Blood flow during exercise: influence of dehydration and heat stress

José González-Alonso
Volume of water in body fluid compartments

Total body water = ~45 L or ~65% body weight

Sawka et al. 1988
Water loss due to sweating

Sawka et al. 1988
Water losses from different compartments

Costill & Fink, 1976

Plasma
~0.4 L

Interstitial
~1.5 L

Intracellular
~2.0 L

4 L sweat loss
Dehydration impairs peripheral blood flow

Trunk, head & arms

Cardiac Output

Legs Blood Flow

Blood Flow Trunk, Head & Arms

Forearm Blood Flow

Time (min)

Euhydration
≈ 4 L/min
Dehydration

60% $\dot{VO}_2$max

$T_a = 35^\circ$C, rh = 50%

Cerebral blood flow during exercise in the heat

Brain Blood Flow (L/min)

- Control
- Dehydration

55% \( \dot{V}O_2 \text{max} \)

\( T_a = 35^\circ \text{C}; \, rh = 50\%; \)

fan cooling

Graded cardiovascular effects of dehydration

\[ CO = HR \times SV \]

- Cardiac Output (L/min)
- Heart Rate (beats/min)
- Stroke Volume (ml)

Cycling ≈ 60% \( \dot{VO}_2 \max \)
\( T_a = 35^\circ C; \ rh = 50\% \):
Fan cooling

Determinants of leg blood flow

\[ \text{LBF} = \text{Leg Vascular Conductance} \times \text{Perfusion Pressure} \times \text{MAP} \]
Mechanisms reducing leg perfusion with dehydration

Noradrenaline (nmol/L)

Adrenaline (nmol/L)

Mean Arterial Pressure (mmHg)

Leg Vascular Conductance (U)

Mechanisms of leg blood flow decline?

LBF = Leg Vascular Conductance $\approx$ x MAP
Dehydration at rest and small muscle mass exercise

Control  | 2% Dehydration | 3.5% Dehydration | Rehydration

Leg Blood Flow (L/min)

Rest | Exercise

Cardiac Output (L/min)

Rest | Exercise

Mechanisms controlling perfusion

Vasoconstrictor Activity

Vasodilator Activity
Multiple mechanisms involved in local perfusion regulation

1. Metabolic influences
2. Neurohumoral influences
3. Mechanical influences
   - Extravascular compression
   - Circumferential stretch
4. Endothelial and paracrine influences
   - Shear stress

Conducted vasodilation
Differential catecholamine response

Single leg knee-extensor exercise

Two leg cycling

Arterial noradrenaline (nmol/L)

Control
2% Dehydration
3.5% Dehydration
Rehydration

Rest
Exercise


Time (min)
Mechanisms reducing cardiac output with dehydration?

Cardiac output $\downarrow$ or $\approx$

Heart rate $\uparrow$ → Stroke volume $\downarrow$ or $\downarrow$

End-diastolic volume $\downarrow$ or $\downarrow$

End-systolic volume $\uparrow$ or $?$
Dehydration reduces SV by diminishing cardiac filling

SV↓ = EDV ↓ ESV

Data represent mean ± SD.

Rest vs. Exercise: # = P<0.05, † = P<0.01

Control vs. Dehydration: * = P<0.05, ‡ = P<0.01
Physiological effects of exercise-dehydration – prolonged exercise

Heat stress
Heat stress during incremental cycling

- Cardiac output, liters \cdot min^{-1}
- Heart rate, beats \cdot min^{-1}
- Aortic mean pressure, mmHg
- Total peripheral resistance (PRL)

43°C
26°C

Rowell et al. J Clin Invest 1966
Limb hyperemia with systemic hyperthermia

Exercise
≈ 0.7 L/min

Rest
≈ 1.1 L/min
Heat stress at rest and single leg exercise

\[ \Delta Q = 5.3 \text{ vs. } 3.8 \text{ L/min} \]
Heat stress and incremental single leg exercise

\[ \Delta \text{LBF} = 0.6 \text{ L/min} \]
Blood flow with heat stress, prolonged exercise

\[ T_c = \approx 40 \, ^\circ C \]

\[ T_{sk} = \approx 38 \, ^\circ C \]

60% VO\textsubscript{2max}
Physiological strain during high intensity exercise

**Figure 3.** Oxygen uptake (L/min) and heart rate (beats/min) during cycling at approximately 400 W. The graphs show the responses during maximal cycle ergometer exercise at constant power output when subjects were euhydrated or dehydrated with normal or elevated thermal strain (EU-normal, EU-hyper, DH-normal, DH-hyper). Values are means ± SE for 6 subjects. *Significant differences from EU-normal, 0.01 < * < 0.05.
Maximal exercise and heat stress

Heat Stress

≈ 380 W

Control

Femoral venous blood temperature (°C)

Heart rate (beats/min)

Fatigue

Hyperthermia

Normal

Normal

Fatigue

Heat stress and maximal cycling

Cardiac output

Leg blood flow

Cardiac output and two-legged blood flow (L min⁻¹)

Mean arterial blood pressure (mm Hg⁻¹)

Time (min)

Active muscle metabolism is compromised

![Graph showing changes in muscle metabolism during exercise](image-url)

- **Two-legged O₂ Delivery (L/min)**
- **Two-legged O₂ Uptake (L/min)**

**Time (min)**: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9

**Significance**: *Significantly different from baseline.*

**References**: González-Alonso & Calbet *Circulation* 2003
Limitations in brain flow during maximal exercise

González-Alonso et al. J Physiol 2004
Reductions in brain perfusion during maximal exercise

*Trangmar et al. J Physiol 2014*
Maintained CMRO$_2$ during maximal exercise
Conclusions

• The effects of dehydration and heat stress on cardiovascular function are dependent upon the type, intensity and duration of exercise.

• Moderate dehydration and/or heat stress do not compromise cardiovascular function at rest and during small muscle mass exercise.

• The greatest cardiovascular strain with dehydration and/or heat stress are seen during intense large muscle mass exercise, and can lead to compromised active muscle metabolism and accelerated fatigue, but not brain metabolism.
Future research avenues