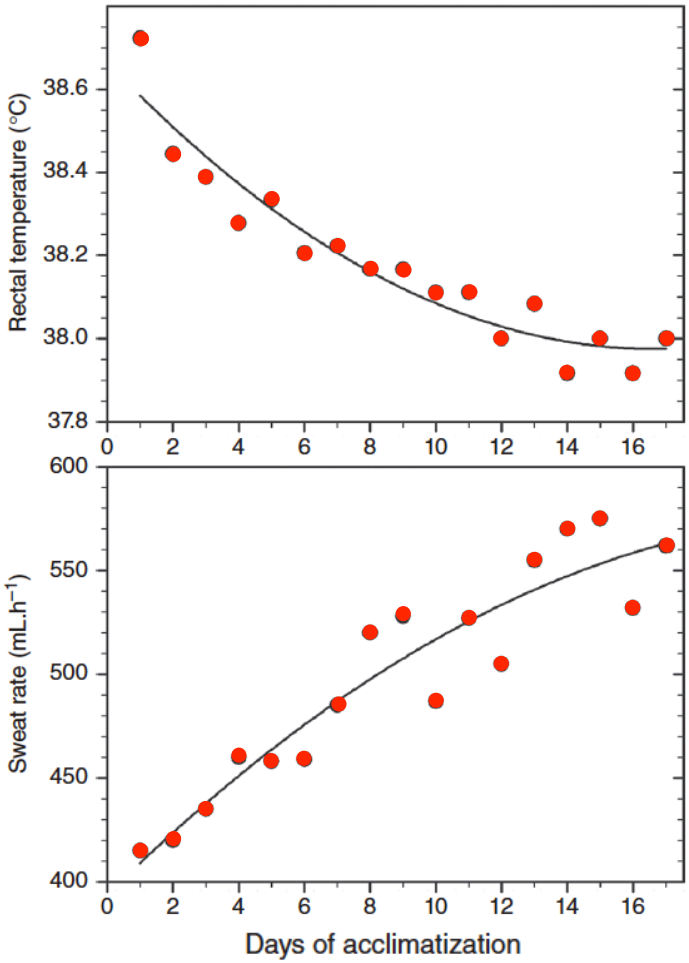
Brunel University London

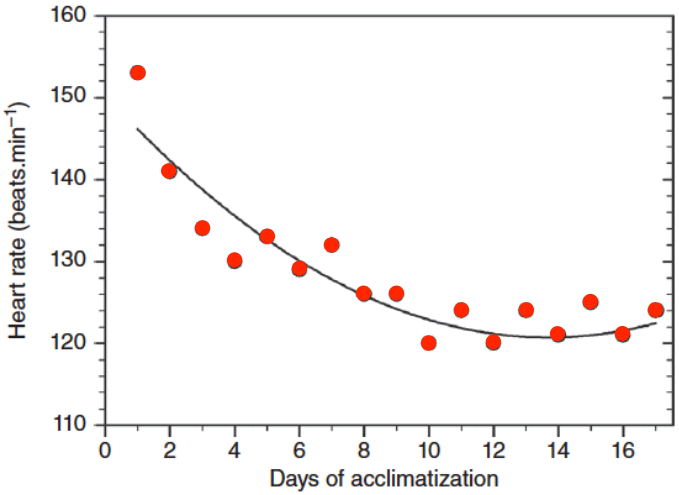
Heat Adaptation

José González-Alonso

TOKYO 2020

Reduced physiological strain during exercise with heat acclimation



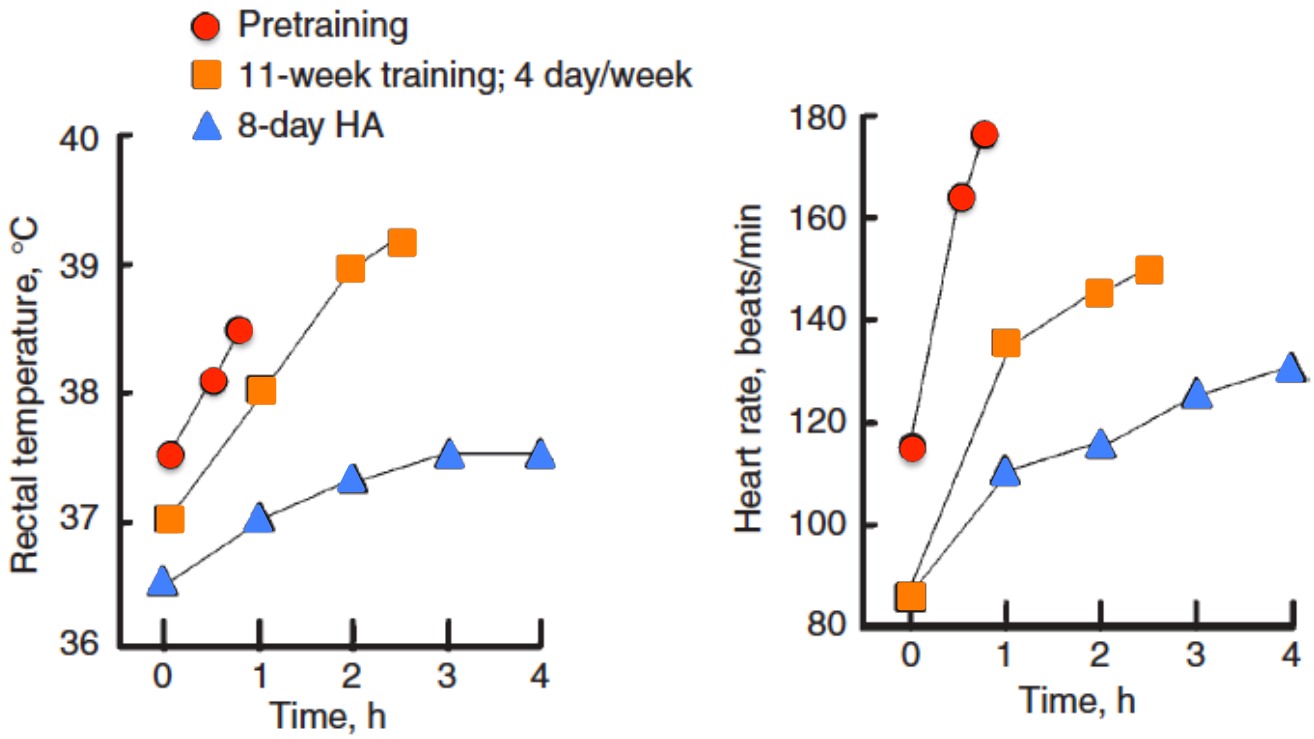


T_c ↓
HR ↓
SR ↑

Bench stepping 12 steps/min,
4 h at 34°C, 80% relative humidity

Wyndham et al. *J Appl Physiol* 25: 586-593, 1968

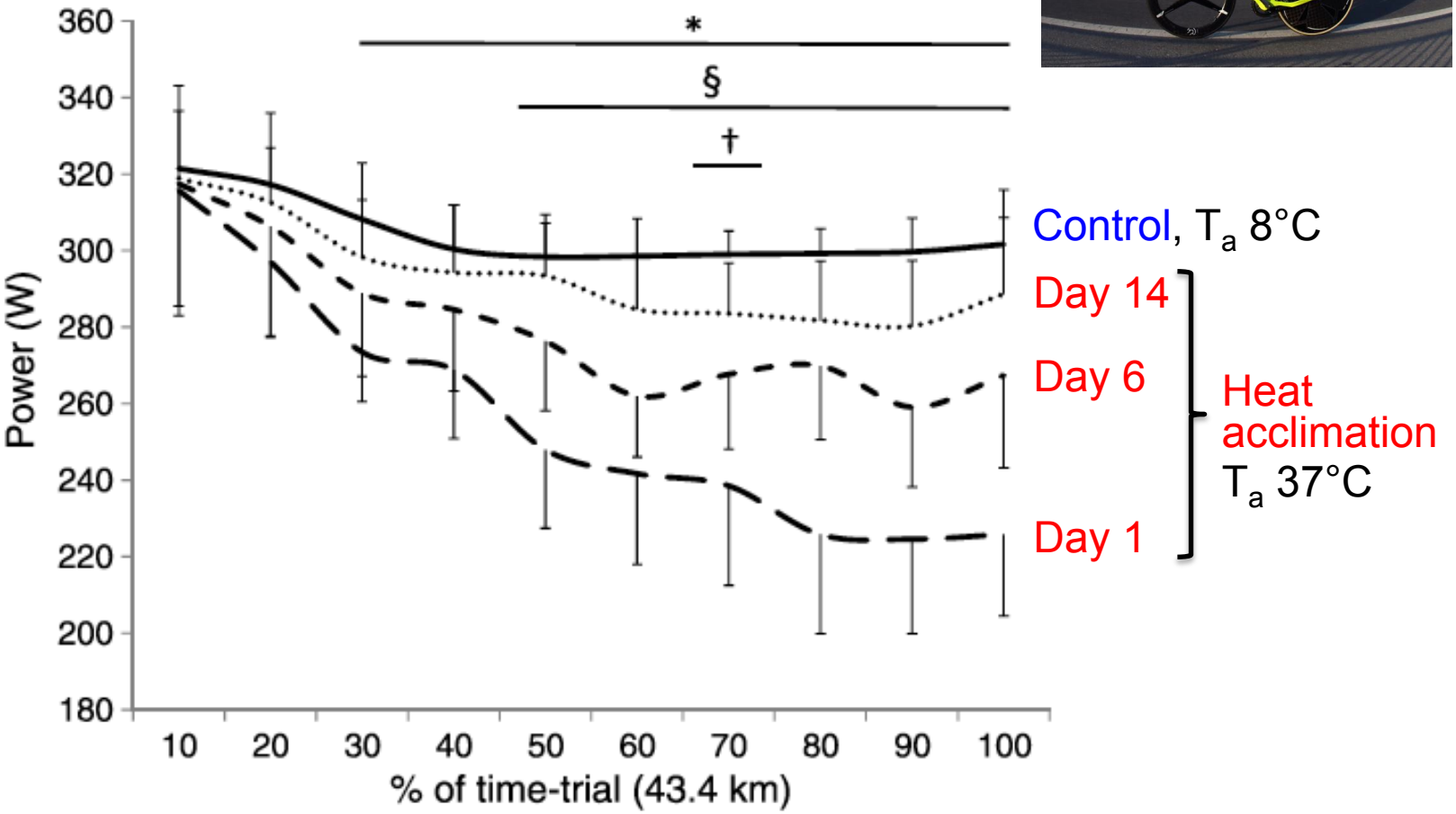
Benefits of aerobic training and heat acclimation on reducing physiological strain and improving endurance performance in the heat



Treadmill walking, 30-35% $\dot{V}O_{2max}$ in 6 young women

Cohen & Gisolfi. *Med Sci Sports Exerc* 14: 46-52, 1982

Improved time trial performance with heat acclimation in trained cyclists



Racinais et al. *Med Sci Sports Exerc* 14:46-52, 2015

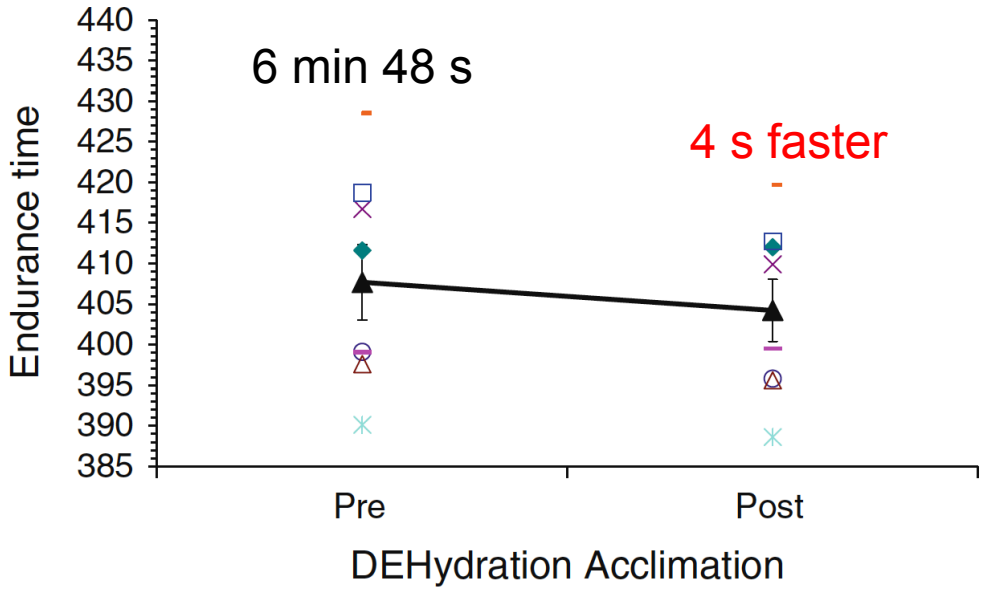
Time trial responses of trained cyclists

Variables	Control	Heat acclimation		
		Day 1	Day 6	Day 14
Final T_{re}, °C	38.5±0.6	40.2±0.4*	40.2±0.4*	40.1±0.4*
$HR_{mean,}$ beats/min	166±2	173±1*	170±3*	172±4*
Power $output_{mean}$, W	304±9	256±19*	280±19*	294±15
Time (min)	66±3	77±6*	69±4*	66±5

Mean±SD; n = 9; VO_{2max} 4.8 L/min; 62 mL/kg/min; 13-15 h training per week

Racinais et al. *Med Sci Sports Exerc* 14:46-52, 2015

Heat acclimation (5 days) and 2 km rowing performance

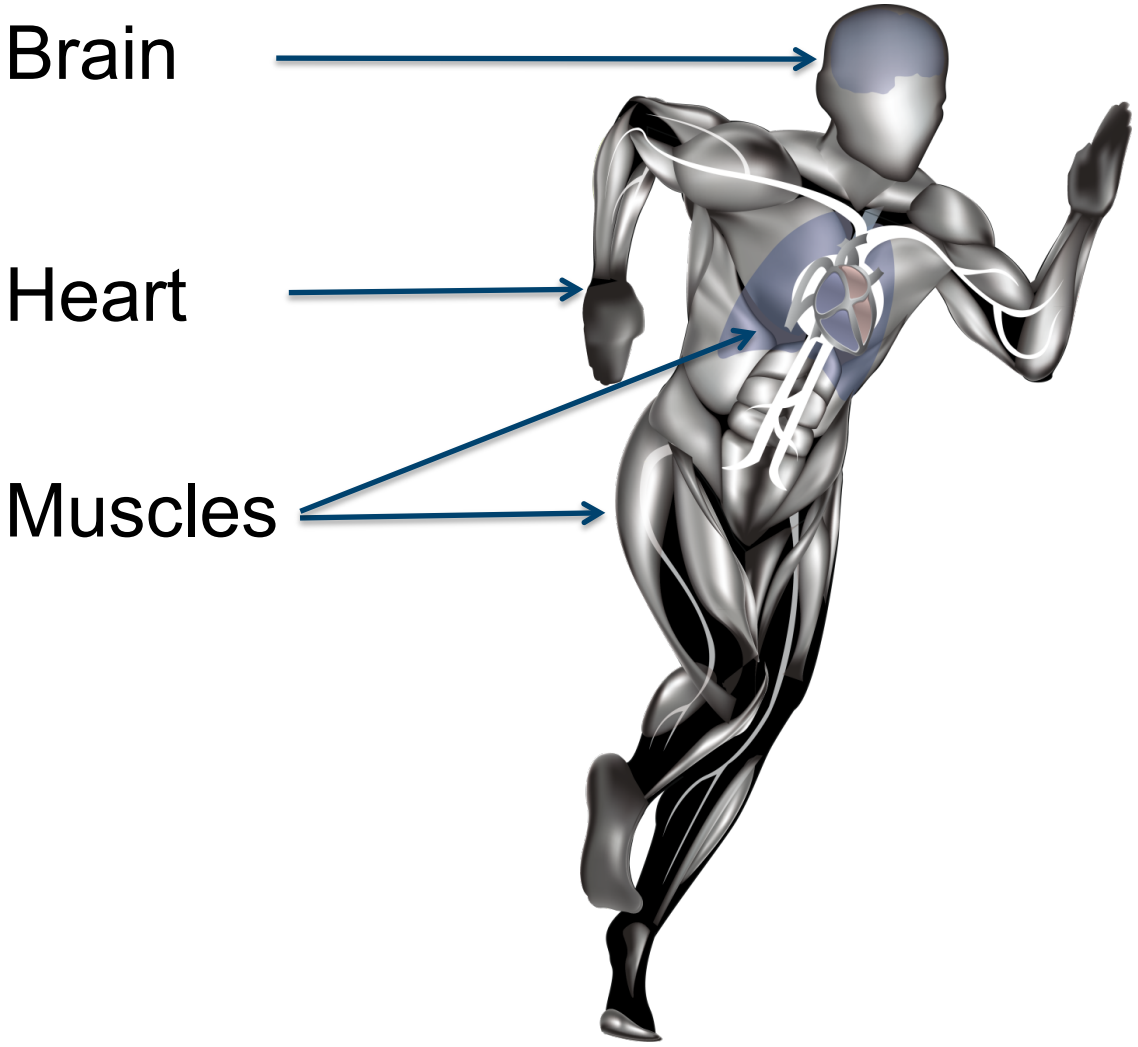


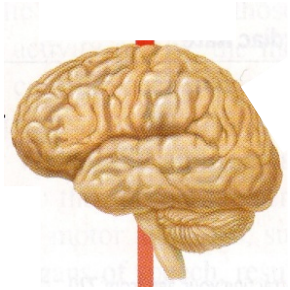
90-min rowing
T_a = 40°C, 60% rh
N = 9 rowers
VO_{2max} = 66 mL/kg/min

Tokyo 2020
30°C and ≥ 60% rh

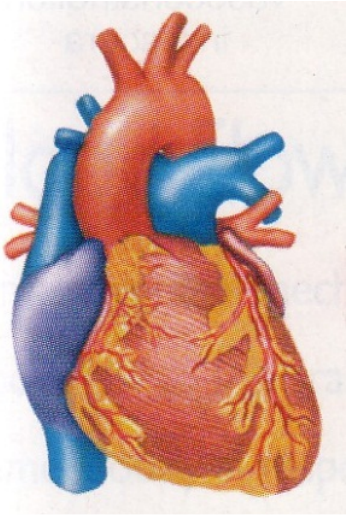
Garret et al. *Eur J Appl Physiol* 112:1827-1837, 2012

What determines maximal endurance performance?



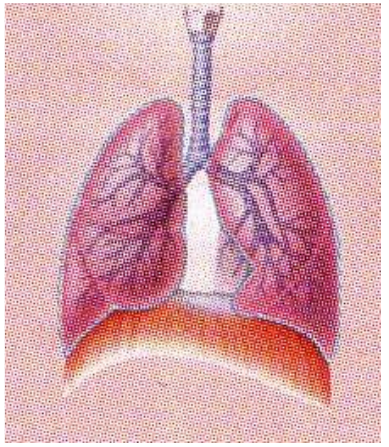


Cerebral circulation



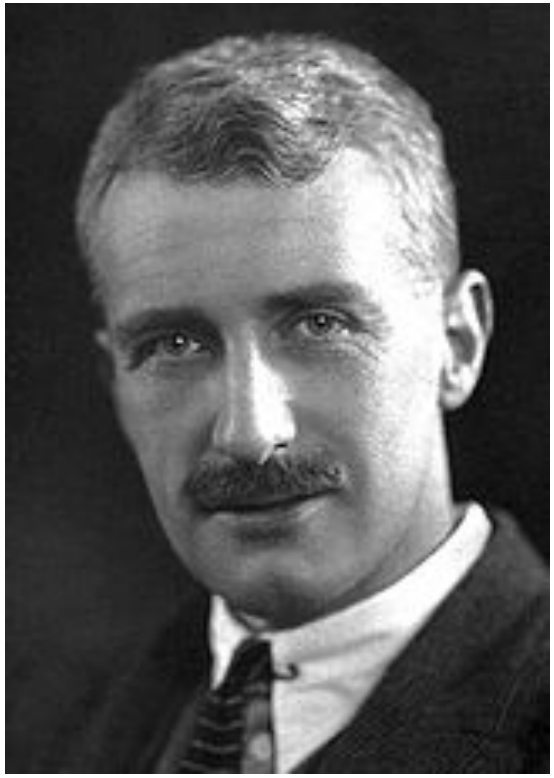
Heart circulation

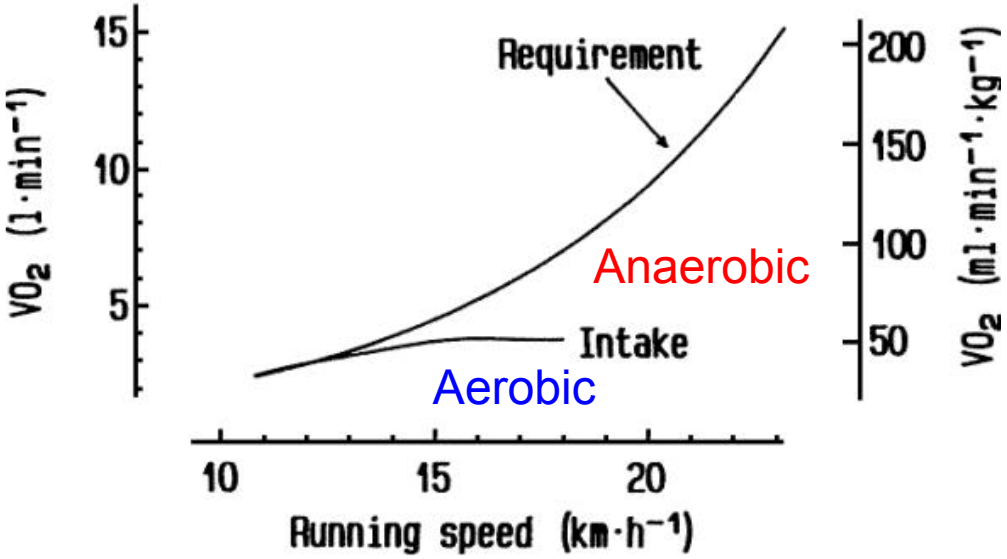
Skeletal muscle circulation



Respiratory muscle circulation

Classic fatigue paradigm: energy provision *vs.* energy utilization



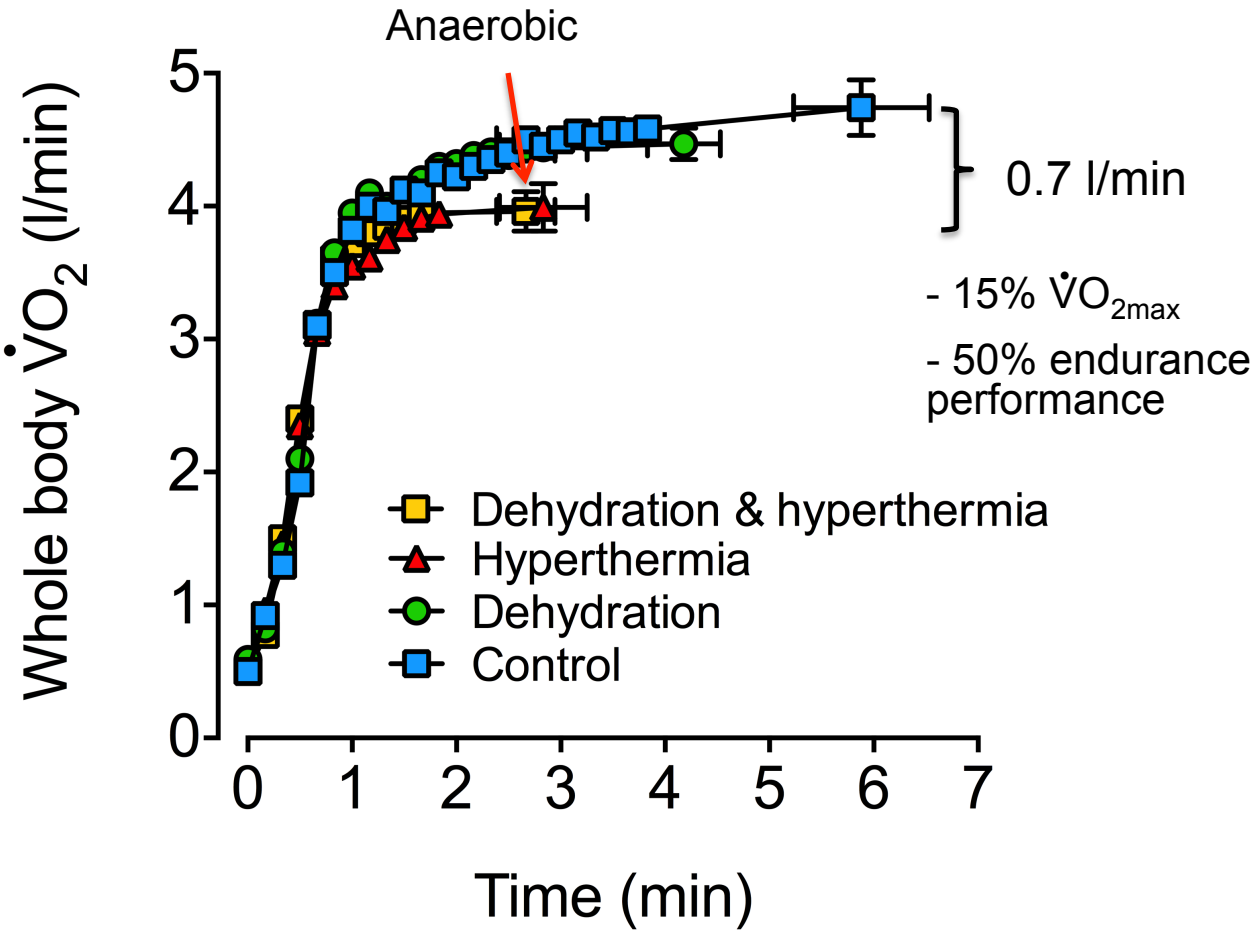


Hill & Lupton. Quart Res J, 1923

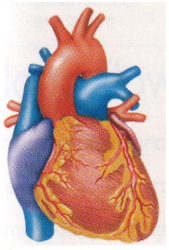
Archibald Vivian Hill (1886 – 1977) shared the 1922 Nobel Prize in Physiology or Medicine for his elucidation of the production of heat and mechanical work in muscles.

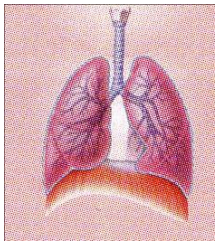
Compromised $\dot{V}O_{2max}$ during maximal endurance exercise

Cycling ≈ 400 W



Nybo et al. *J Appl Physiol* 90: 1057-1064, 2001





Ohm's law

Fick principle

Pressure

MAP

II

$\dot{V}O_2$ = Flow (CO) x a-$\bar{v}O_2$ diff

X

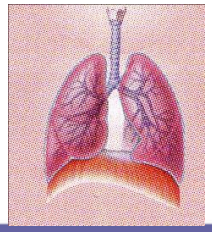
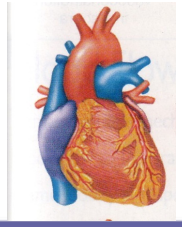
Resistance

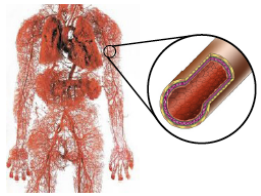
TPR

Determinants of the O_2 transport and utilization chain according to the Fick Principle

Organ Systems and Pathways in O_2 Uptake Process [Convection (Delivery), Release, Diffusion, and Use]

$$\dot{V}O_2 = CO \times (C_aO_2 - C_vO_2)$$


Pulmonary	Cardiac	Hematologic	Vascular	Mitochondrial
Ventilation/Gas Exchange	Stroke Volume Heart Rate	Hb Concentration Mediators of Release	Vasoregulation Capillary Network	Krebs Cycle-ATP Generation
O_2 Diffusion (Alveolar)	O_2 Delivery	O_2 Delivery and Release	O_2 Diffusion	O_2 Use (Extraction)

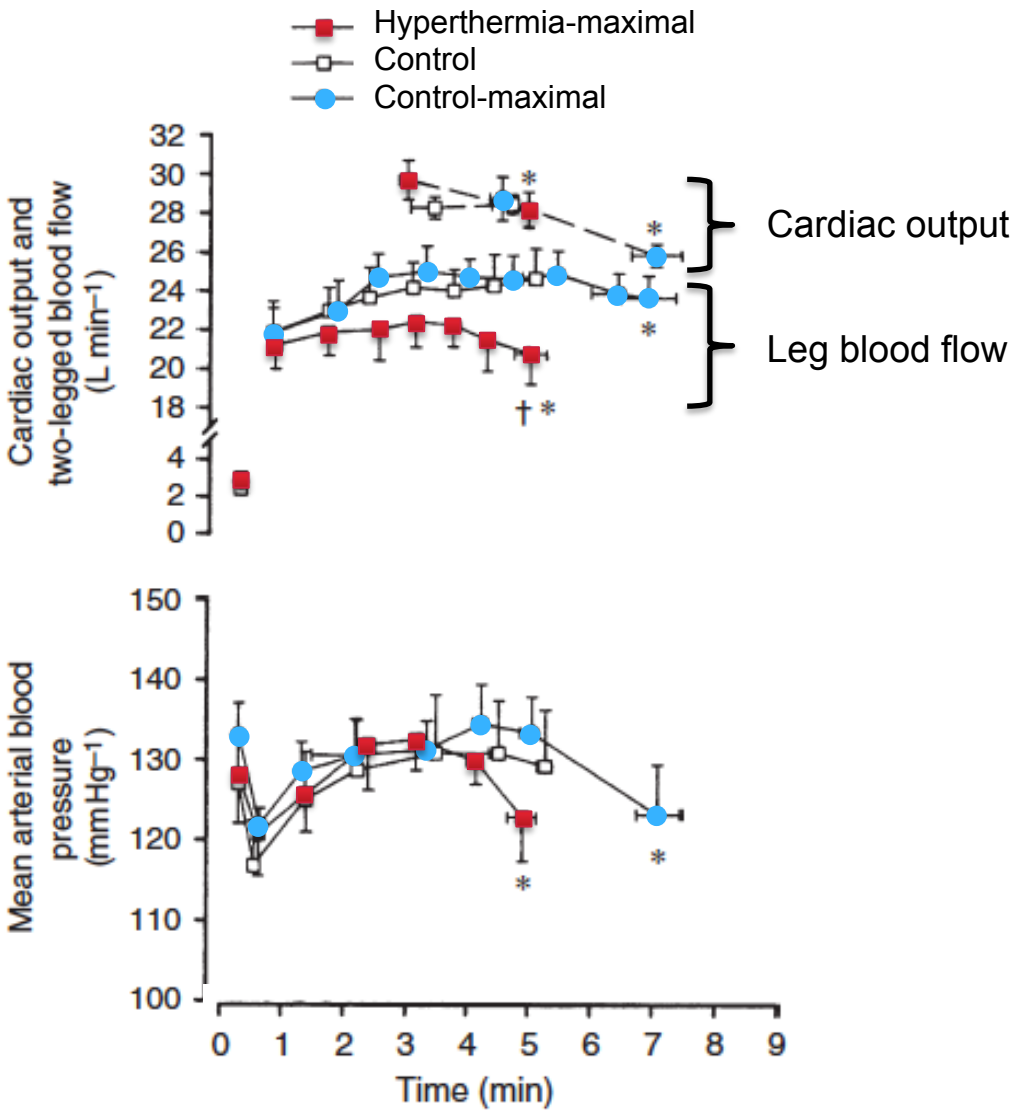
Modified from Gauzzi et al. *J Am Coll Cardiol* 70: 1618-1636, 2017

Impaired blood flow during maximal aerobic exercise

Hyperthermia

Control

≈ 360 W

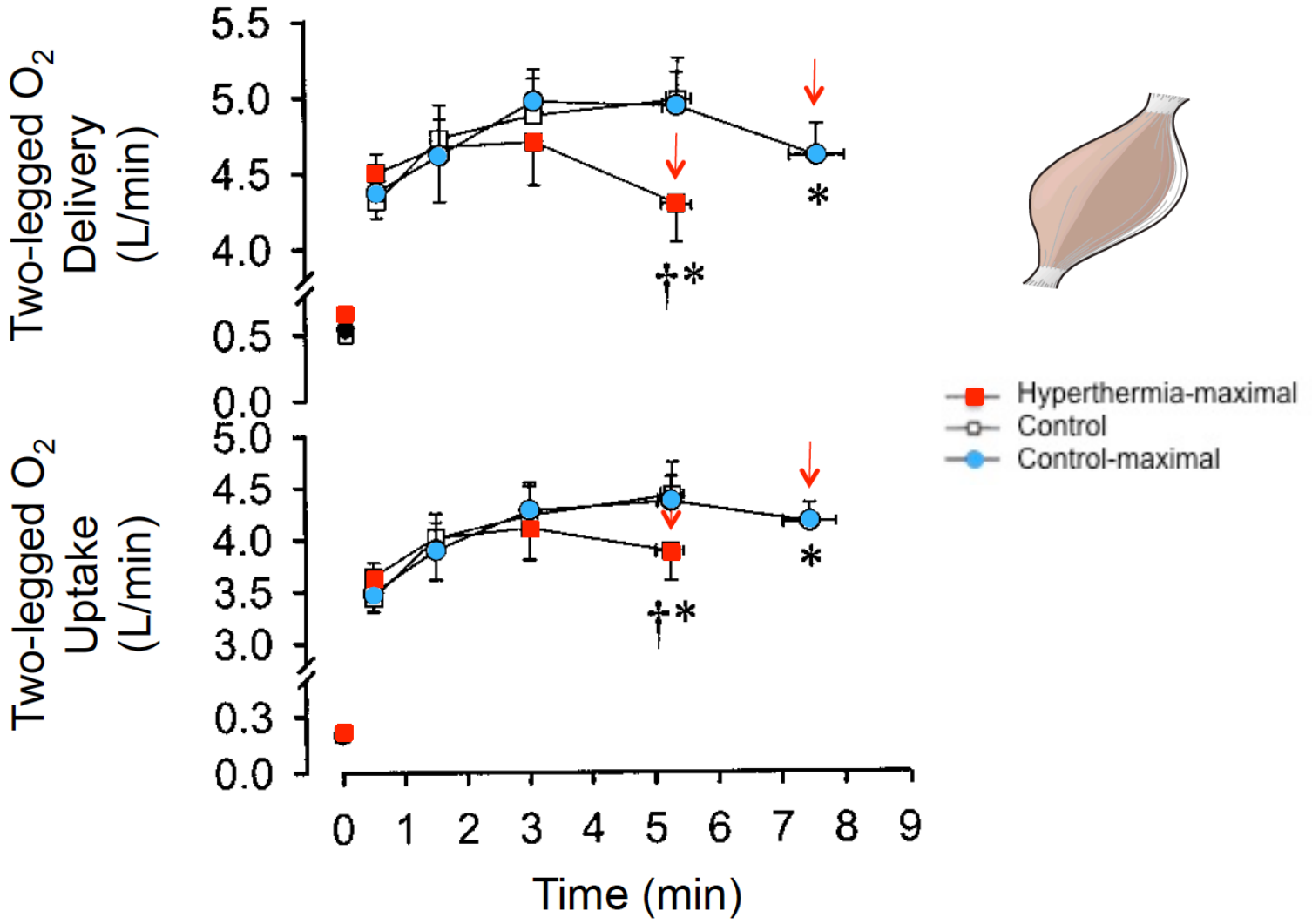


González-Alonso & Calbet *Circulation* 107: 824-830, 2003

Metabolic impact of lower muscle blood flow

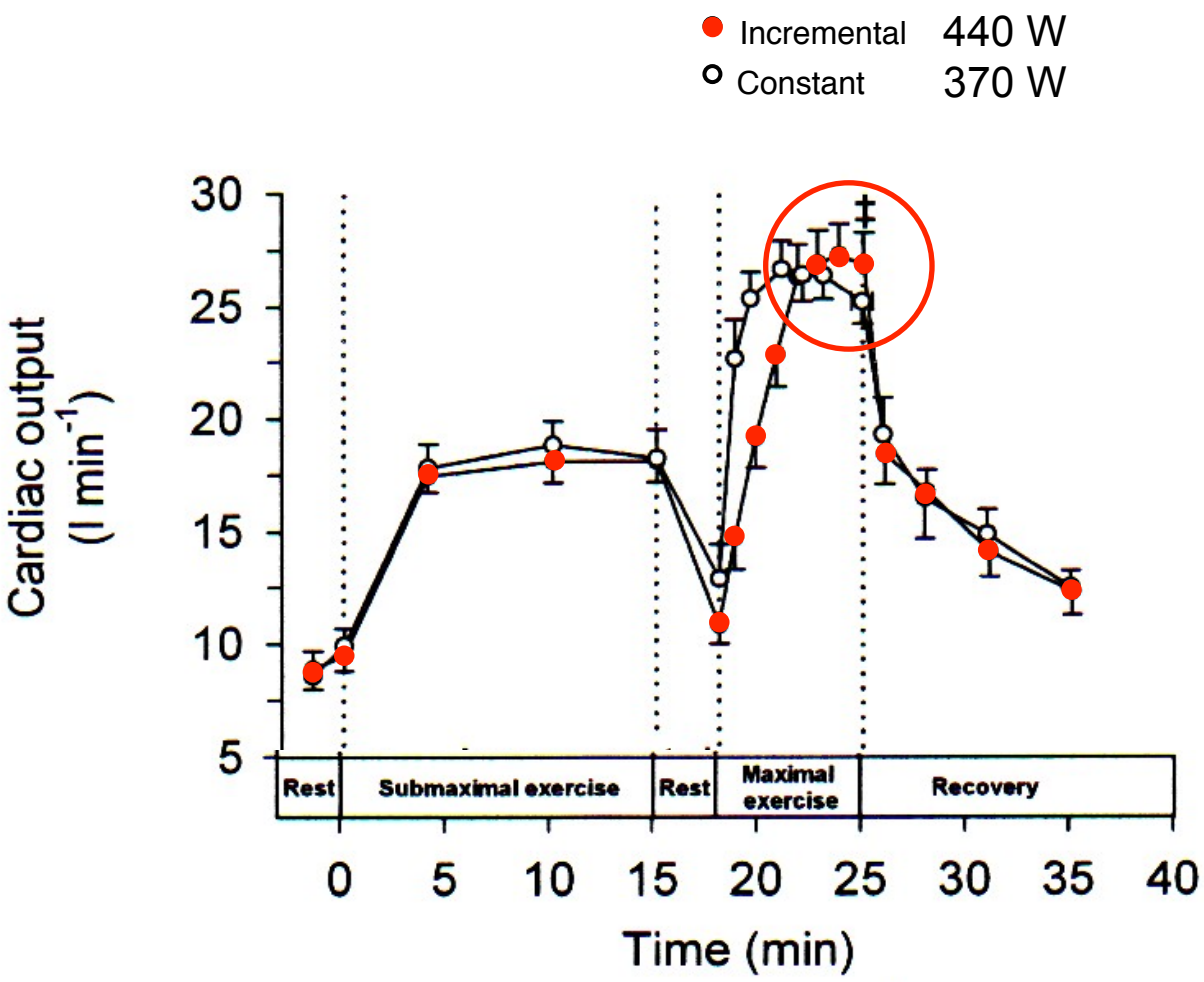
Leg $\dot{V}O_2$? = leg blood flow ↓ x $(C_aO_2 - C_{fv}O_2)$?

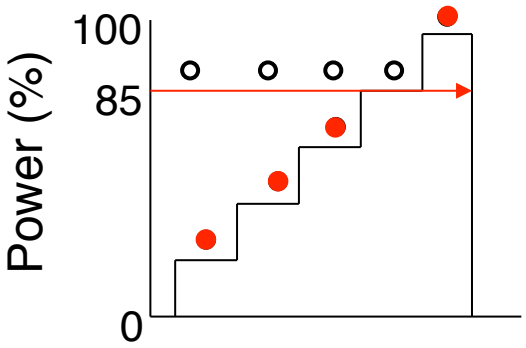
Active muscle metabolism is compromised during maximal endurance exercise



González-Alonso & Calbet *Circulation* 107: 824-830, 2003

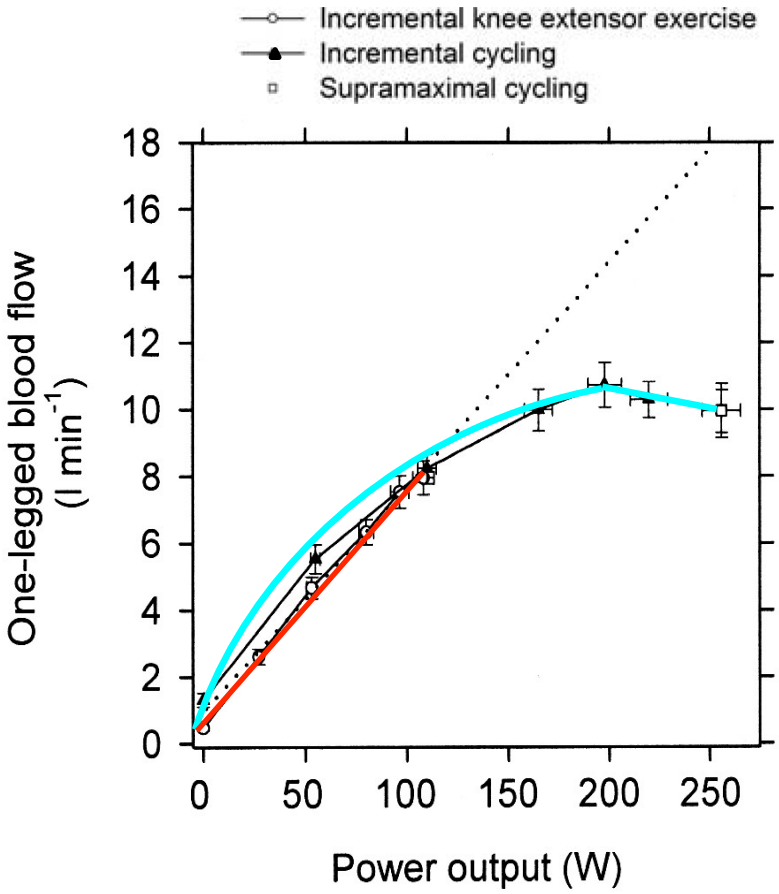
Limitations in cardiac output during constant load vs. incremental maximal endurance exercise

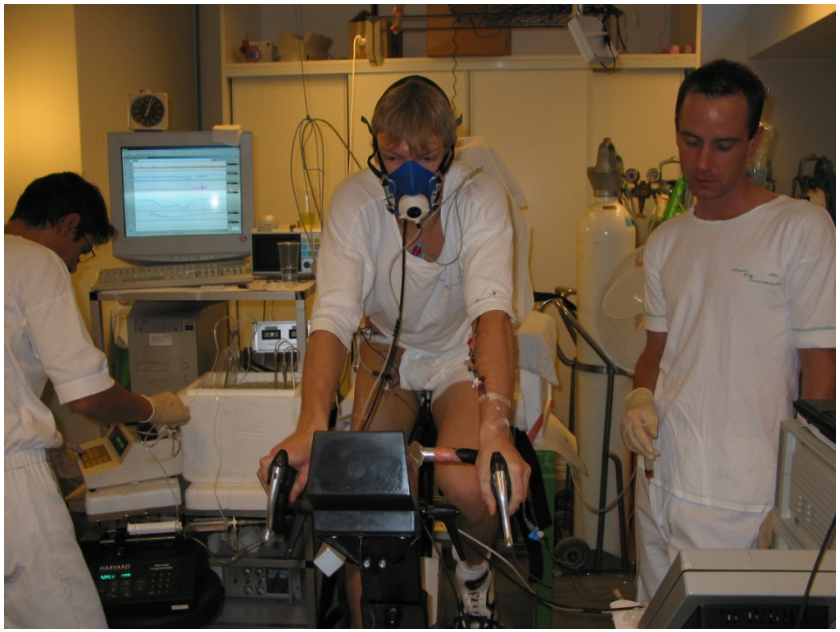




Mortensen et al. J Physiol 566: 273-285, 2005

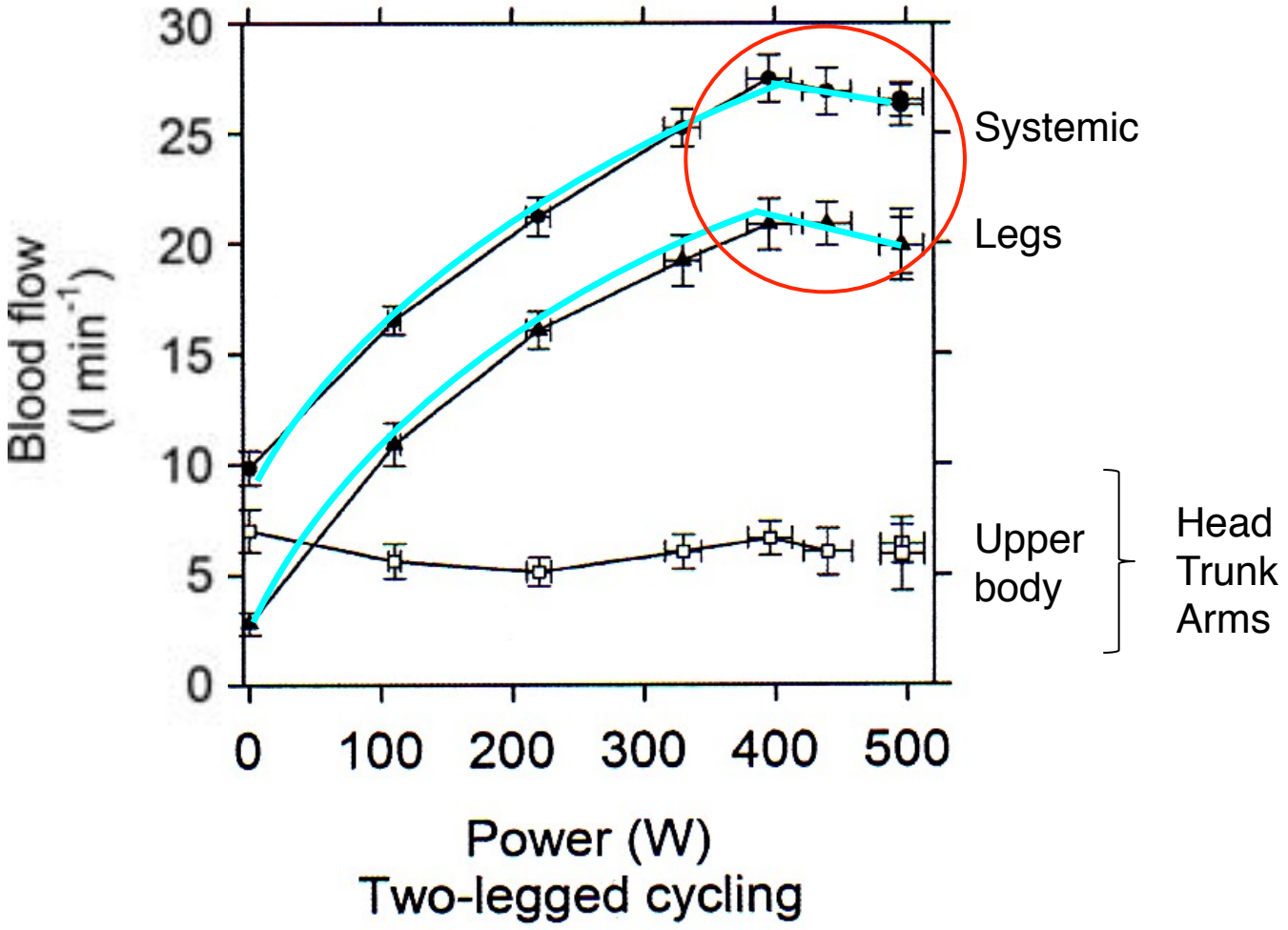
Plateau in locomotor limb blood flow during maximal cycling by not during maximal knee-extensor exercise





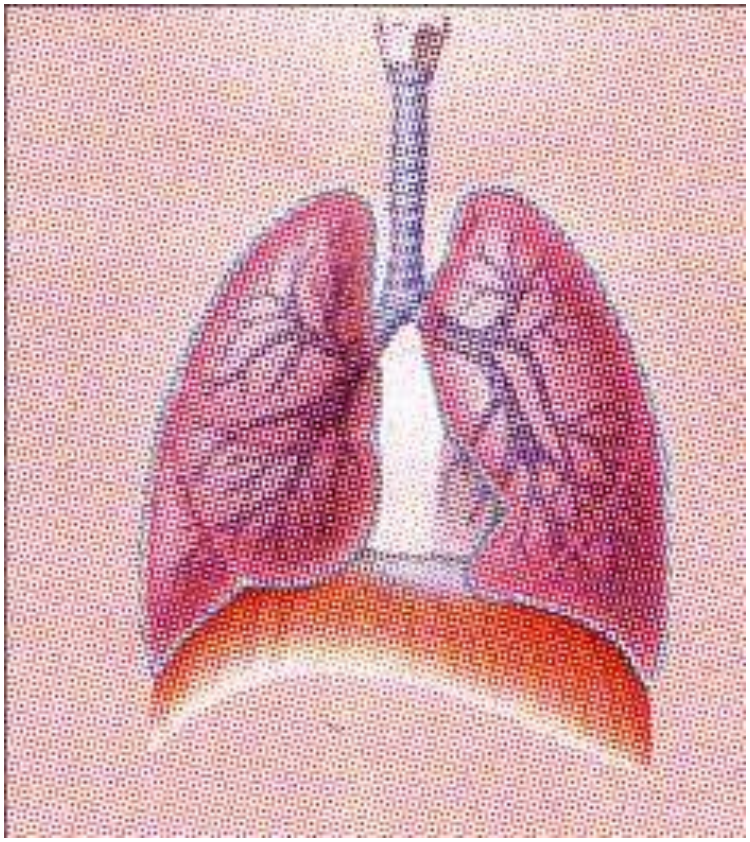
Mortensen et al. *J Physiol* 586: 2621-2635, 2008

Restrictions in systemic and locomotor limb blood flow during maximal endurance exercise

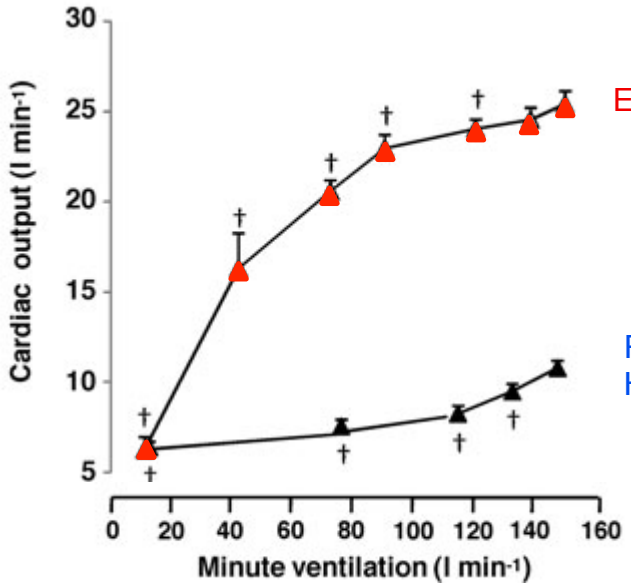


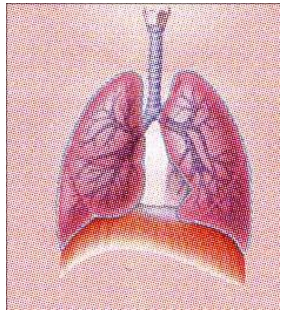
Mortensen et al. *J Physiol* 586: 2621-2635, 2008

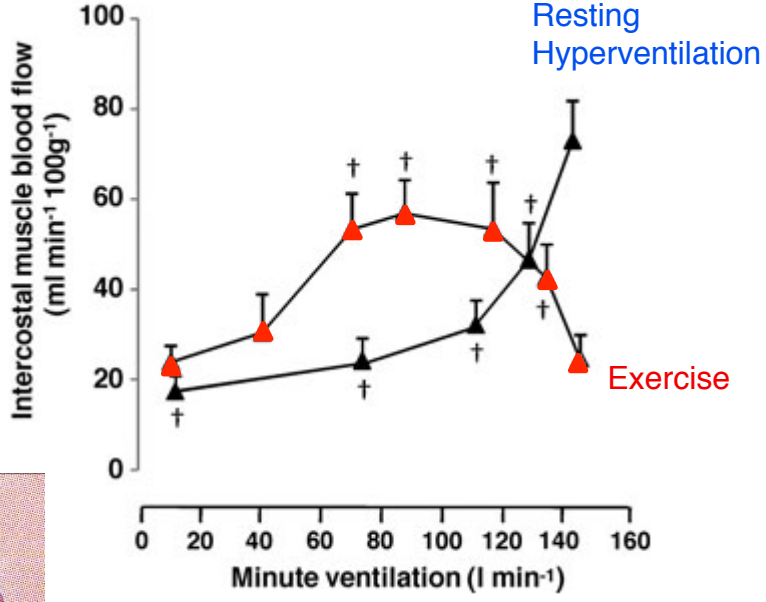
The respiratory muscle circulation



Reduced respiratory muscle blood flow during maximal endurance exercise

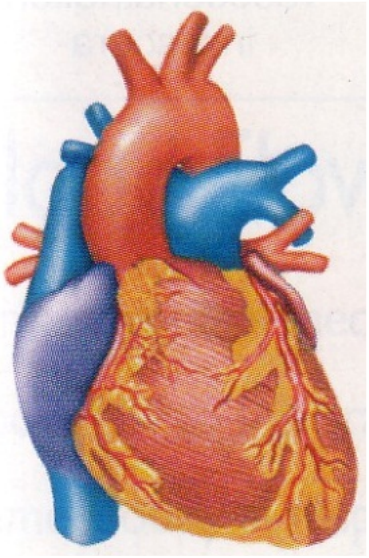




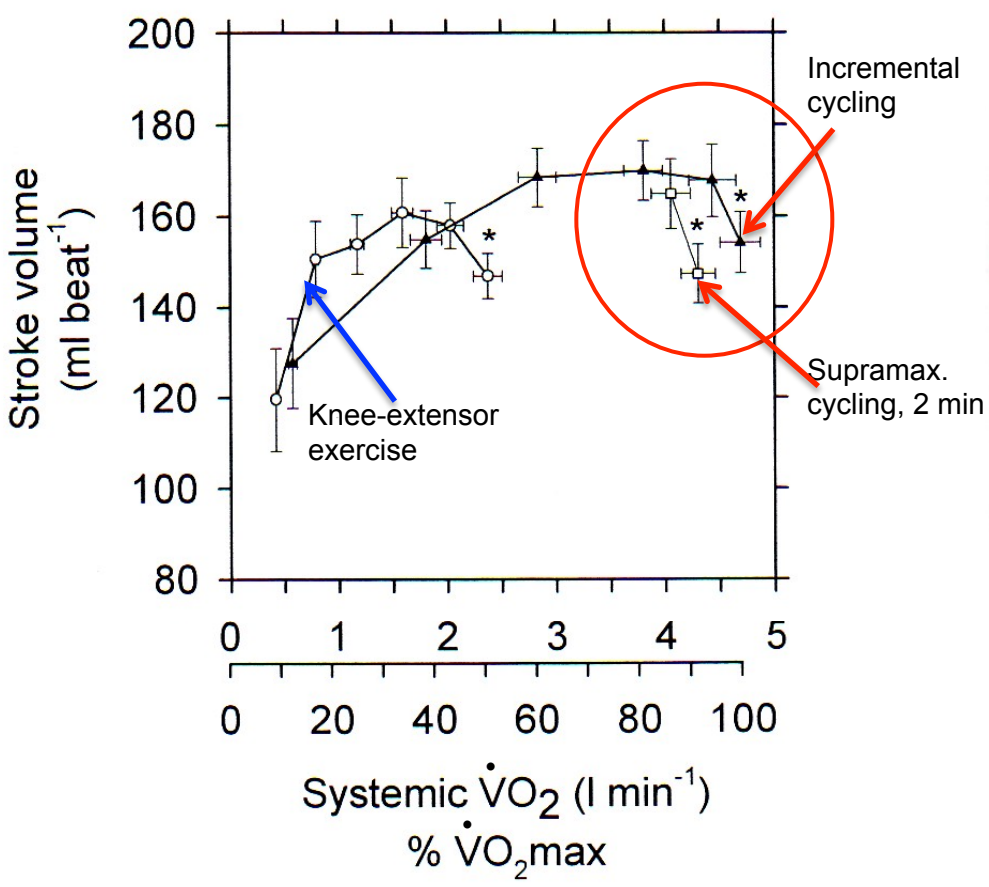


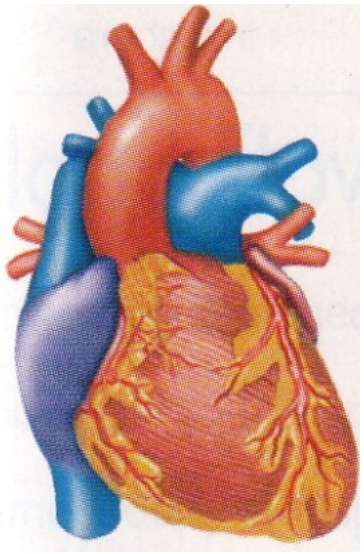
Vogiatzis et al. J Physiol 587: 3665-3677, 2009

The heart circulation



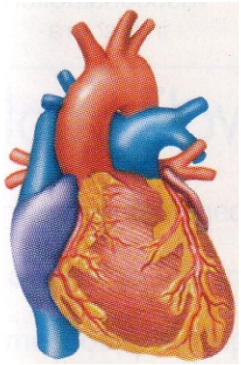
Stroke volume declines during maximal endurance exercise

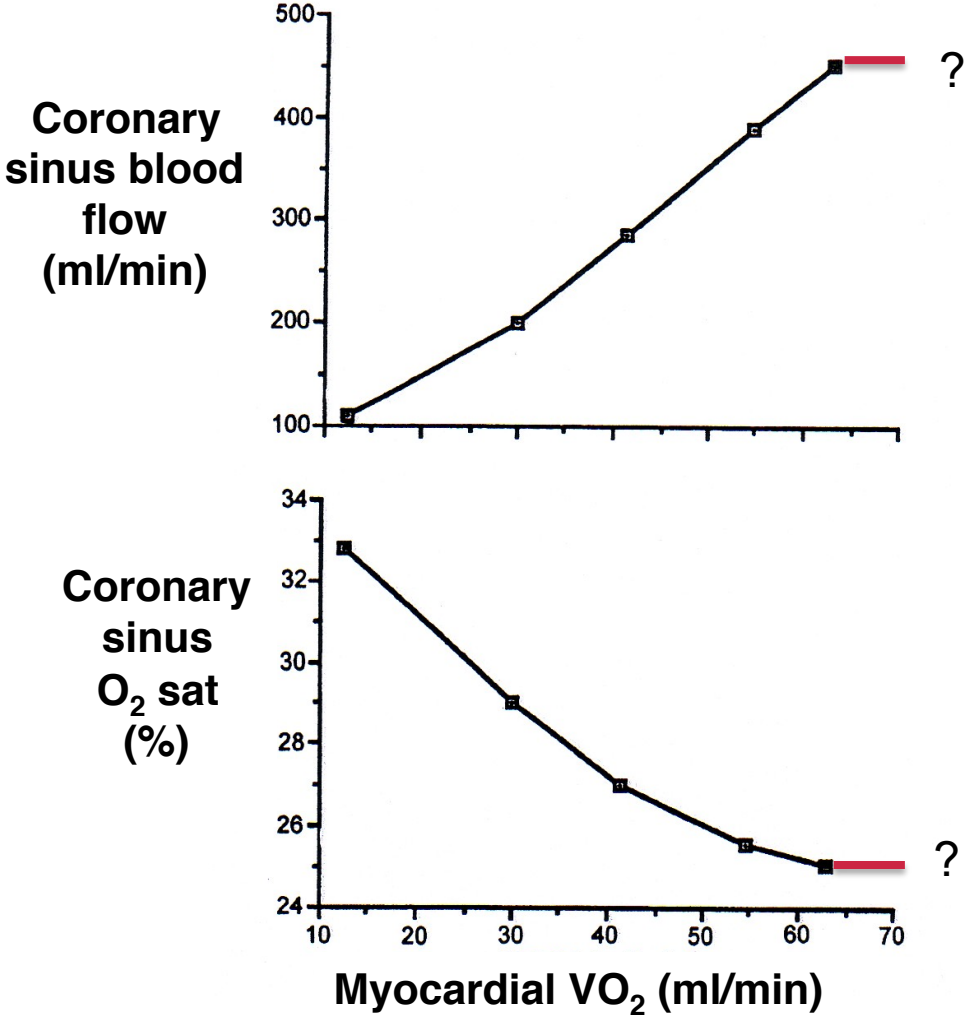




Mortensen et al. *J Physiol* 586: 2621-2635, 2008

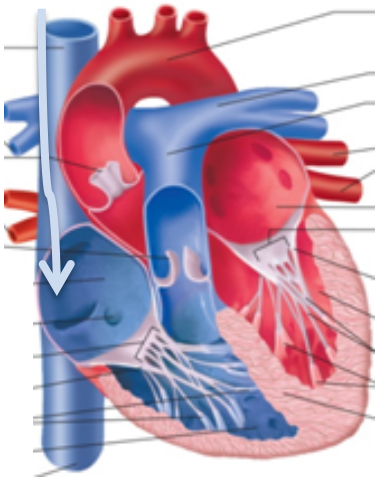
Heart circulation

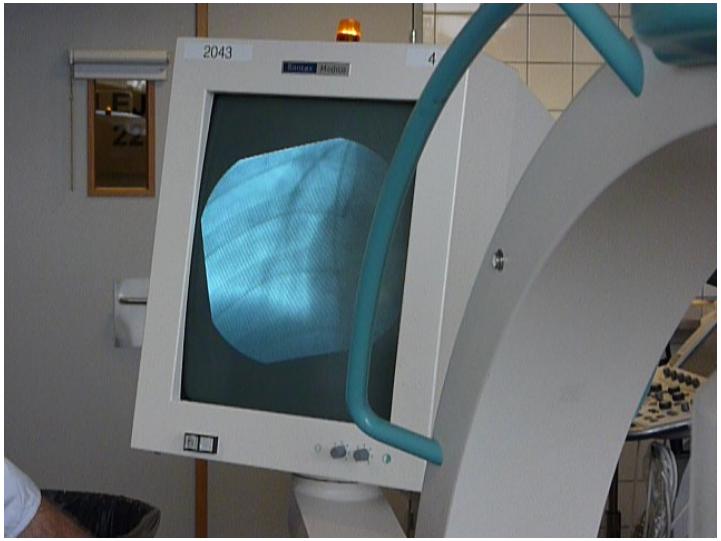




Kaijser & Kanstrup. Exercise & Circulation In Health and Disease, 1999.

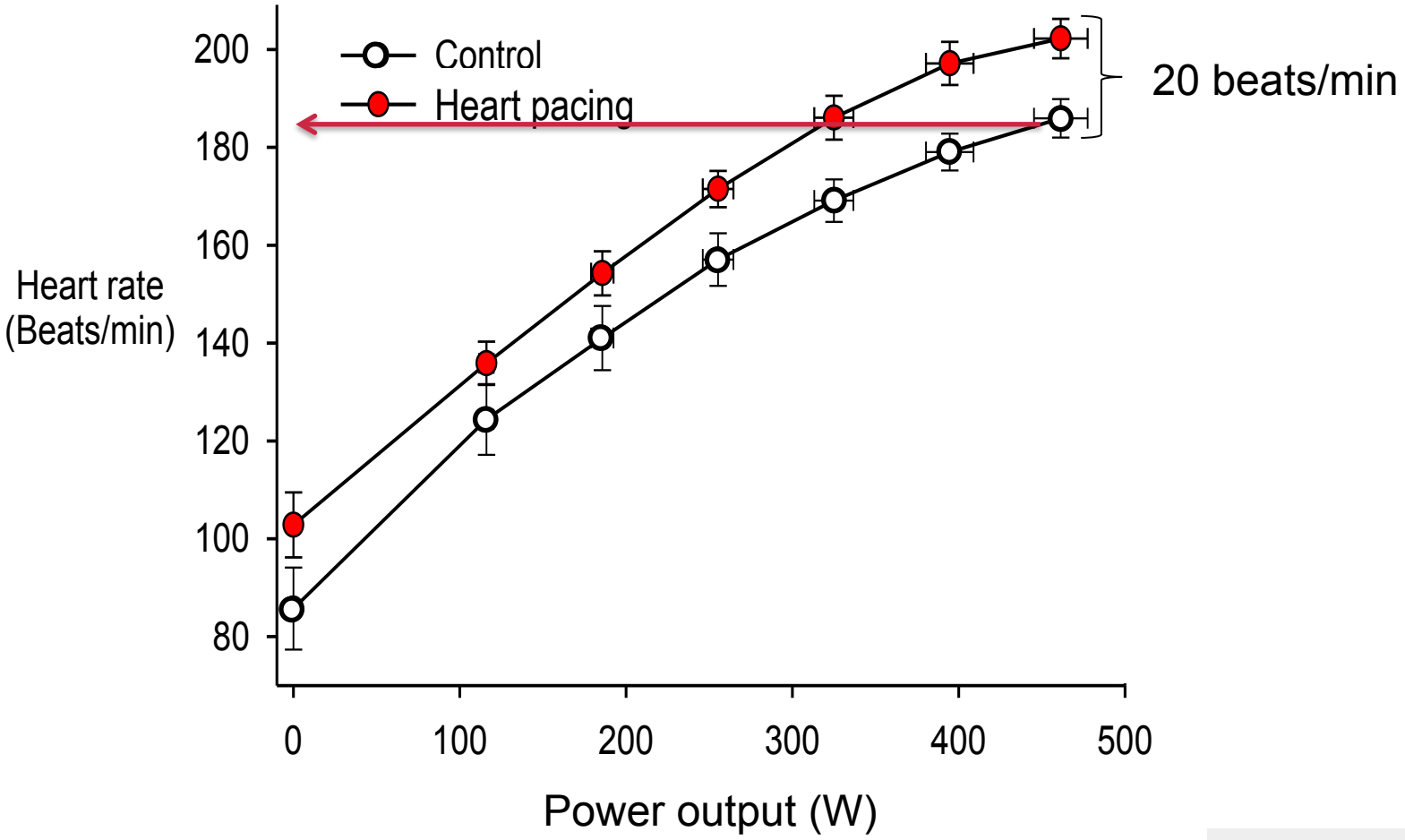
Does heart rate limit human cardiovascular capacity? Insight from heart pacing studies





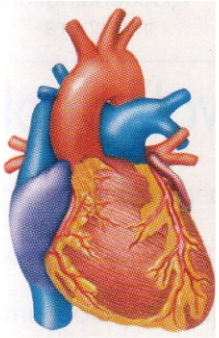
Munch et al . *J Physiol* 592: 377-390, 2014

Heart rate does not limit cardiovascular or aerobic capacity

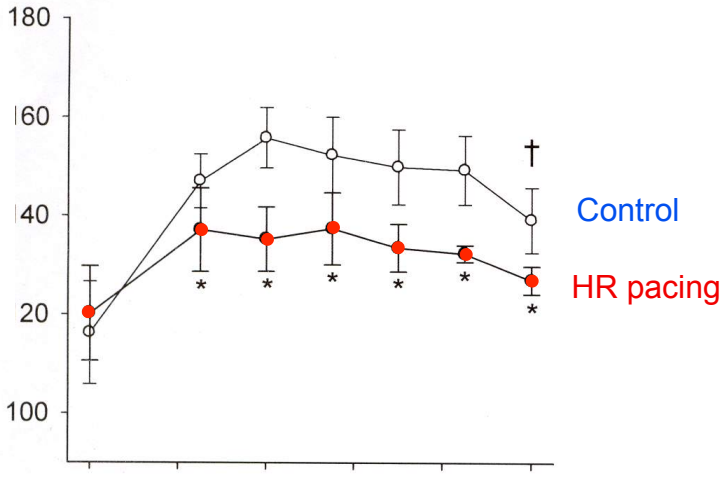


Munch et al . *J Physiol* 592: 377-390, 2014

Cardiac output and locomotor limb blood flow are unaffected by HR pacing

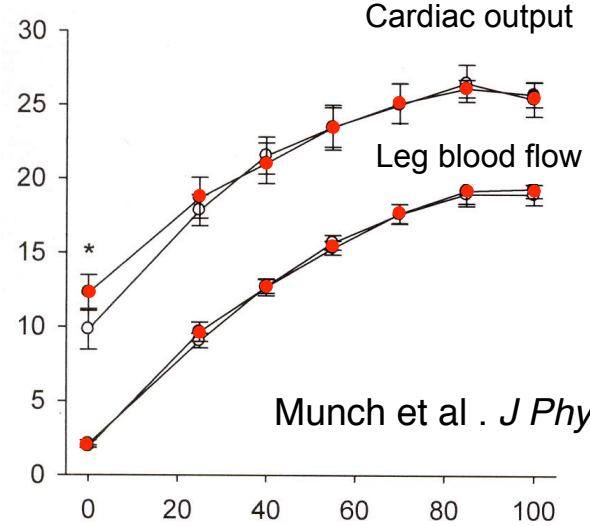


Stroke volume (ml/beat)



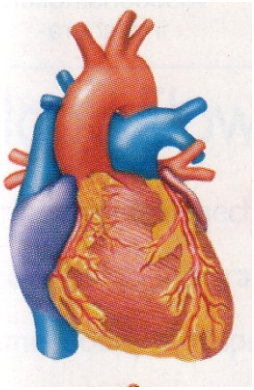
$\dot{Q}$ = HR ↑ x SV ↓

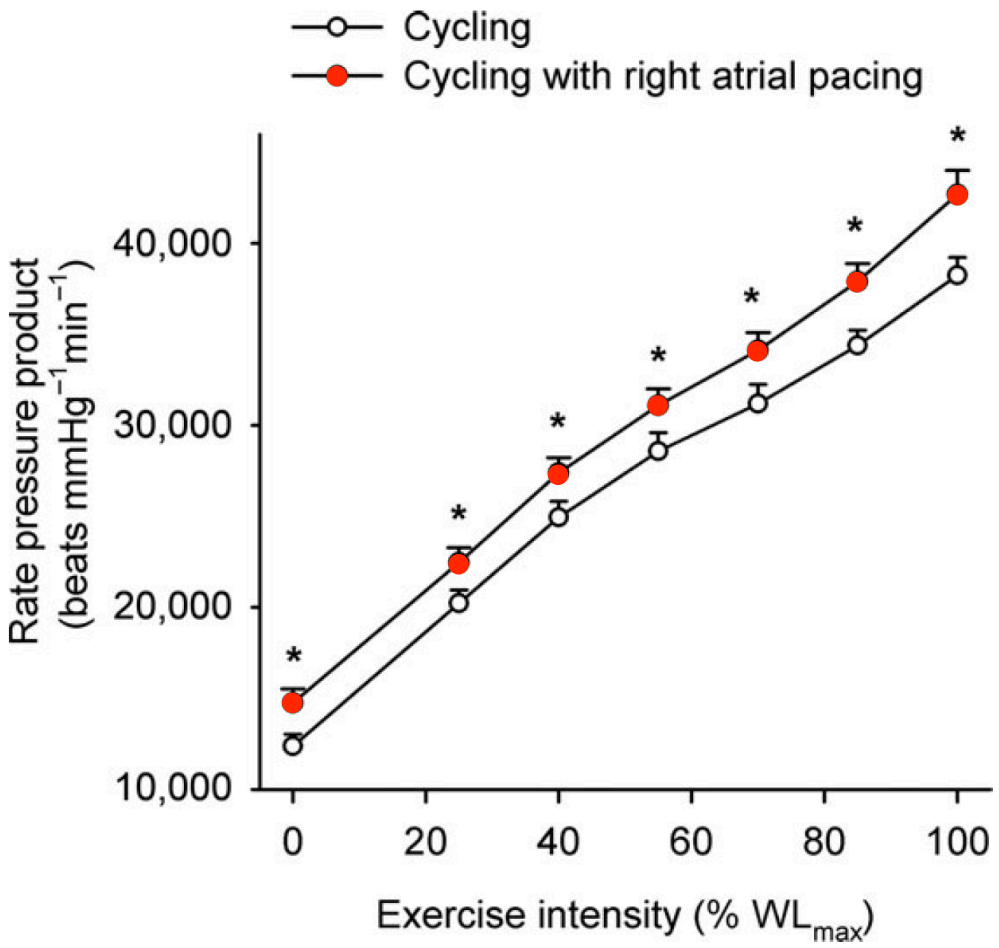
Blood flow (L/min)



Munch et al . *J Physiol* 592: 377-390, 2014

Myocardial $\dot{V}O_2$ is not limiting maximal endurance perfomance

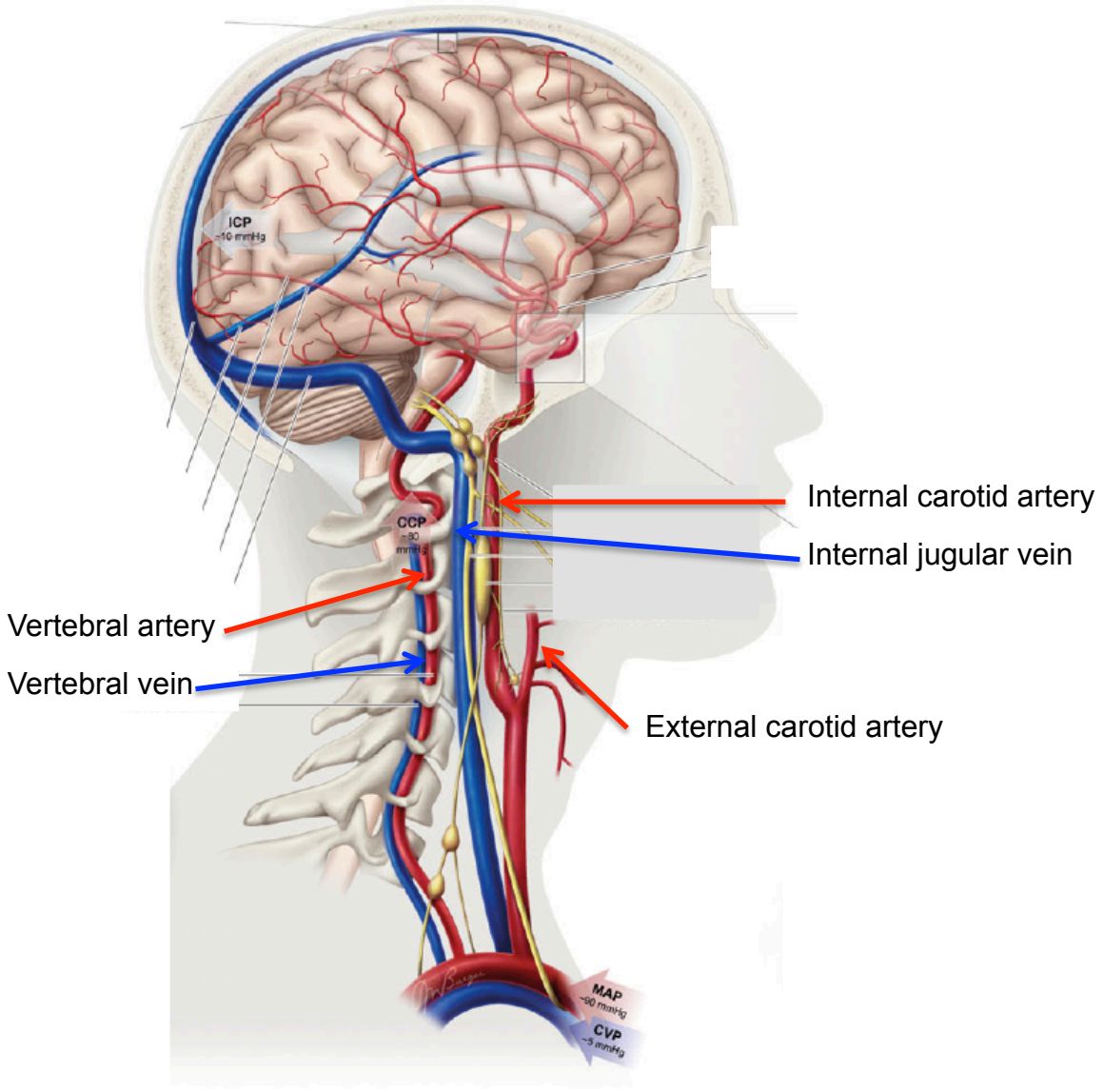




Munch et al . *J Physiol* 592: 377-390, 2014

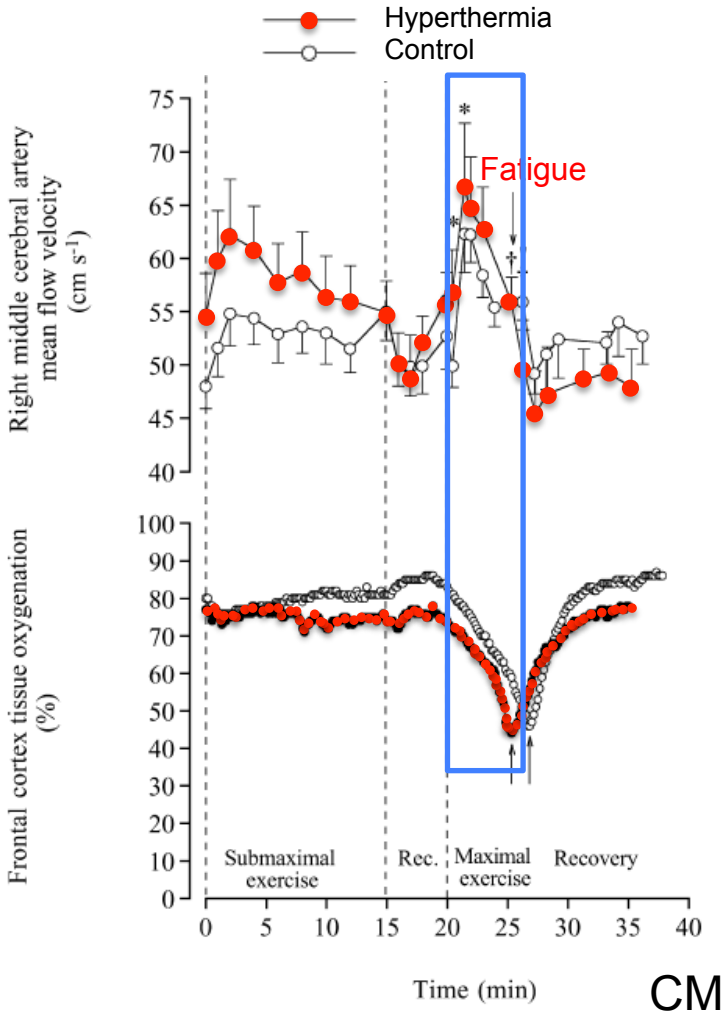
What is the impact on the human brain circulation and metabolism?

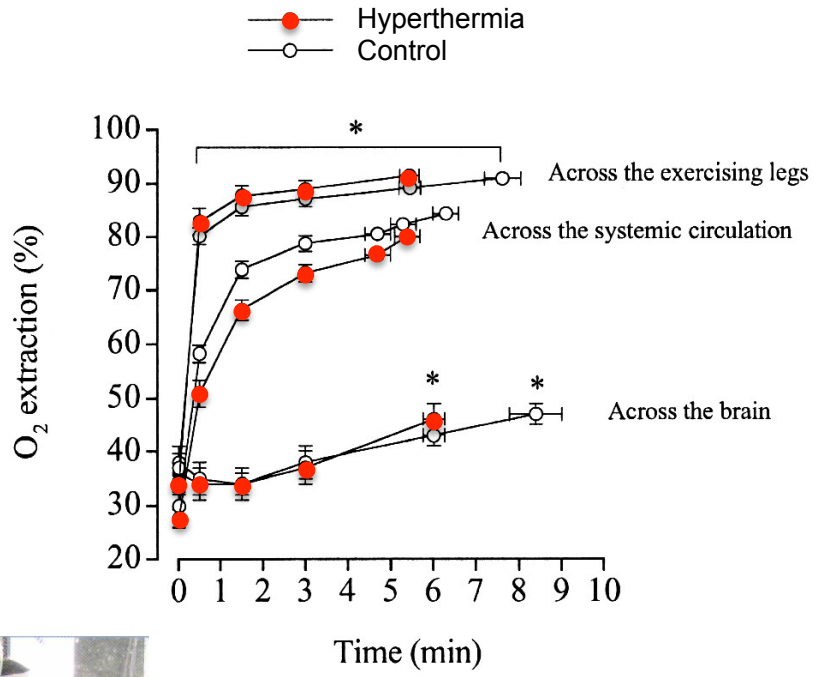
Arterial and venous brain circulation



Modified from Willie et al. *J Physiol* 592: 841-859, 2014

Brain flow limitations during maximal endurance exercise





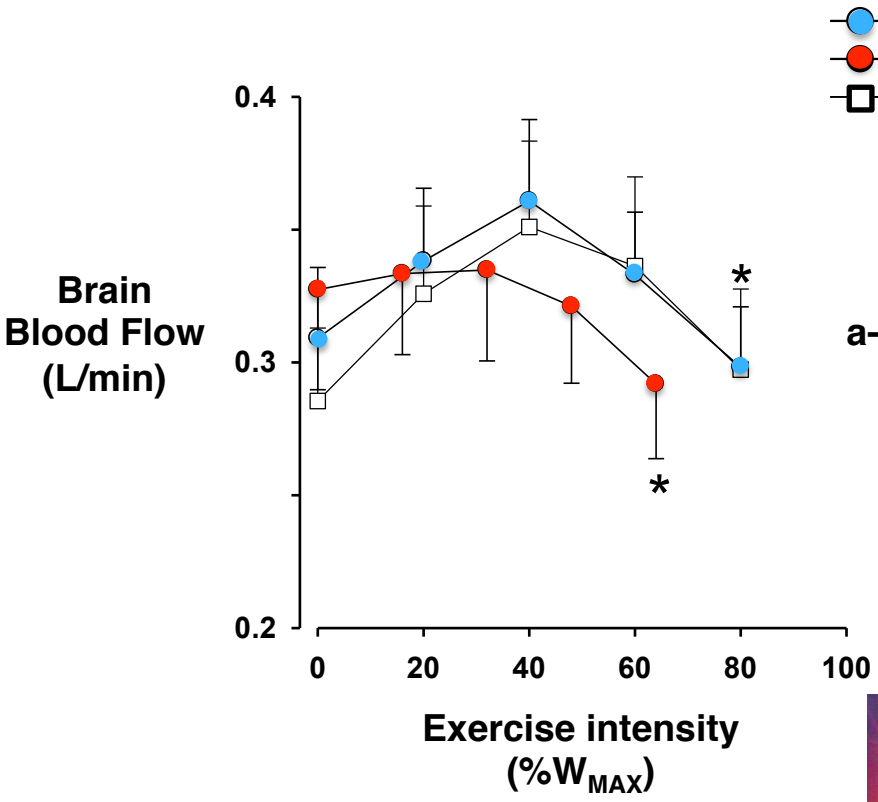
brain a-v O_2 diff ↑

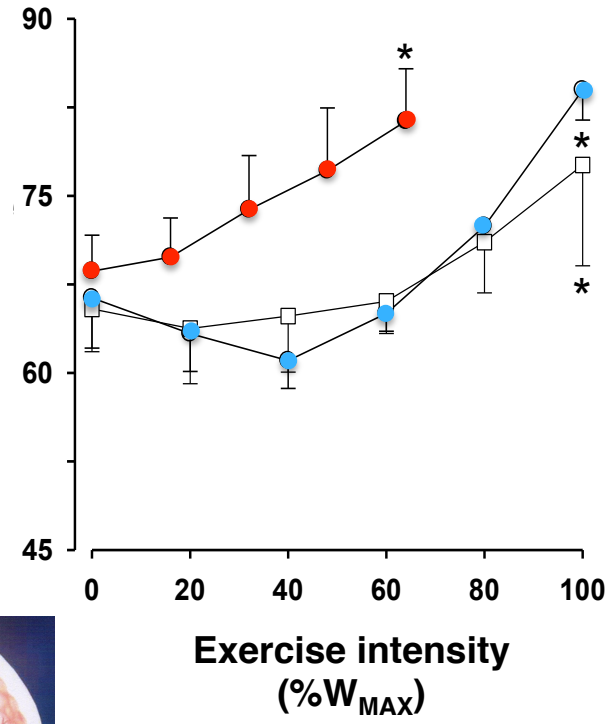
$CMRO_2 = CBF \downarrow \times a\text{-}vO_2$ diff ?

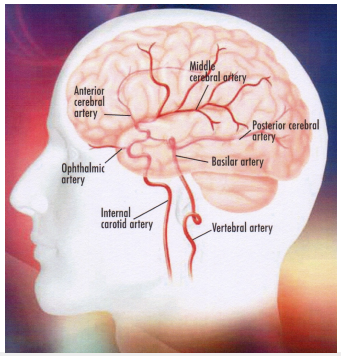
González-Alonso et al. *J Physiol* 557: 331-342, 2004


Incremental Exercise 1
30 minutes passive rest
Prolonged Exercise – Experimental
Prolonged Exercise – Control
Incremental Exercise 2
0:22:38

Dehydration accelerates the reductions in brain perfusion during maximal endurance exercise



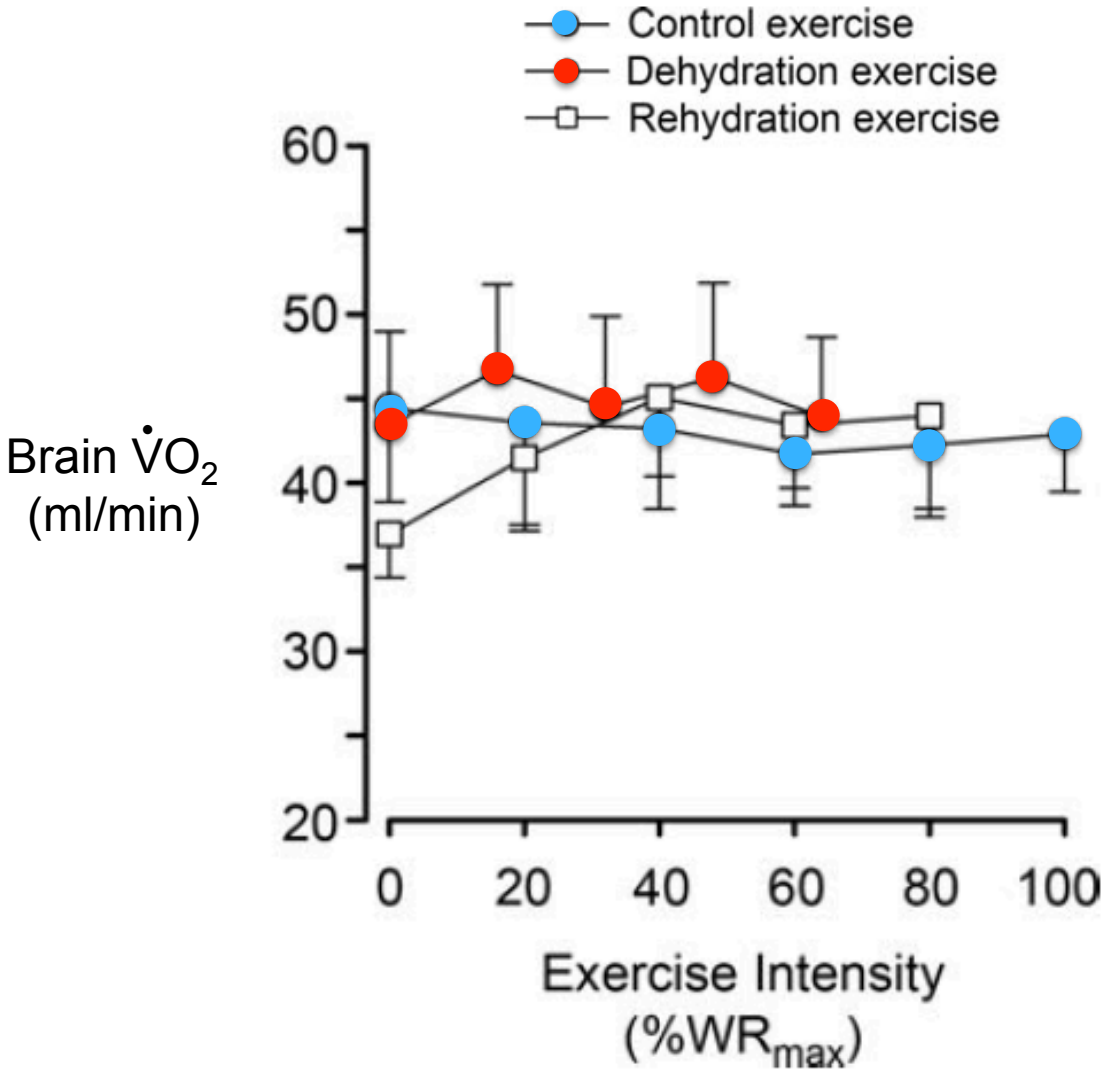


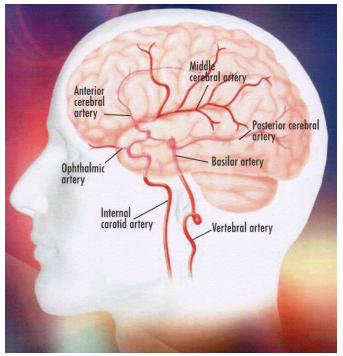


$CMRO_2 = CBF \downarrow \times a\text{-}vO_2\ diff \uparrow$

Trangmar et al. *J Physiol* 592: 3143-3160, 2014

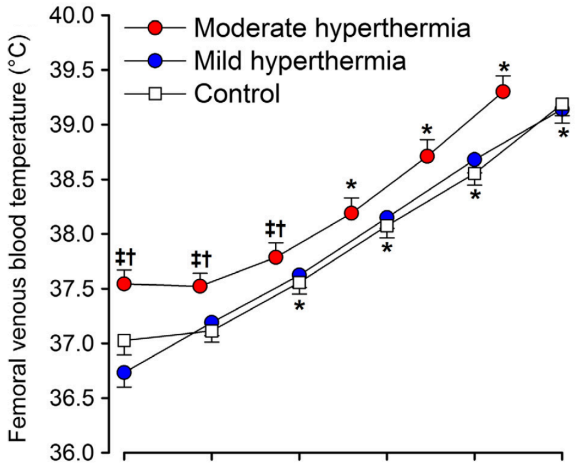
Maintained brain $\dot{V}O_2$ during maximal endurance exercise

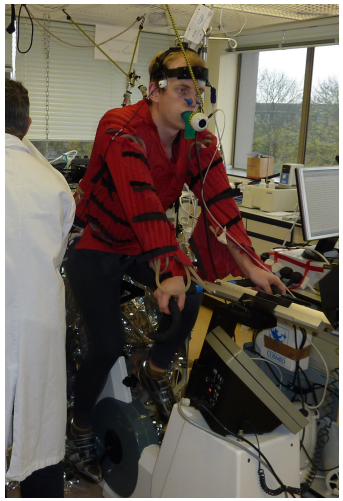


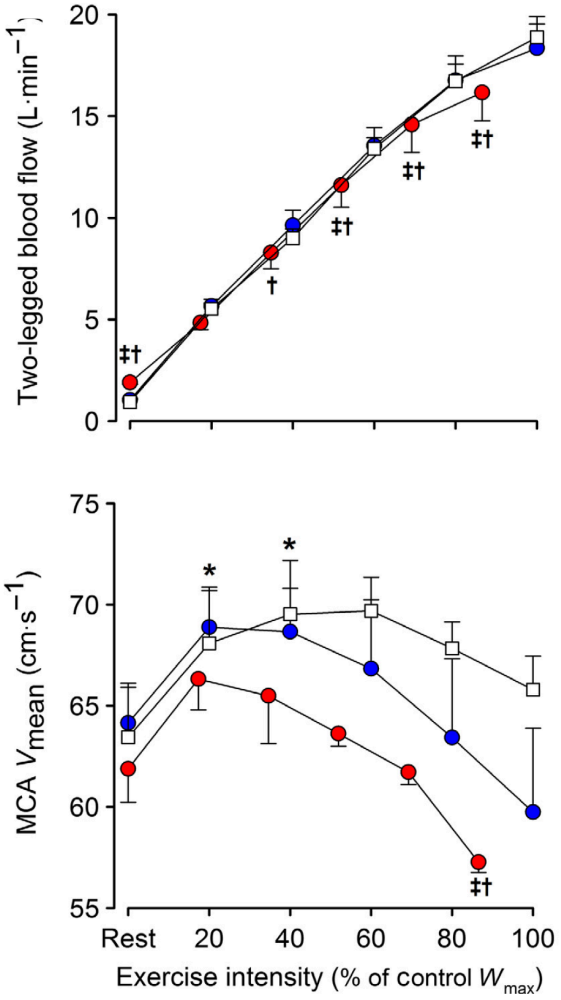


Trangmar et al. *J Physiol* 592: 3143-3160, 2014

Brief heat stress does not impair aerobic exercise performance







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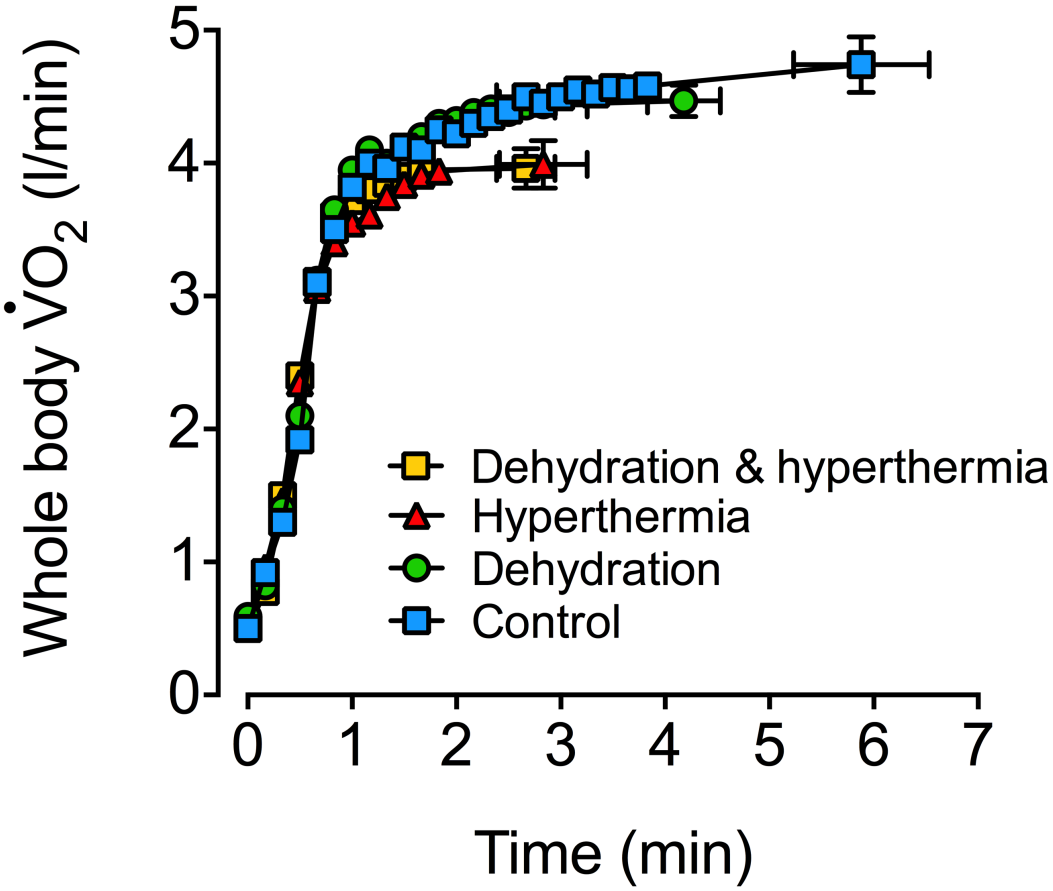
What are the physiological determinants of maximal endurance exercise?



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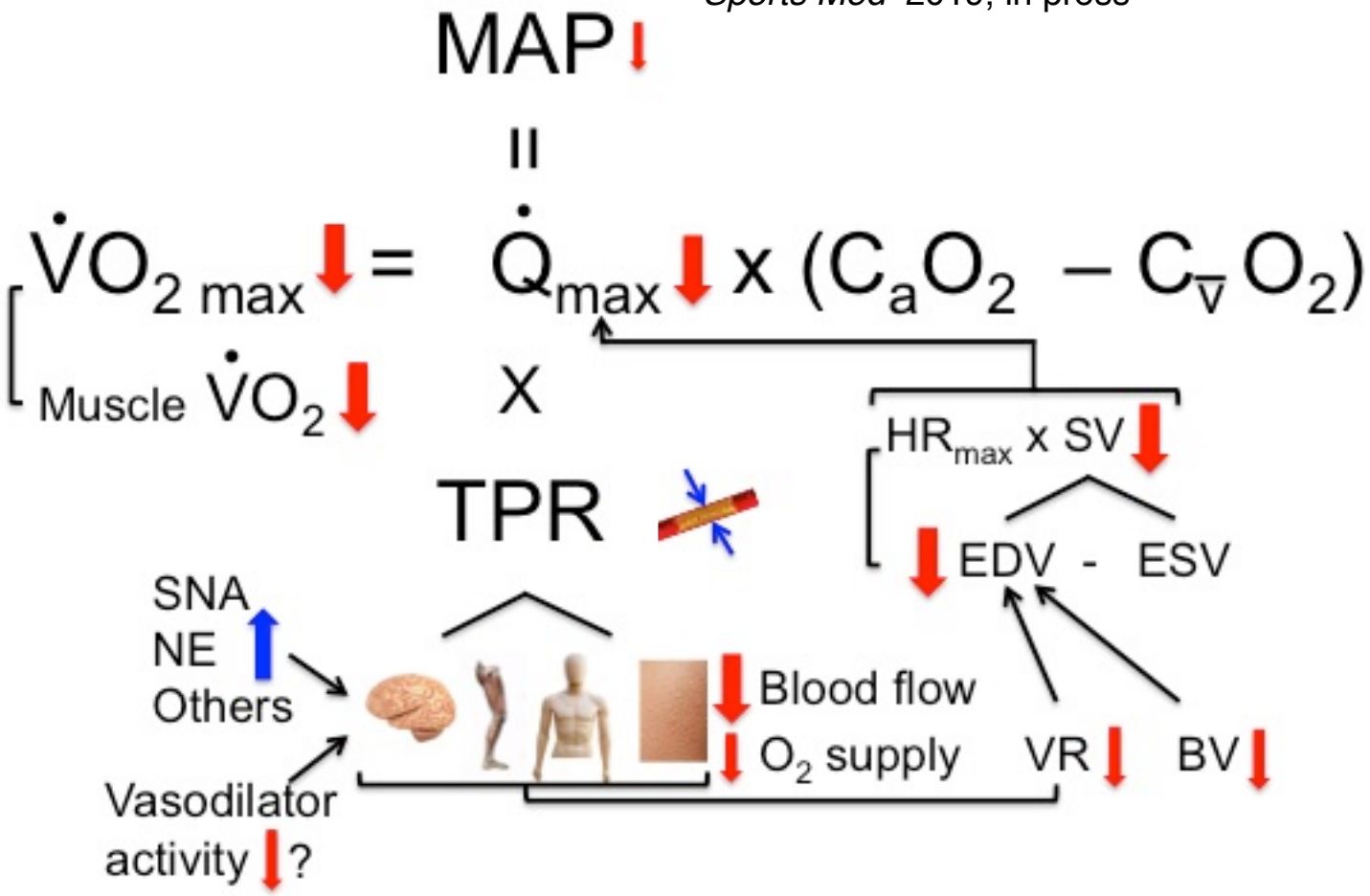
Physiological determinants of maximal endurance exercise

Trangmar & González-Alonso. Heat, hydration and the human brain, heart and skeletal muscles. *Sports Med* 2019, in press



Conclusions

- Heat acclimation confers beneficial physiological and performance effects.
- The effects of heat acclimation are relatively small in elite athletes.
- The impact of heat stress on performance depends on the duration of heat exposure, particularly on whether internal body hyperthermia is present at the start of competition.
- To optimise performance in the heat, elite rowers/athletes should start maximal endurance performance competitions in a euhydrated and normothermic condition.

Thank you for your attention

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