ENDURANCE: Physiological Demands & Limitations

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Physiological Determinants of Endurance Performance

Joyner and Coyle, 2008
Physiological Determinants of Endurance Performance

AVERAGE RACE PACE

Exercise Economy

Rate of Aerobic Energy Expenditure

- Anaerobic Contribution?
- VO₂ Kinetics
- VO₂ Max
- LT & LTP

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FIGURE 1—Energy system contribution in 10-s time intervals for the 200, 400, 800, and 1500 m. Data are mean values ± SD.
Maximal Oxygen Uptake

- The maximal rate at which ATP can be re-synthesised aerobically
- Strong correlations between VO$_2$ max and endurance performance in heterogeneous groups
- Elite runners tend to have high VO$_2$ max values (70-85 ml/kg/min in men, 60-75 ml/kg/min in women)
VO₂ Max and Performance

(From: Karlsson & Saltin, 1971)
How to Improve VO$_2$ Max?

The Fick Equation: $VO_2 = (HR \times SV) \times a-vO_2$ difference

$VO_2$ max limited by the maximal cardiac output

Therefore, training at near-maximal HR is considered to be an effective way to enhance $VO_2$ max

An example session is 5 x 3 min hard effort with 2-3 min recovery
Running Economy

- The oxygen cost of running at sub-maximal speeds (ml/kg/min or ml/kg/km)
- Significant inter-individual variability
- Influenced by anthropometric, physiological, biomechanical, and technical factors
- Generally better in longer distance specialists
Running Economy at 16 km/h
Running Economy and Performance

(From: Conley and Krahenbuhl, 1980)
Running Economy and Performance

(From: Conley and Krahenbuhl, 1980)
Running Velocity at VO$_2$ Max

- The interaction of VO$_2$ max and running economy
- Provides ‘functional expression’ of VO$_2$ max in units of km/h
- Helps explain difference in performance in athletes with similar VO$_2$ max
- Enables accurate prediction of race performance
Running Velocity at VO$_2$ Max

VO$_2$ (mL/kg/min)

Running Speed (km/h)
How to Improve Economy?

- Economy is related to anthropometrical, physiological and biomechanical factors
- Optimal training is unclear but economy is known to improve over many years
- It is possible that accumulating a high volume of endurance training over many years is necessary to ‘hone’ economy
- Consistent (high-volume?) training over many years seems to be key
- There is some evidence that altitude training and certain types of strength training might also benefit economy
Relative volumes of different training in experimental (E) and control (C) groups during 9-wk explosive-type strength and endurance training

Changes in running economy in explosive training and control conditions

Group–by–training interaction $p < 0.01$

$\dot{V}O_2$ (ml x kg$^{-1}$ x min$^{-1}$)

Weeks
Changes in 5 km performance in explosive training and control conditions

Group-by-training interaction p < 0.05
Blood lactate values are quite sensitive to improved endurance fitness.
Maximal Lactate Steady State
How to Improve LT and LTP?

- The blood [lactate] reflects the balance between muscle lactate production and lactate clearance
- A good volume of decent quality training is necessary to increase muscle mitochondrial density – which should reduce lactate production at any given exercise intensity
- Sustained ‘tempo’ exercise at and above the LTP might help to stimulate adaptation of the body’s ability to ‘clear’ lactate
- Regulating the intensity of continuous endurance exercise is very important in optimising the training effect
Training Zones

“Easy”  “Steady”  “Tempo”  “Interval”

LT  LTP

BLa (mmol/L) vs. Running Speed km/h

HR (b/min) vs. Running Speed km/h
VO$_2$ Kinetics

Phase I: "Cardiodynamic"
Phase II: Muscle VO$_2$ (?)
Phase III: Steady-State

Time (s)
The Time Constant ($\tau$) and Error Signal for VO$_2$ Kinetics

$$y = BL + \text{Amp}(1 - e^{-t/\tau})$$

$BL$: Baseline

$Amp$: Amplitude

$Error$ $Signal$
$\Delta VO_2$ (% final VO$_2$)

Time (min)

O$_2$ Deficit

$\tau=10\text{s}$

$\tau=45\text{s}$

$\tau=90\text{s}$
O₂ Deficit and Fatigue

O₂ Deficit = MRT x Amplitude

- A LARGER O₂ deficit means:
  - greater PCr breakdown
  - greater ADP and Pi accumulation
  - greater H⁺ and lactate accumulation
  - greater rate of glycogen degradation
Effects of interventions on \( \text{Vo}_2 \) kinetics and performance during high-intensity exercise
Training
**Vo₂ kinetics are very fast in elite endurance athletes**

Jones and Koppo (2005)
Acute endurance training enhances $\text{Vo}_2$ kinetics

Carter et al. (2000)
Low-intensity or high-intensity training?


Influence of continuous and interval training on oxygen uptake on-kinetics.
Berger NJ, Tolfrey K, Williams AG, Jones AM.

A continuous training group that completed three to four sessions per week of 30-min duration at 60% VO2peak (LO); an interval training group that completed three to four sessions per week involving 20 x 1-min exercise bouts at 90% VO2peak

Continuous and interval training were similarly effective in reducing the amplitude of the VO2 slow component
Repeated sprint training also effective in improving VO$_2$ kinetics

**Moderate**

- RST Post $\tau_p = 18$ s
- RST Pre $\tau_p = 30$ s

**Severe**

- RST Post $\tau_p = 17$ s
- RST Pre $\tau_p = 28$ s

- ET Post $\tau_p = 21$ s
- ET Pre $\tau_p = 23$ s

- ET Post $\tau_p = 35$ s
- ET Pre $\tau_p = 38$ s
Enhanced exercise tolerance correlated with improved $\text{VO}_2$ kinetics
Warm-Up/Priming
“Priming” Exercise

A

80% LT/80% LT

B

80% LT/50% Δ

C

50% Δ/80% LT

D

50% Δ/50% Δ

Gerbino et al. (1996)
Time course of the priming effect
Optimizing the “priming” effect: influence of prior exercise intensity and recovery duration on O₂ uptake kinetics and severe-intensity exercise tolerance

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Interaction of prior exercise intensity and subsequent recovery duration

Figure 2
Optimal ‘warm-up’ enhances performance

Pre-exercise blood [lactate] of ~ 3 mM appears to be optimal

Prior *high-intensity* exercise coupled with *sufficient* recovery optimizes the balance between preserving the effects of prior exercise on VO₂ kinetics and providing sufficient time for muscle homeostasis to be restored.
“In elite middle-distance athletes, 800-m time-trial performance was significantly faster following HWU (HWU, 124.5 ± 8.3 vs. CON, 125.7 ± 8.7 s, P<0.05).”
Effects of interventions on \( \text{Vo}_2 \) kinetics and performance during high-intensity exercise

- EPO, APVE, Hyperoxia
- Training, Priming, Nitrate, Bicarbonate, Hyperoxia

![Graph showing changes in oxygen uptake over time with interventions marked at different stages.](image-url)
Obrigado pela vossa atenção!