<td>±52.8</td>
</tr>
<tr>
<td></td>
<td>±8</td>
<td>±9</td>
<td>±27</td>
</tr>
</tbody>
</table>

IAT = individual anaerobic threshold; LT₄ = 4 mmol/L threshold.

Trainingszonen

Regeneration / compensation:
- Exercise for „recovery“ or long-distance training
- Stabilizing rather than increasing performance
- No threshold shift
- Continuous exercise
- Stabilizing mitochondrial density and capillary flow

Aerobic performance I & II:
- Exercise for improving basic aerobic fitness
- Shift of thresholds to higher intensities
- Either as continuous (I) or interval-based exercise
- Increasing capillary flow and mitochondrial density

Anaerobic, maximal capacity:
- Exercise for improving peak performance
- Usually no relevant threshold shift
- Maximal consumption of all energy sources
- Increasing „lactate tolerance“

Picture of marathon runners

Picture of 100 m sprinters

Picture of strength athlete
Lactate curves and sports performance

Untrained

Strongest man of the world

Bobsled World champion

Soccer pro

Slalom winner

Cycling pro
Increasing aerobic performance
Ventilation vs. metabolism

n = 30 CAD-patients, interval training

Can we predict performance by VO$_2$max?

- SV$_{max}$
- HR$_{max}$
- CO$_{max}$
- [Hb]; %SaO$_2$
- a-vO$_2$Diff
- Capillary density
- Oxidative enzymes
- %VO$_2$max at LT
- Running economy
- Velocity at LT
- Maximum velocity at distance races

Examples from CPET

**Panel 3**

- **VO₂ peak**: 72 ml/min/kg
- **VO₂ AT**: 49 ml/min/kg
- **VE**: 146 l/min
- **RER**: 1.13
- **HR**: 186/min
- Time on treadmill: 14:30 min
- Finishing time: 2:24 h

- **VO₂ peak**: 38 ml/min/kg
- **VO₂ AT**: 29 ml/min/kg
- **VE**: 97 l/min
- **RER**: 1.02
- **HR**: 179/min
- Time on treadmill: 12:10 min
- Finishing time: 6:13 h
Conclusion

• There is no uniform measure to characterize sports performance from a physiologic background.

• CPET is only one method for assessing exercise performance focusing on physiological backgrounds of aerobic capacity.

• Sports performance is limited by physiological upper limits in cardiac output, blood flow and muscular oxidative capacity.

• Performance in endurance sports is predicted by submaximal parameters rather than maximal oxygen uptake alone.
Kontakt

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