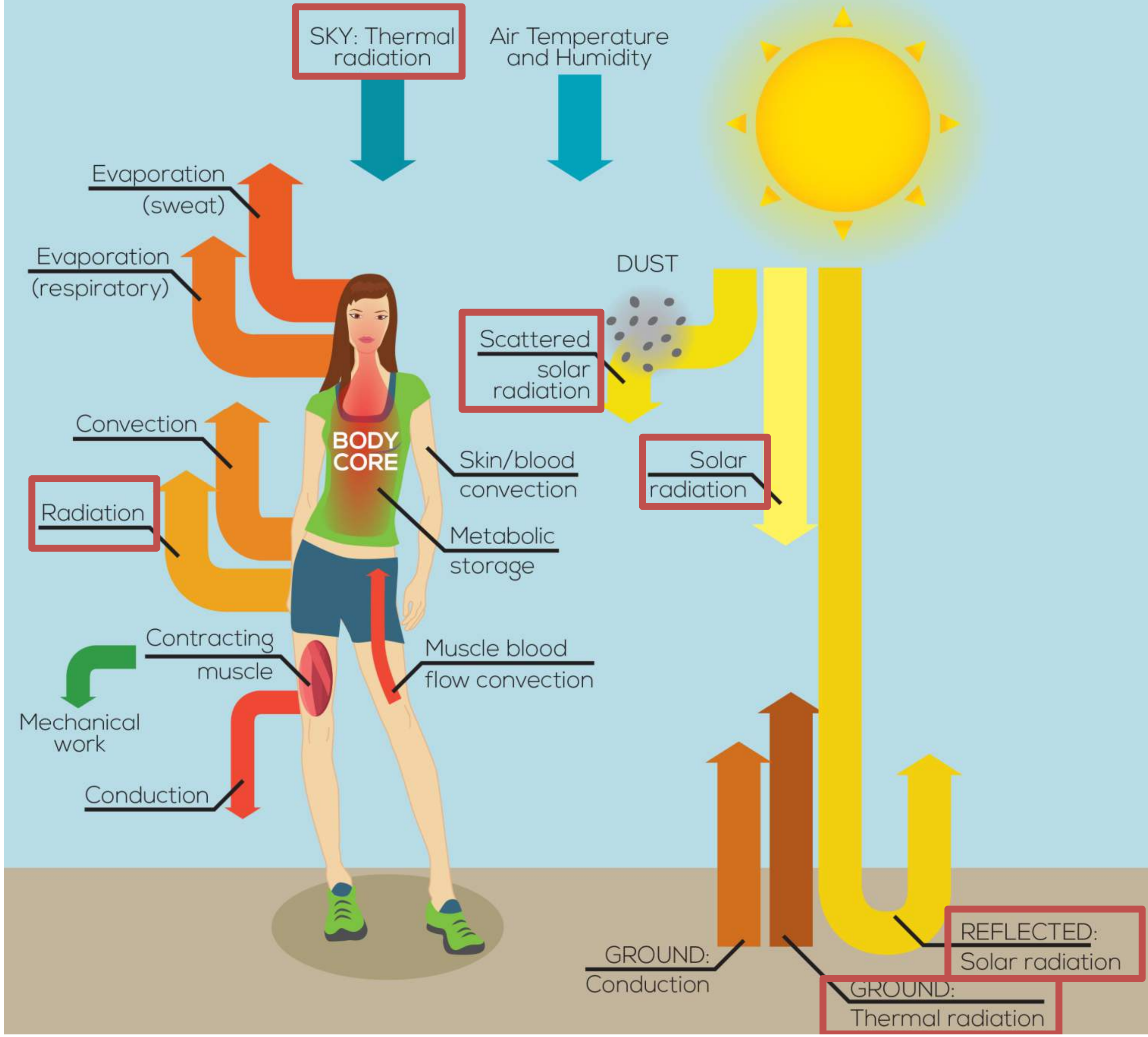
FUNCTIONAL ARCHITECTURE OF HUMAN THERMOREGULATION



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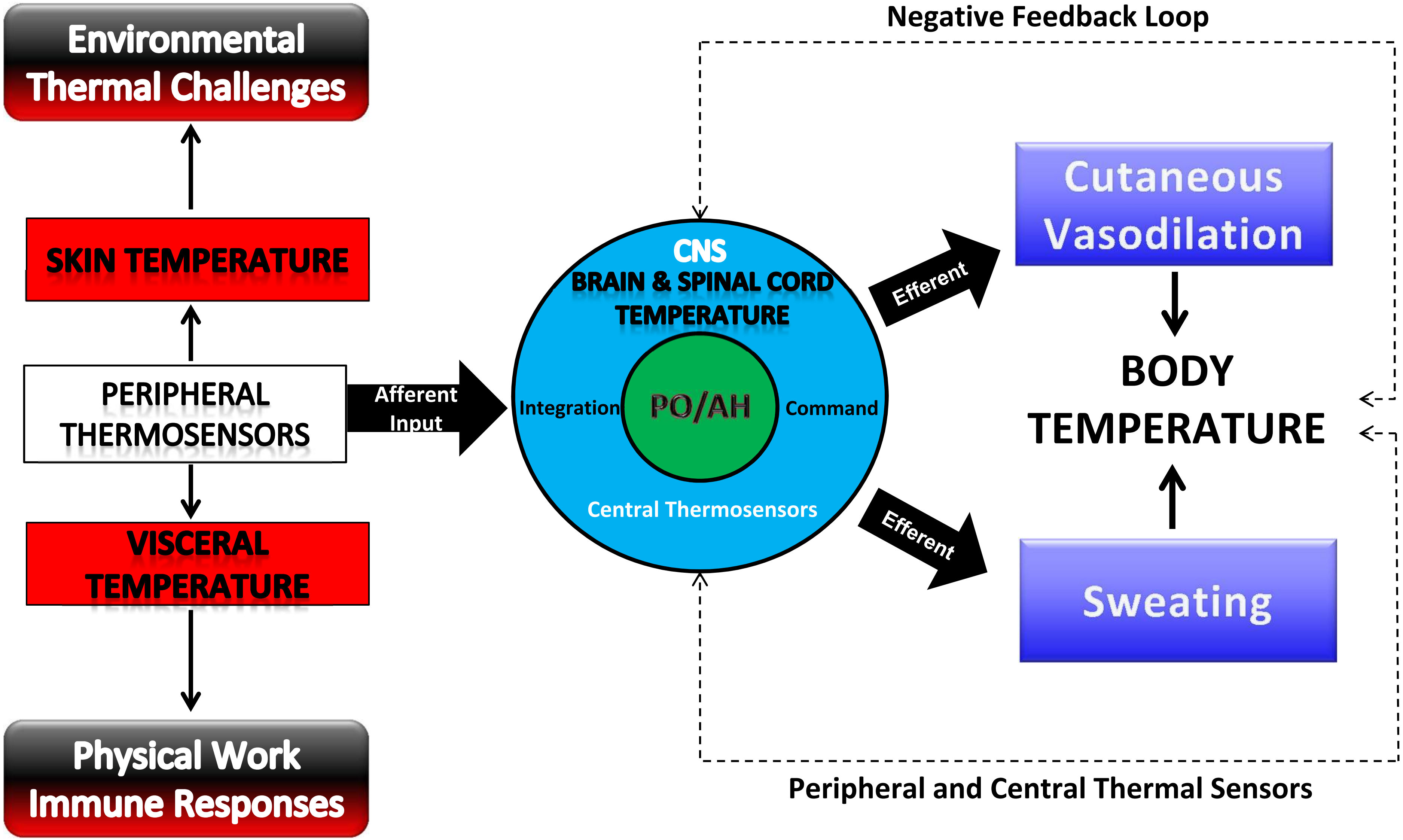
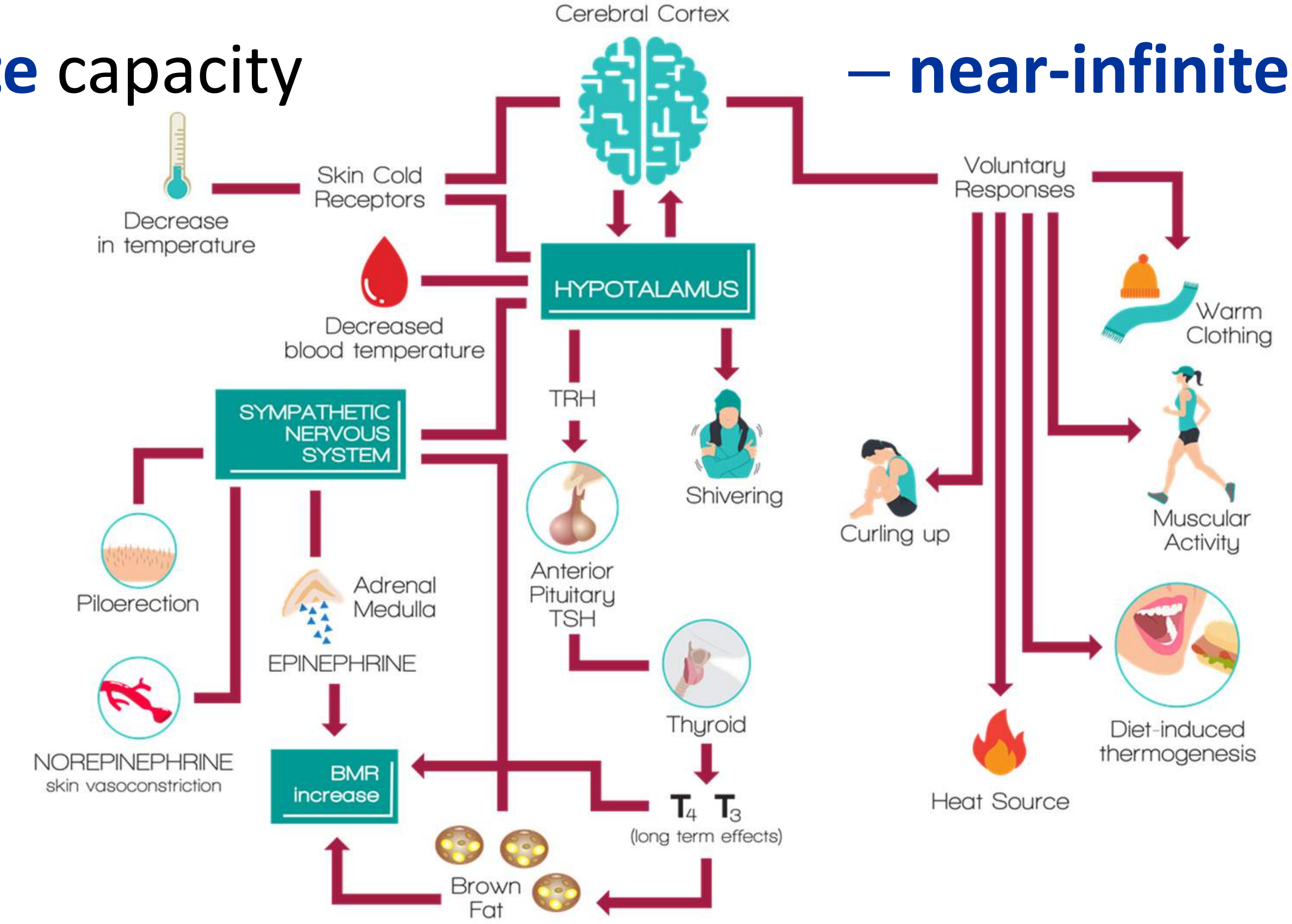
THERMOREGULATION IN THE HEAT



$$S = M - (\pm W) \pm (R + K + C) - E$$

THERMOREGULATION

- **Autonomic/endocrine** thermoregulation
  – **finite** capacity
- **Behavioural** thermoregulation
  – **near-infinite** capacity



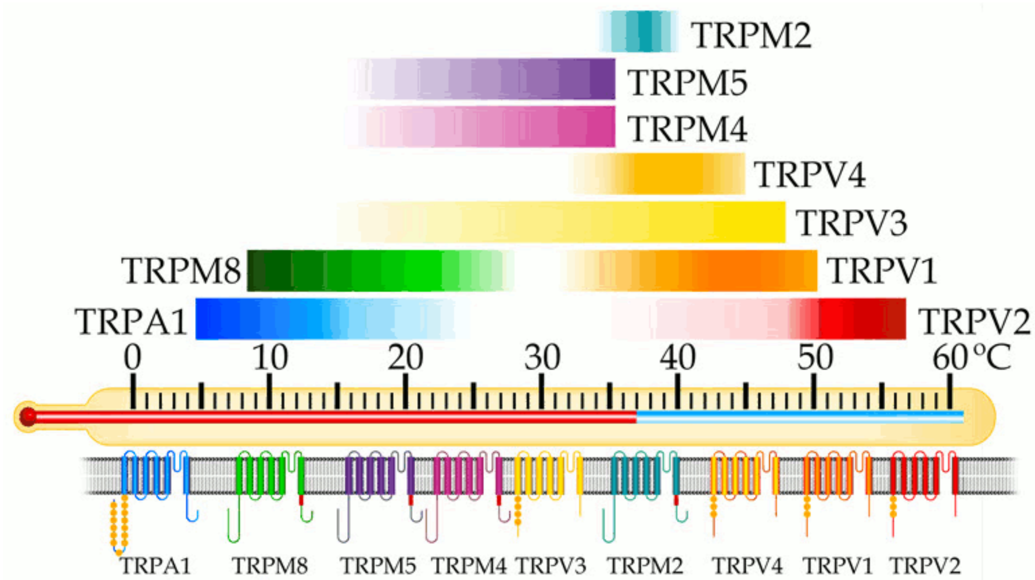
THERMOSENSORS

- Transient receptor potential (TRP) ion channels
  - expressed in pain- and temperature-sensitive neurons
  - 30 proteins divided into 6 sub-families
  - central axons project to lamina I
  - signals are carried to the hypothalamus, the brainstem, and the insular cortex

Flouris & Schlader, SJSMM, 2015

Romanovsky, *AJP-RICP*, 2007

Craig, *Nat Rev*, 2009

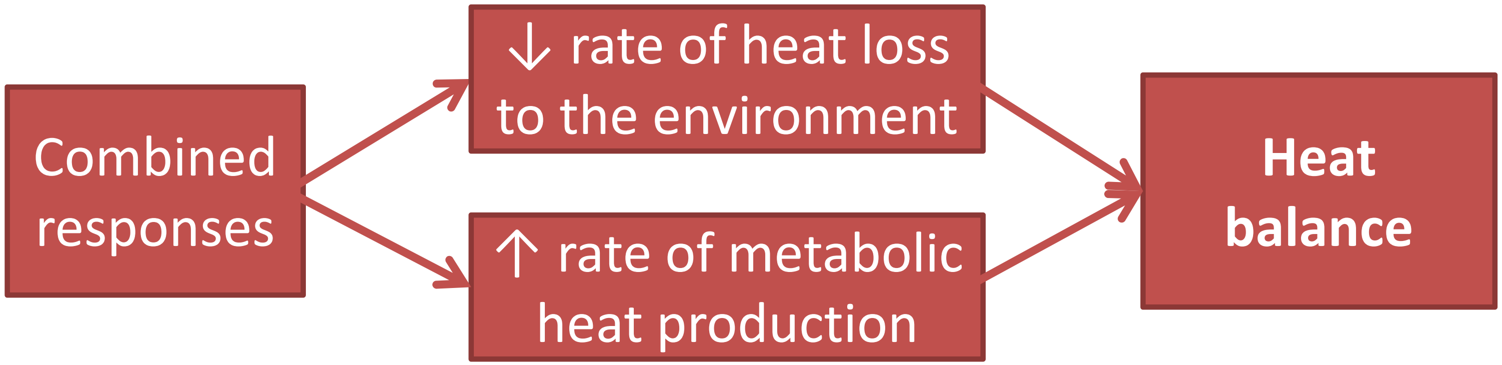


AUTONOMIC THERMOREGULATION

- Reductions in skin/core temperature (**cold**)
  - Heat conservation
    - peripheral vasoconstriction

  - Heat generation
    - shivering thermogenesis

    - non-shivering thermogenesis



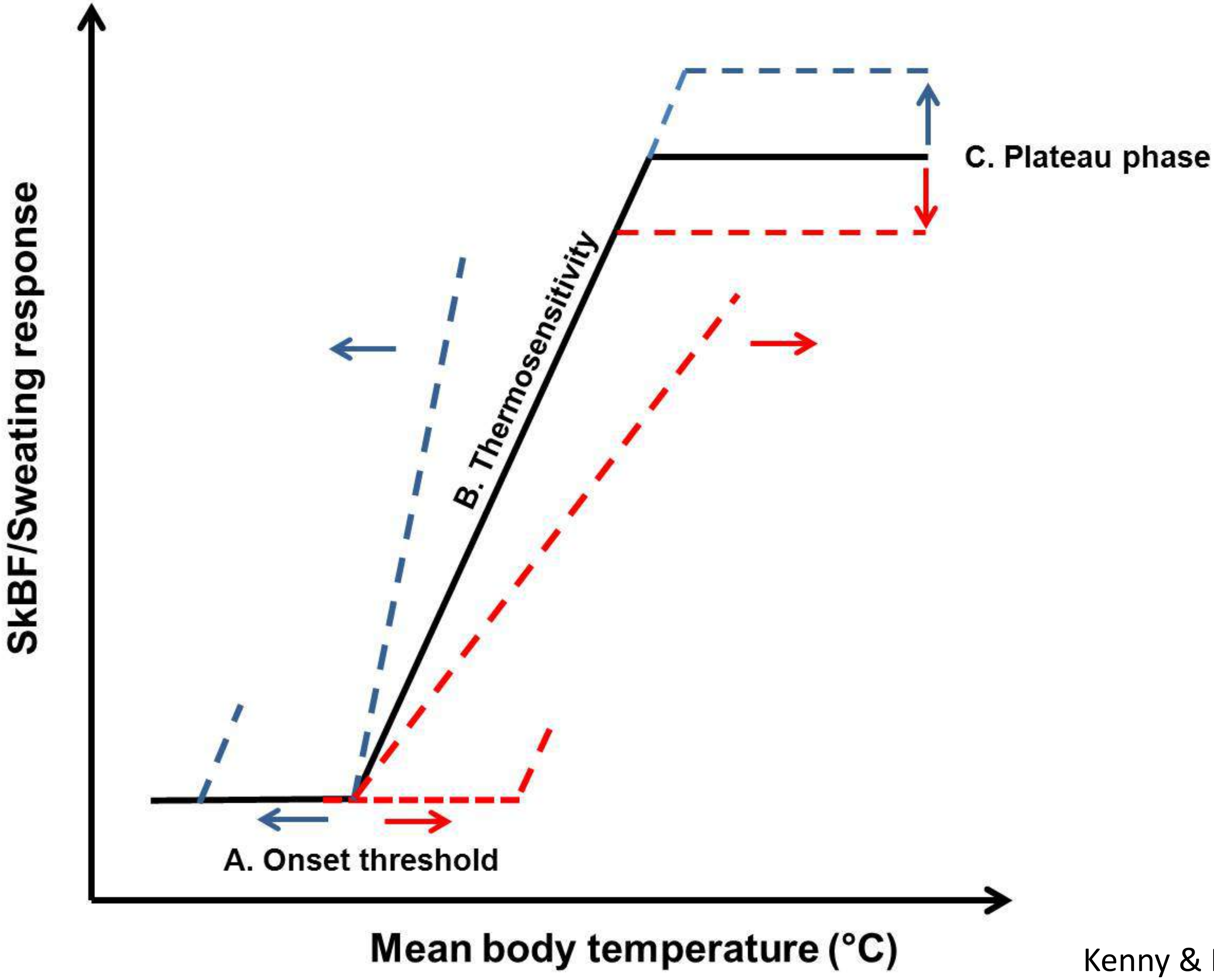
AUTONOMIC THERMOREGULATION

- Increases in skin/core temperature (**heat/work**)
  - Heat dissipation
    - peripheral vasodilation 
    - sweating 

AUTONOMIC THERMOREGULATION

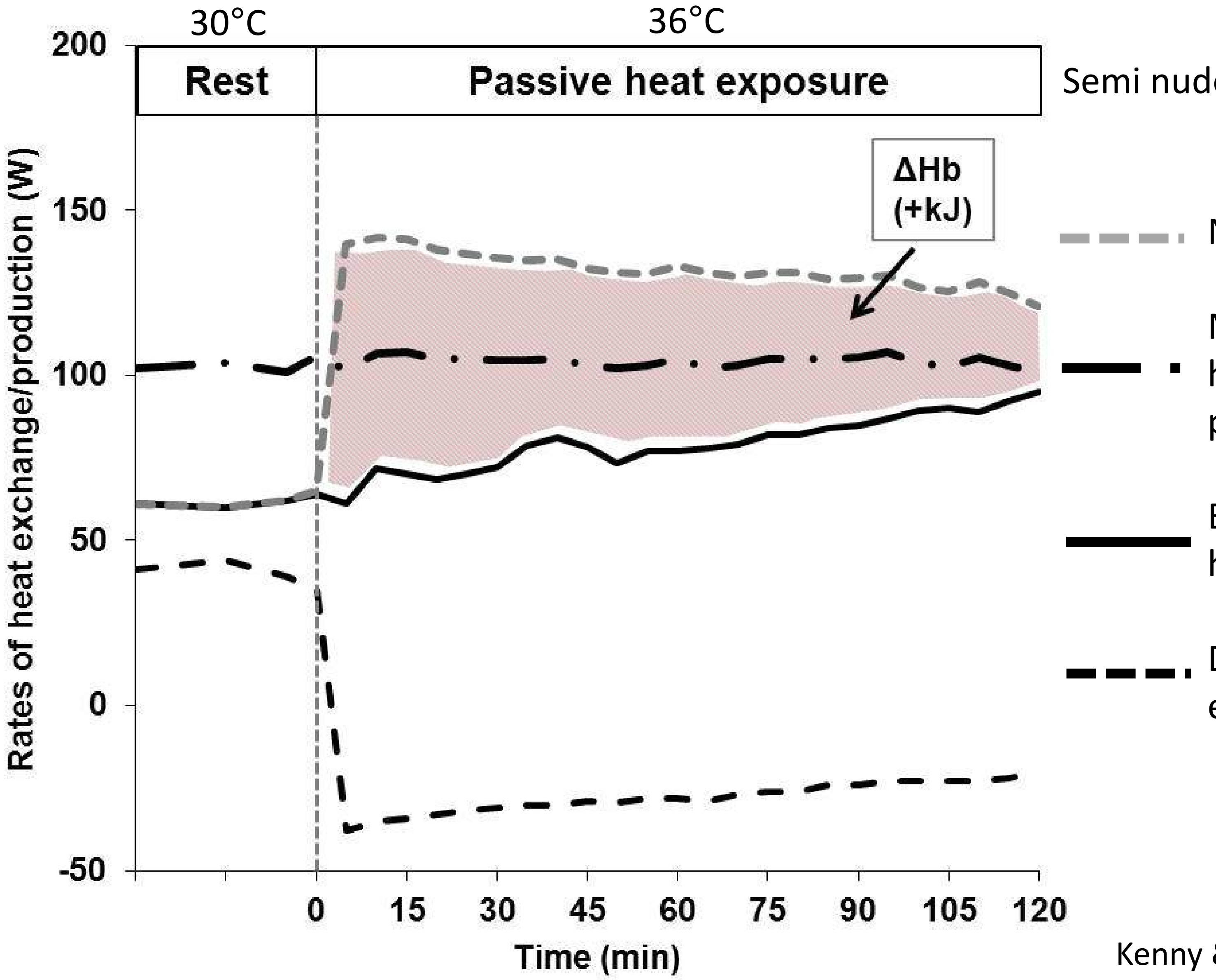
- Each effector response is characterised by a mean body temperature **onset threshold** beyond which it increases proportionally to the change in core and/or skin temperature Bligh, JAP, 2006

AUTONOMIC THERMOREGULATION



Kenny & Flouris, 2014

PASSIVE HEAT EXPOSURE

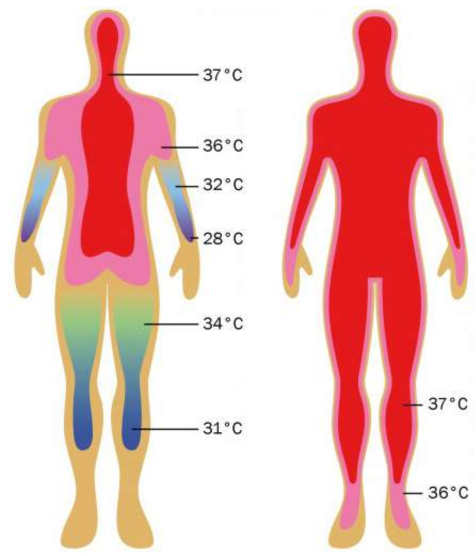


Semi nude adult male

Kenny & Flouris, 2014

PASSIVE HEAT EXPOSURE

- Peripheral vasodilation serves to **decrease the temperature gradient** between the skin and the environment, thus attenuating the rate of dry heat gain
  - **evaporation** is the only means by which the body can lose heat in hot conditions



Compensable conditions → Heat balance → Rate of heat storage = 0

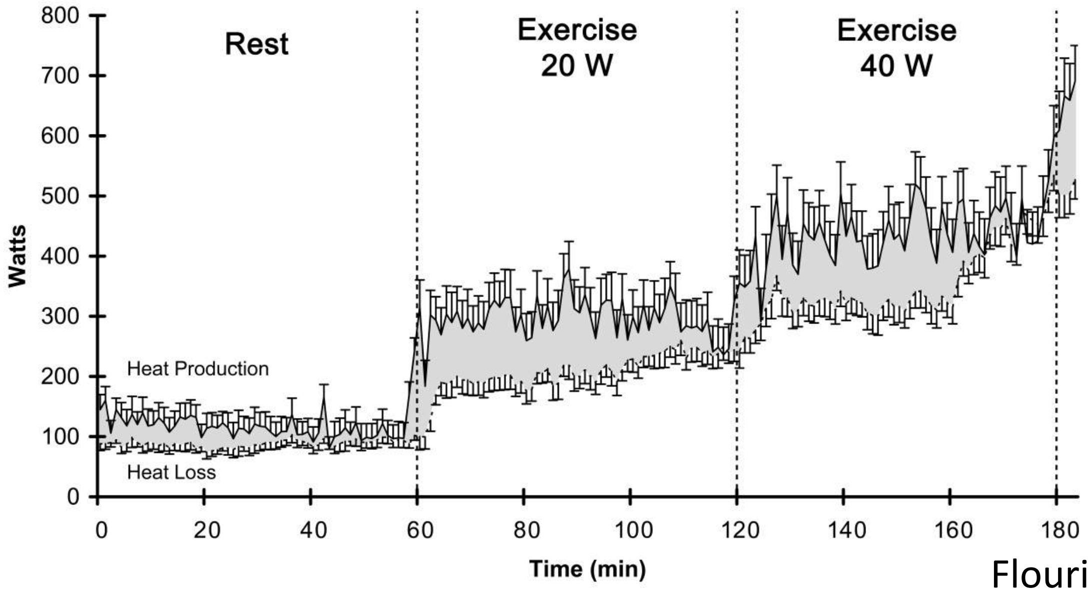
Uncompensable conditions → + heat storage → ↑ core temperature

EVAPORATION

- Water **evaporation** from the skin and the membranes of the respiratory tract is a vital means of dissipating heat
  - conversion of water molecules from fluid to gas requires large amounts of energy (~**600 kcal/L**)

	Rest		Work	
	%	kcal/min	%	kcal/min
Conduction & Convection	20	0.3	15	2.2
Radiation	**60**	**0.9**	5	0.8
Evaporation	20	0.3	**80**	**12**
Total	100	1.5	100	15

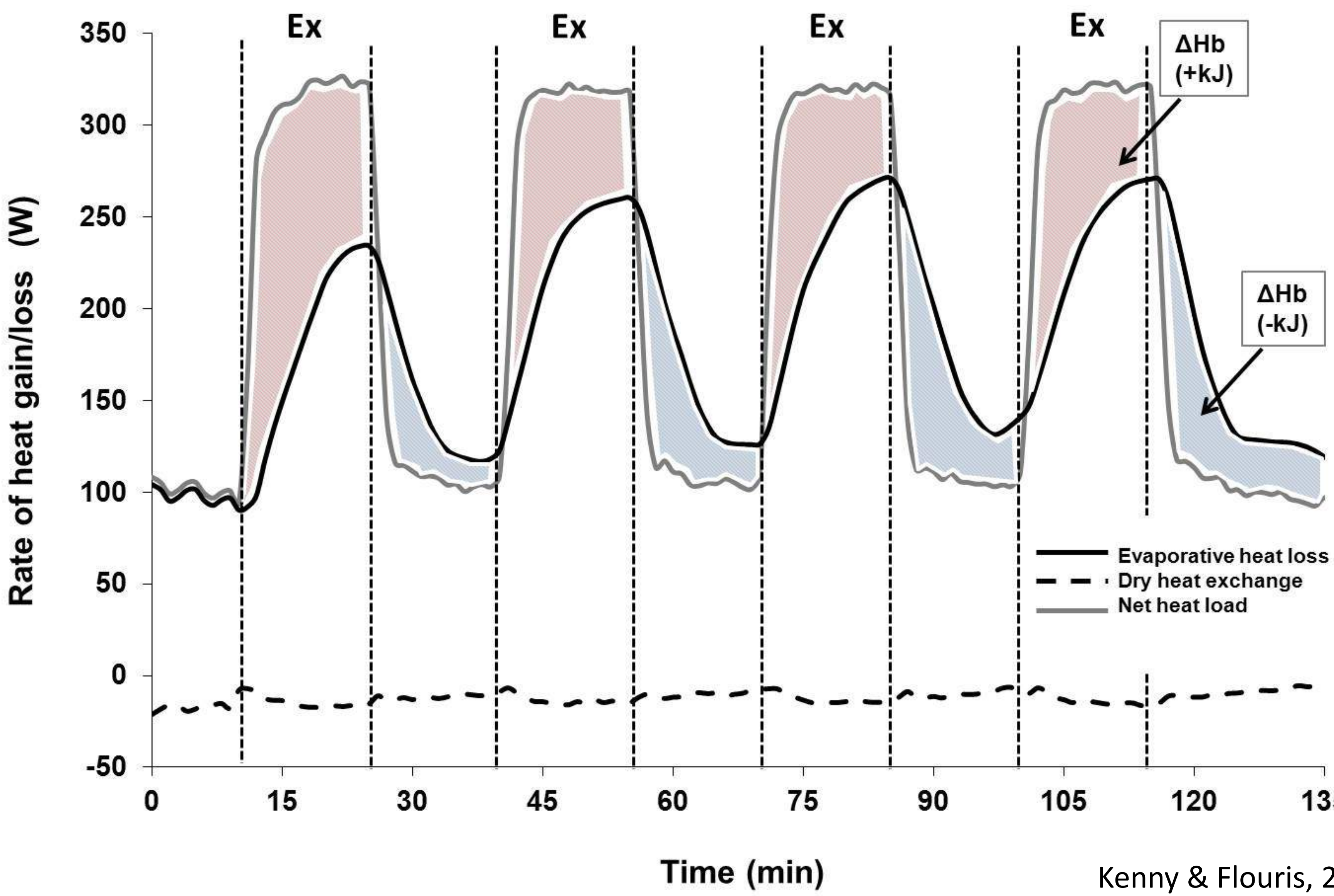
THERMOREGULATION DURING WORK



Flouris & Cheung, EJAP, 2010

- At the **beginning** of work, heat production rises rapidly due to increased metabolism primarily in the working muscles
- The mechanisms of heat dissipation react with significant **delay** and so body temperature rises at the start of work
- When/If heat dissipation reaches heat production (i.e., attainment of heat balance), core temperature will **stabilize**

THERMOREGULATION DURING WORK



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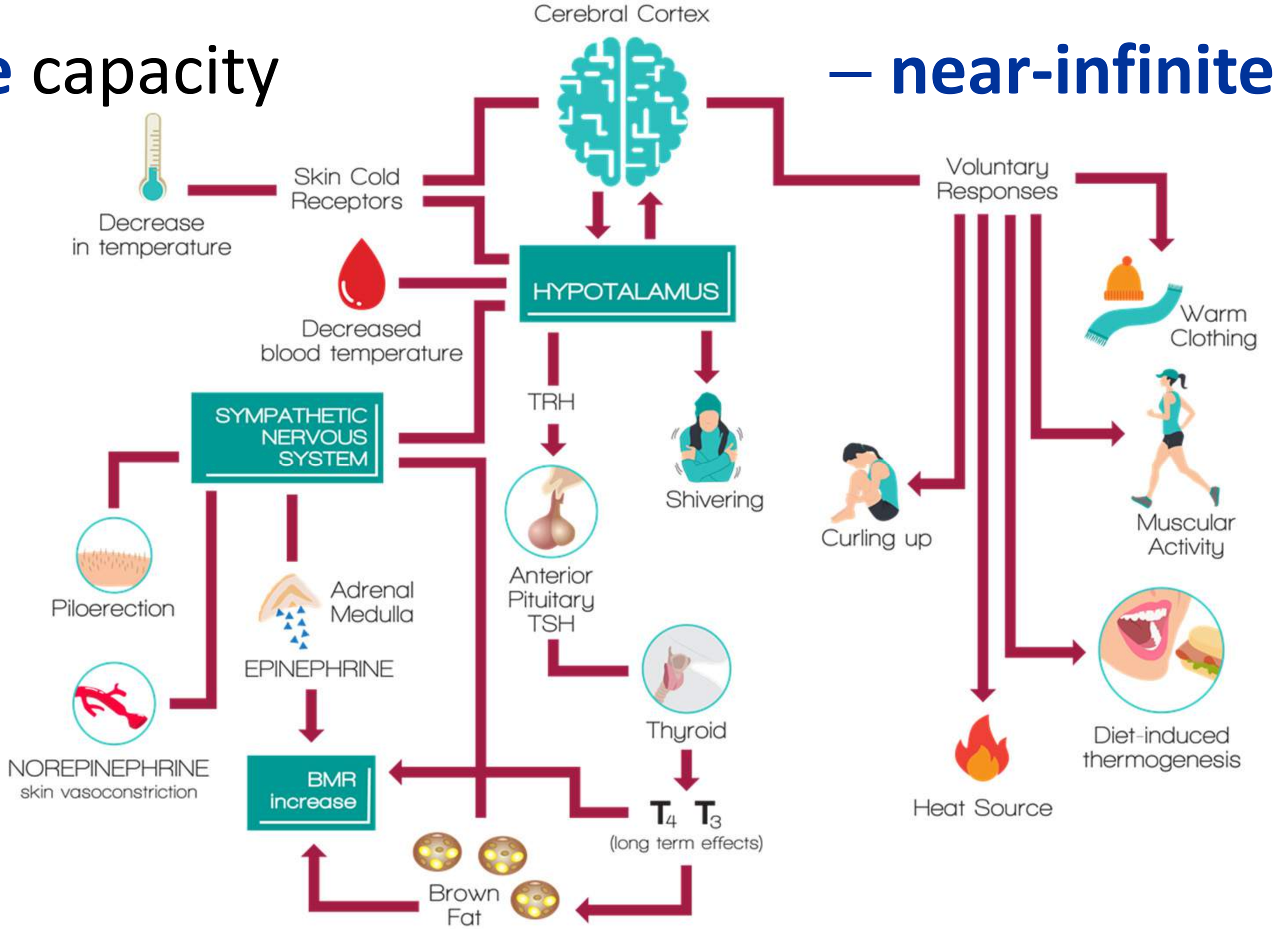
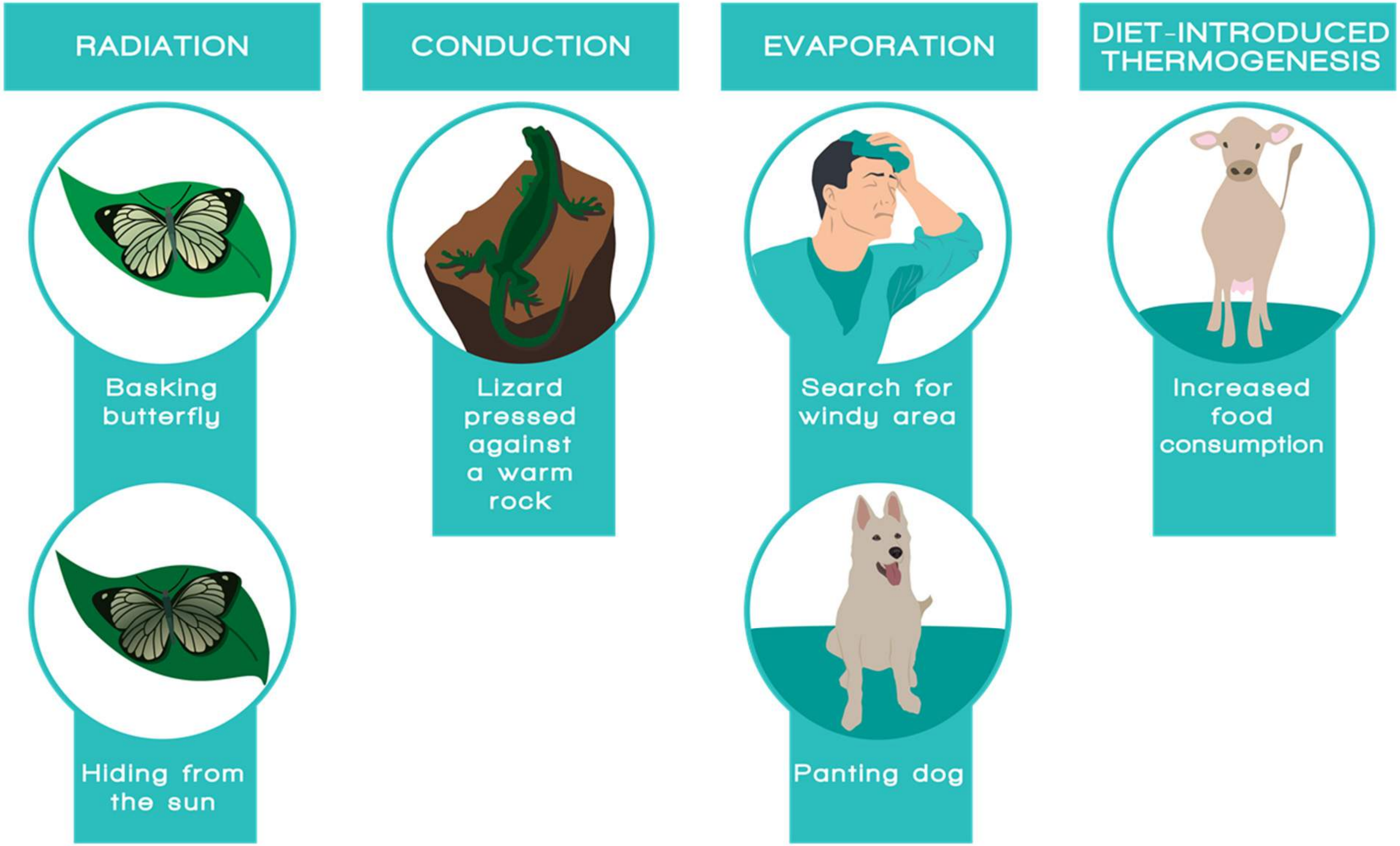


THERMAL BEHAVIOUR



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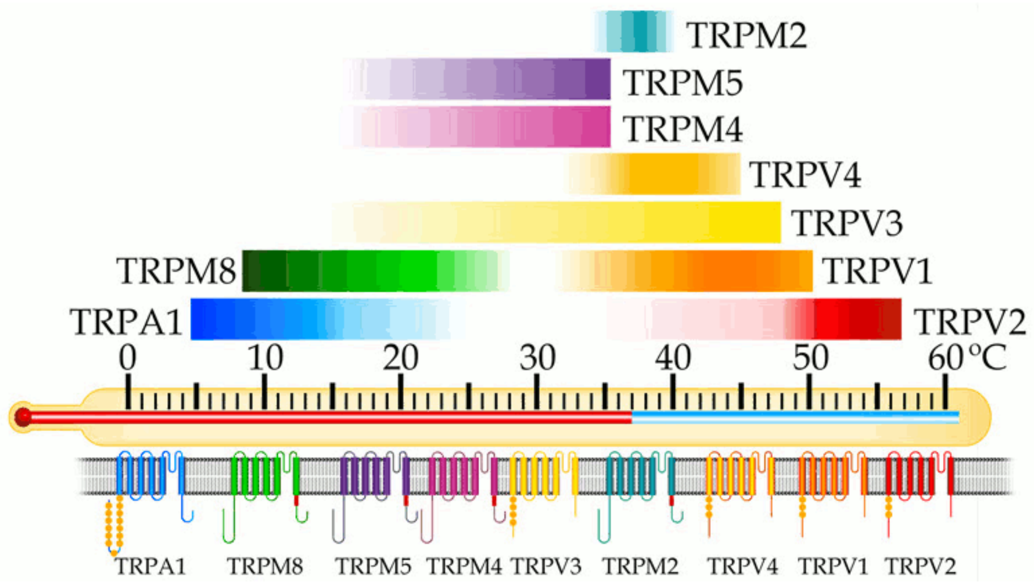
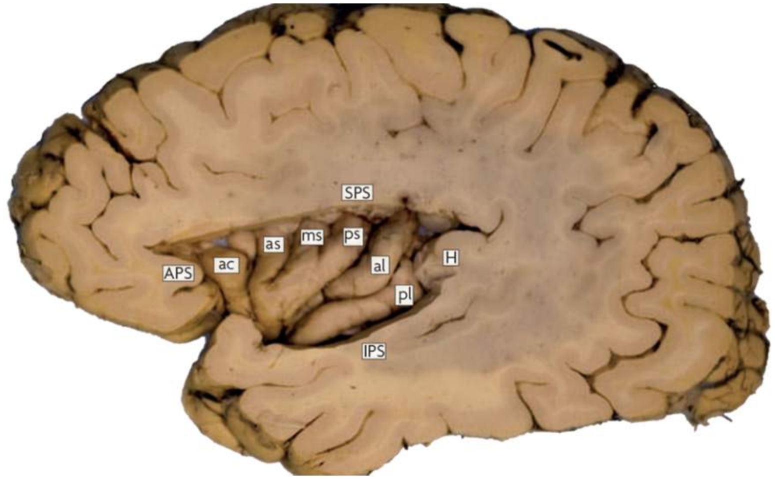


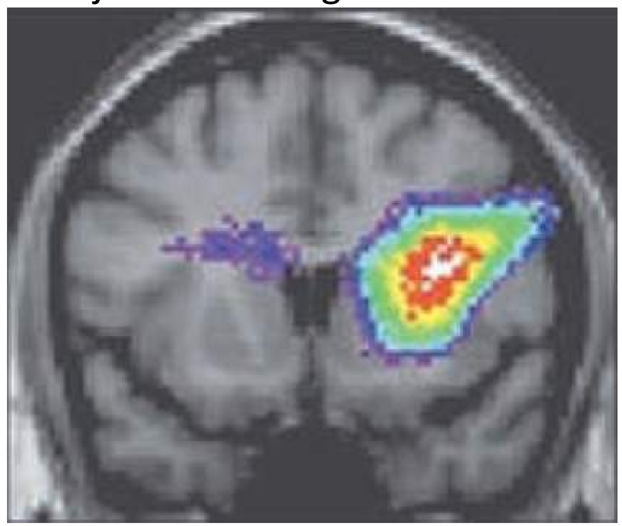
CEREBRAL LOCI OF THERMAL FEELINGS

- In addition to the hypothalamus and the brainstem, lamina I also activates the **insular cortex**



- Integration within the **insula** generates the template for a "**feeling**"
  - a combined representation of homeostatically salient features of the individual's internal and external environment

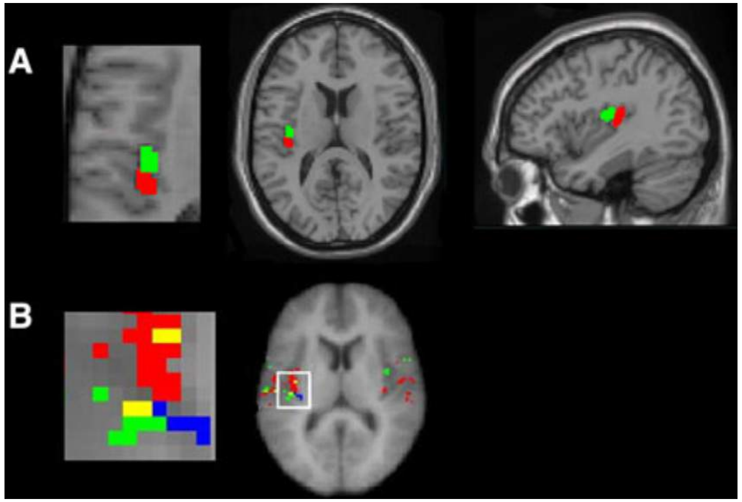
Subjective cooling



Craig, Nat Rev, 2009
Craig, Ann N Y Acad Sci, 2011

CEREBRAL LOCI OF THERMAL FEELINGS

- In addition to the hypothalamus and the brainstem, lamina I also activates the **insular cortex**
- Integration within the **insula** generates the template for a "**feeling**"
  - A: activation due to innocuous cooling (neck; hand)
  - B: activation due to noxious heating (face; arm; leg; overlap)



Hua et al, AJP-RICP, 2005

Brooks et al, Neuroimage, 2005

NEURAL BASIS OF THERMAL BEHAVIOUR

- The preoptic anterior hypothalamus does not play a major role in behavioral thermoregulation

- The cerebral neural pathways important for **behavioural thermoregulation** have little to do with triggering thermoeffector responses (i.e., **autonomic thermoregulation**)

Craig, Ann N Y Acad Sci, 2011
Craig, Nat Rev, 2009

MEASURES OF THERMAL PERCEPTION

- **Thermal comfort**: *subjective indifference with the thermal environment*

  Gagge et al., Environ Res, 1967

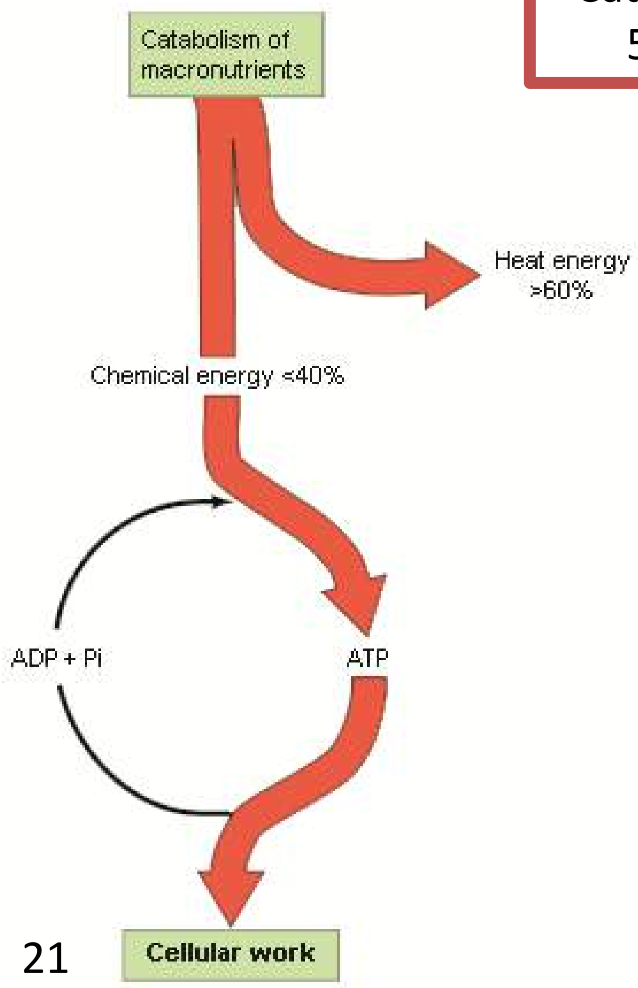
- **Thermal sensation**: *relative intensity of the temperature being sensed*

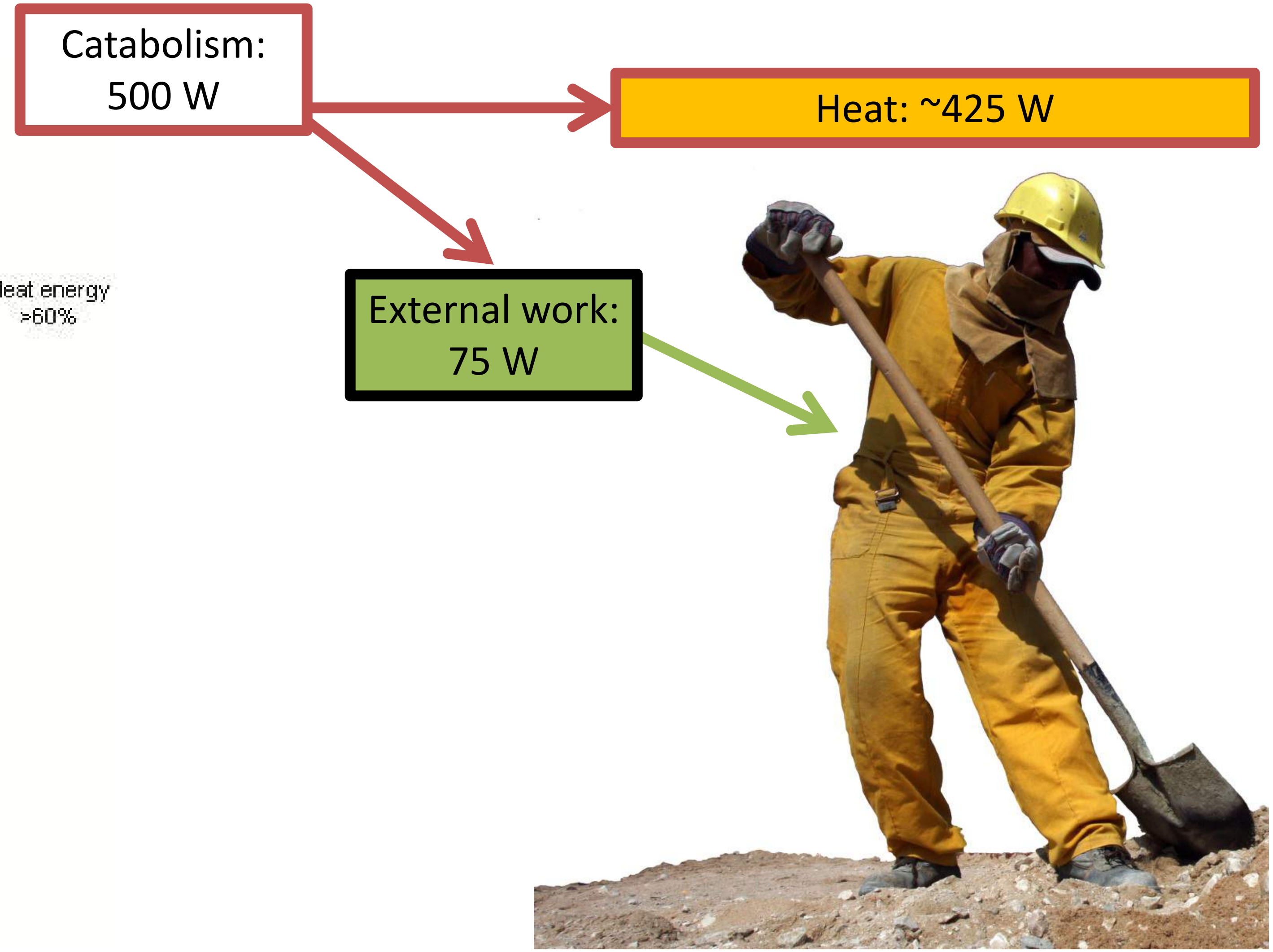
  Gagge et al., Environ Res, 1967

- **Perceived exertion**: *subjective perception of effort*

  Borg, MSSE, 1982

THERMAL BEHAVIOUR DURING WORK



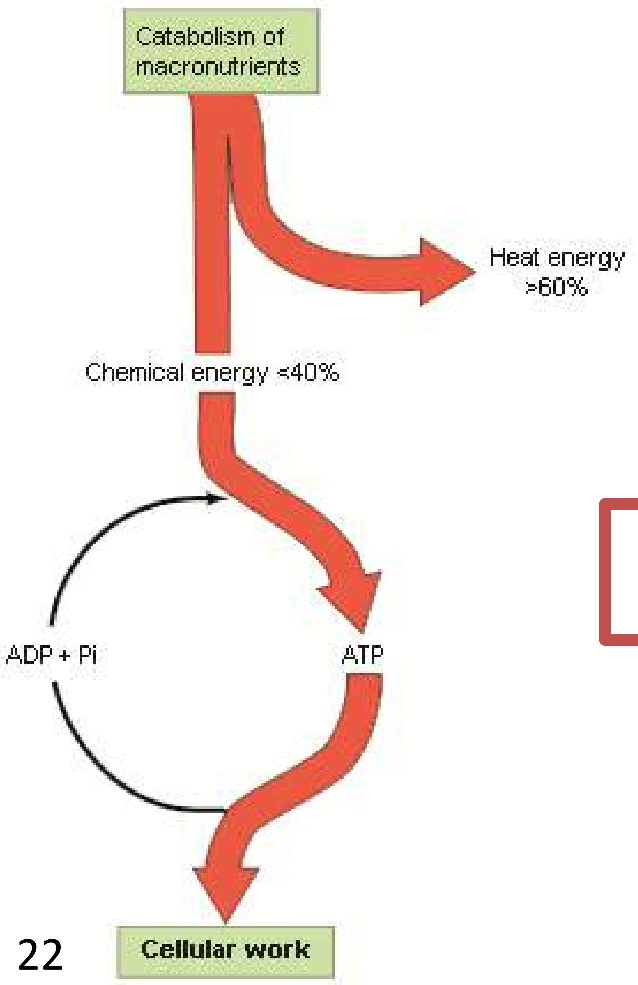


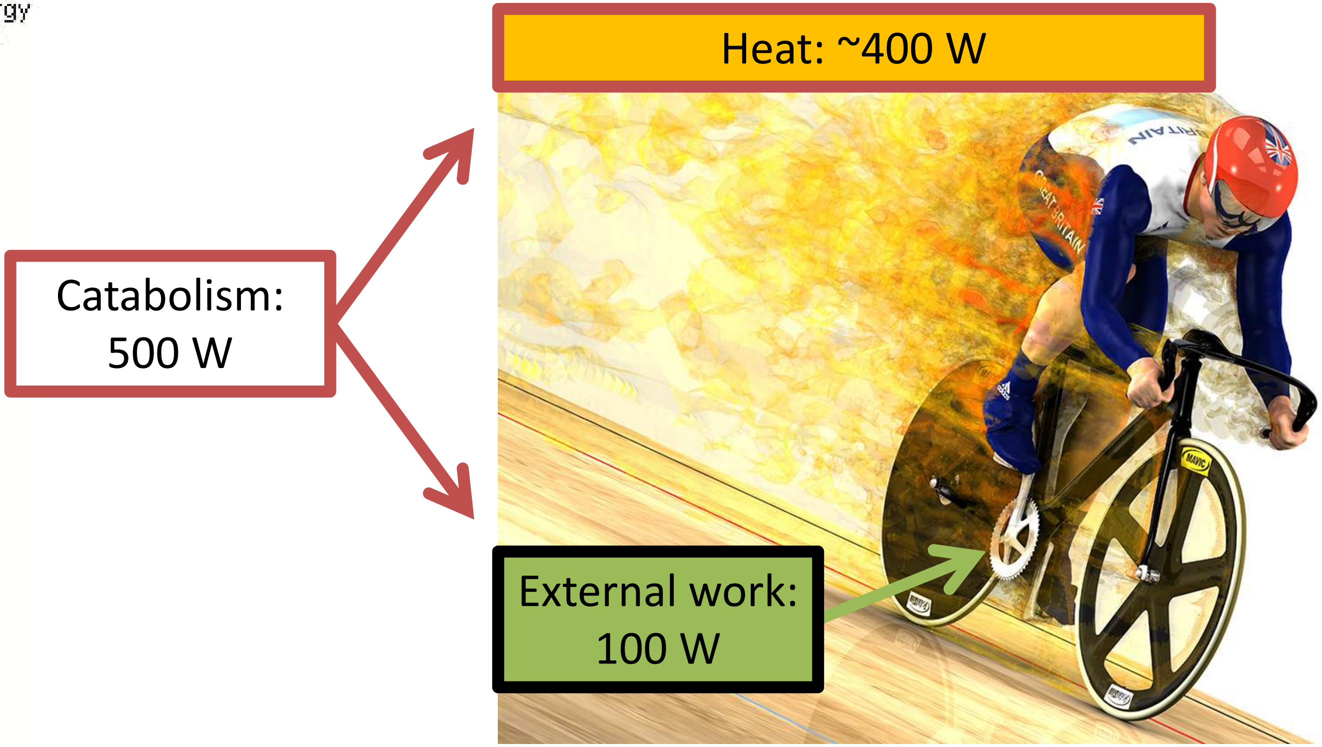
THERMAL BEHAVIOUR DURING WORK

- Cycling (most efficient physical task)

  ~20% of energy used for work

  Whipp & Wasserman, JAP, 1972



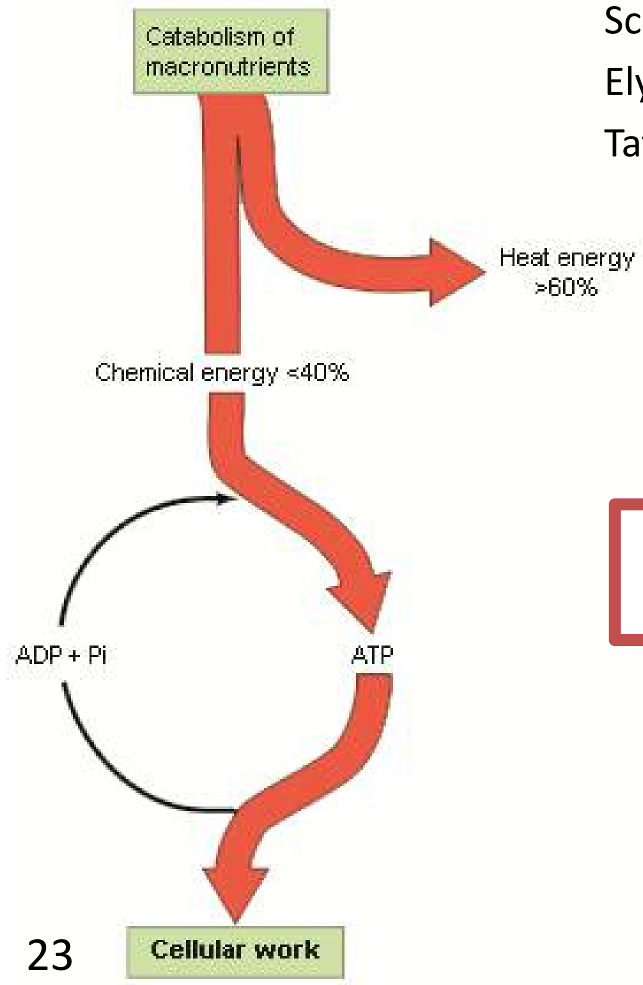


THERMAL BEHAVIOUR DURING WORK

↓ performance & health

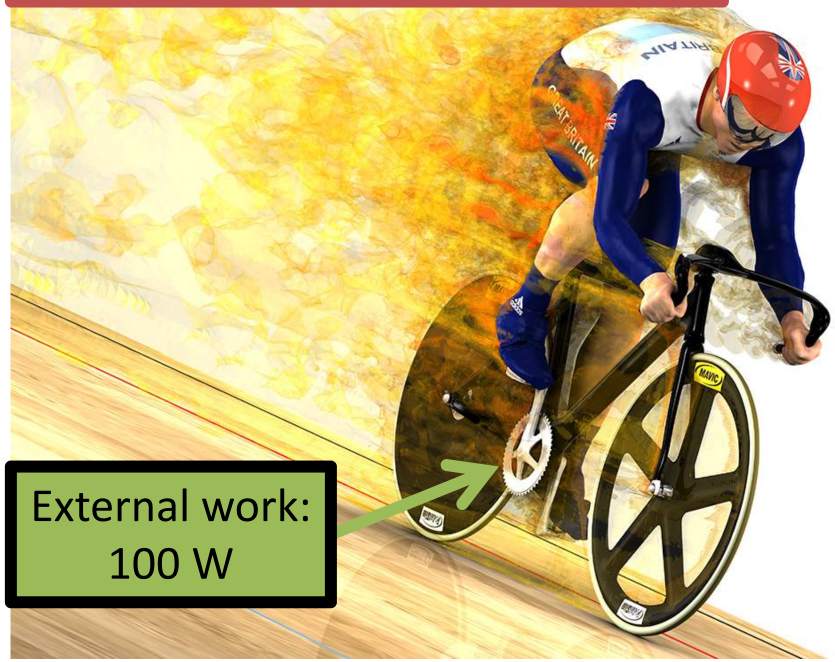
Schlader et al., JTB, 2011
Ely et al, MSSE, 2010
Tatterson et al, JSMS, 2000

↑ core temperature



Catabolism: 500 W

Heat: ~400 W



External work: 100 W

THERMAL BEHAVIOUR DURING WORK

- Changes in work intensity have a major impact on heat balance: $S = \mathbf{M} - (\pm W) \pm (R + C + K) - E$

changes in work intensity affect thermoregulation and are considered **thermoregulatory behaviors**

Flouris & Schlader, SJMSS, 2015

Flouris et al., EJAP, 2011

Schlader et al., JTB, 2011

BEHAVIOURAL THERMOREGULATION

CONSCIOUS RESPONSE TO THERMAL INPUT

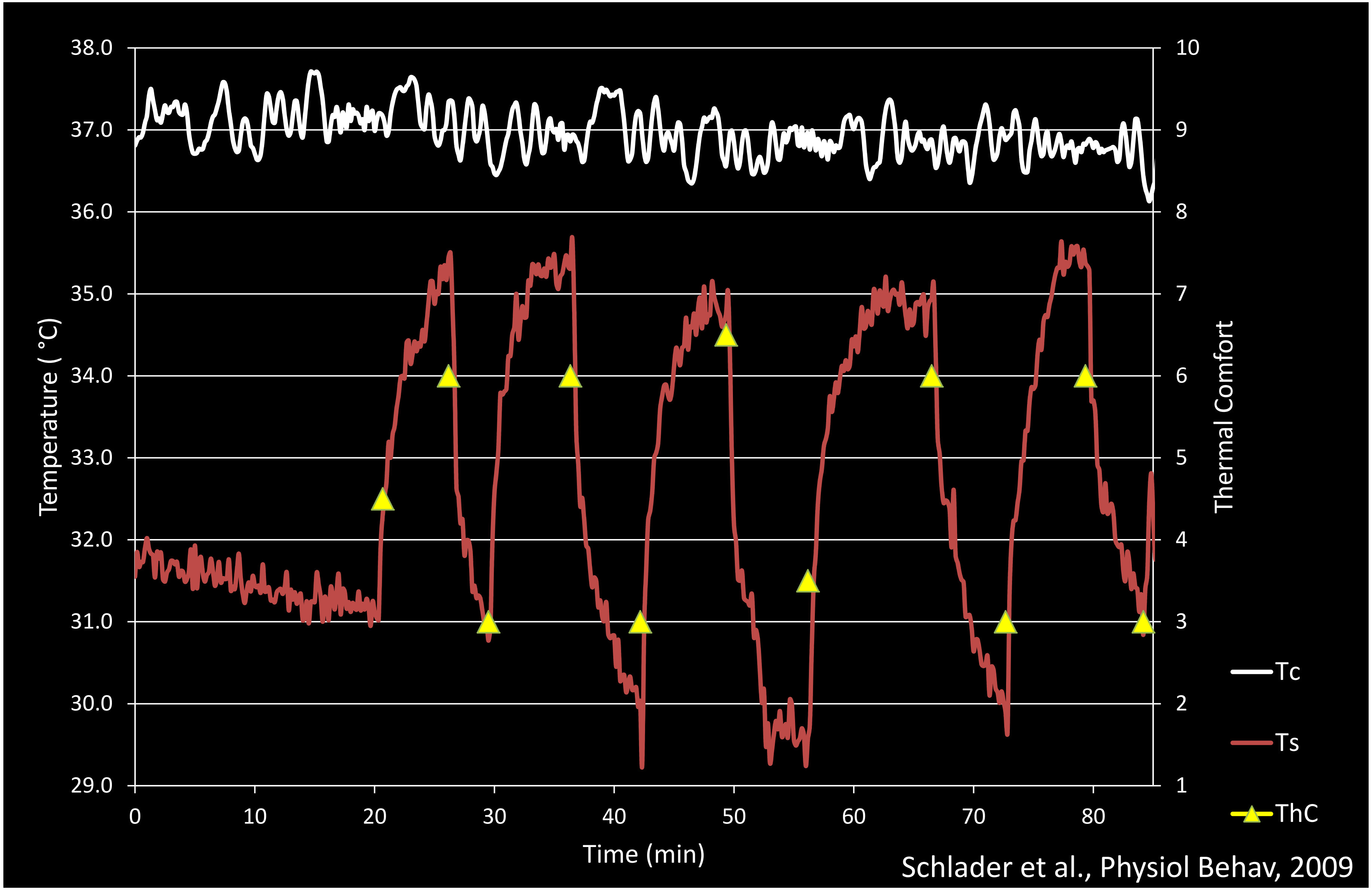
What is the **basis** of our choices for our thermal state?

BASIS OF THERMAL DECISIONS

- Shuttle-box model:
  - freedom of movement between two thermally extreme environments
  - thermoregulatory behavior = **moment at which a conscious decision is made**
    - Tre
    - Tsk
    - thermal comfort
    - time in chamber

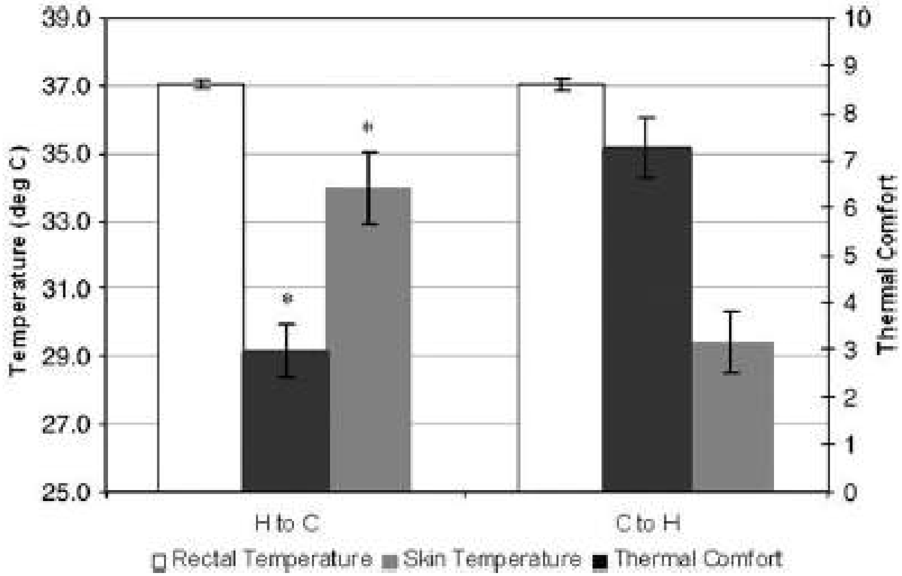
Schlader et al., Physiol Behav, 2009

BASIS OF THERMAL DECISIONS



BASIS OF THERMAL DECISIONS

- High probability of exit at Tsk:
  - cold to hot: 29.6 to 26.4°C
  - hot to cold: 34.1 to 36.2°C



- Behaviour was mainly **driven by Tsk** and not by Tc

Schlader et al., Physiol Behav, 2009

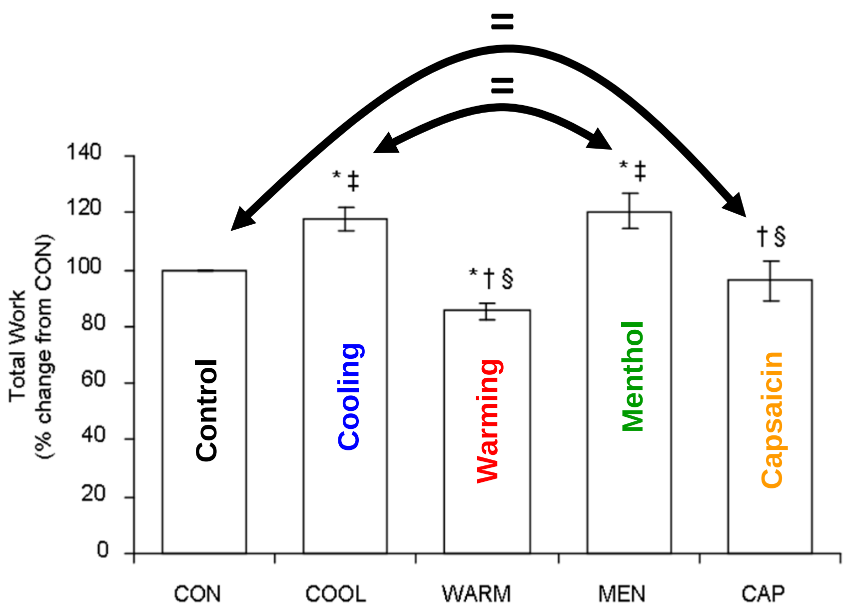
THERMAL VS. NON-THERMAL STIMULI

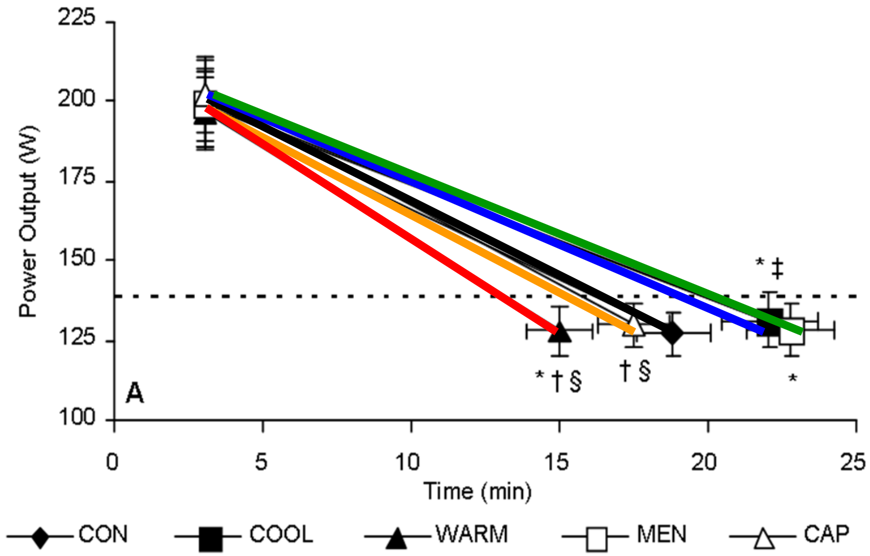
- Cycling protocol:
  - RPE clamped at 16 (hard – very hard)
  - liquid conditioning garment: 55°C

- Conditions:
  - control
  - thermal face **cooling**
  - non-thermal face **cooling (menthol)**
  - thermal face **heating**
  - non-thermal face **heating (capsaicin)**

Schlader et al., Physiol Behav, 2011

THERMAL VS. NON-THERMAL STIMULI





Schlader et al., Physiol Behav, 2011

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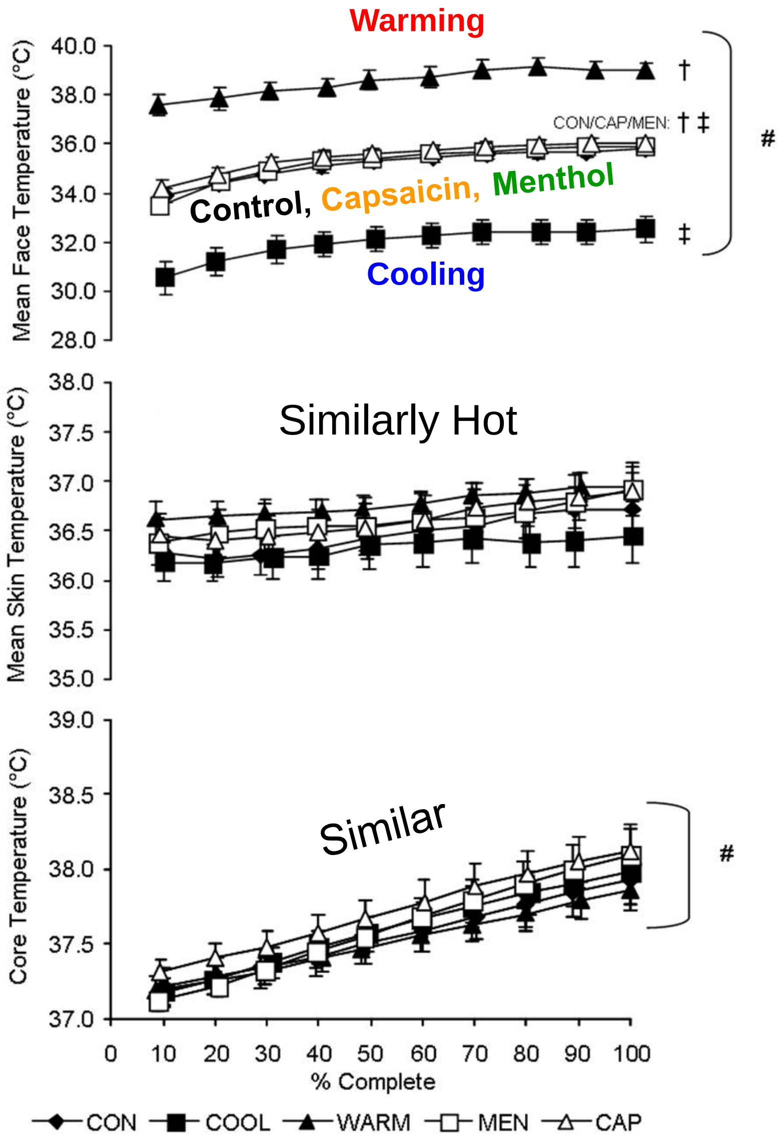
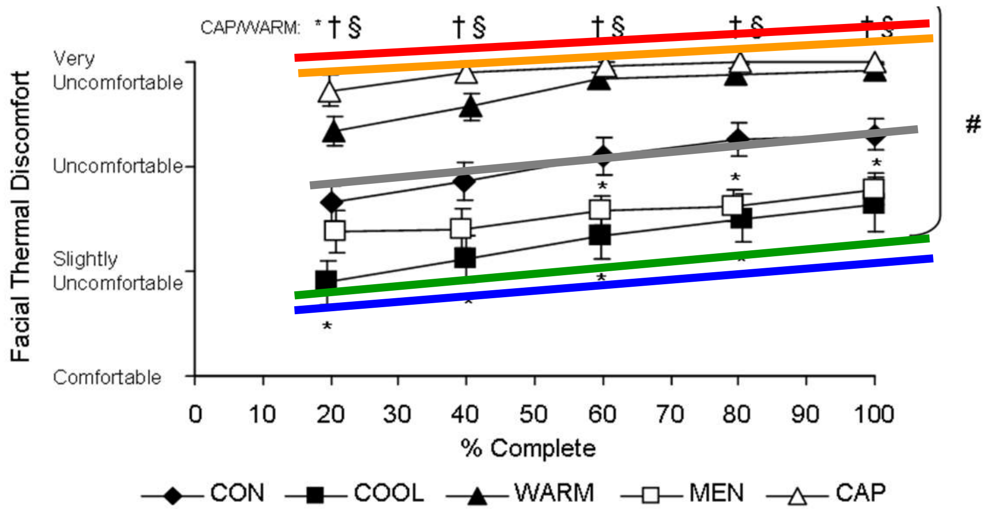




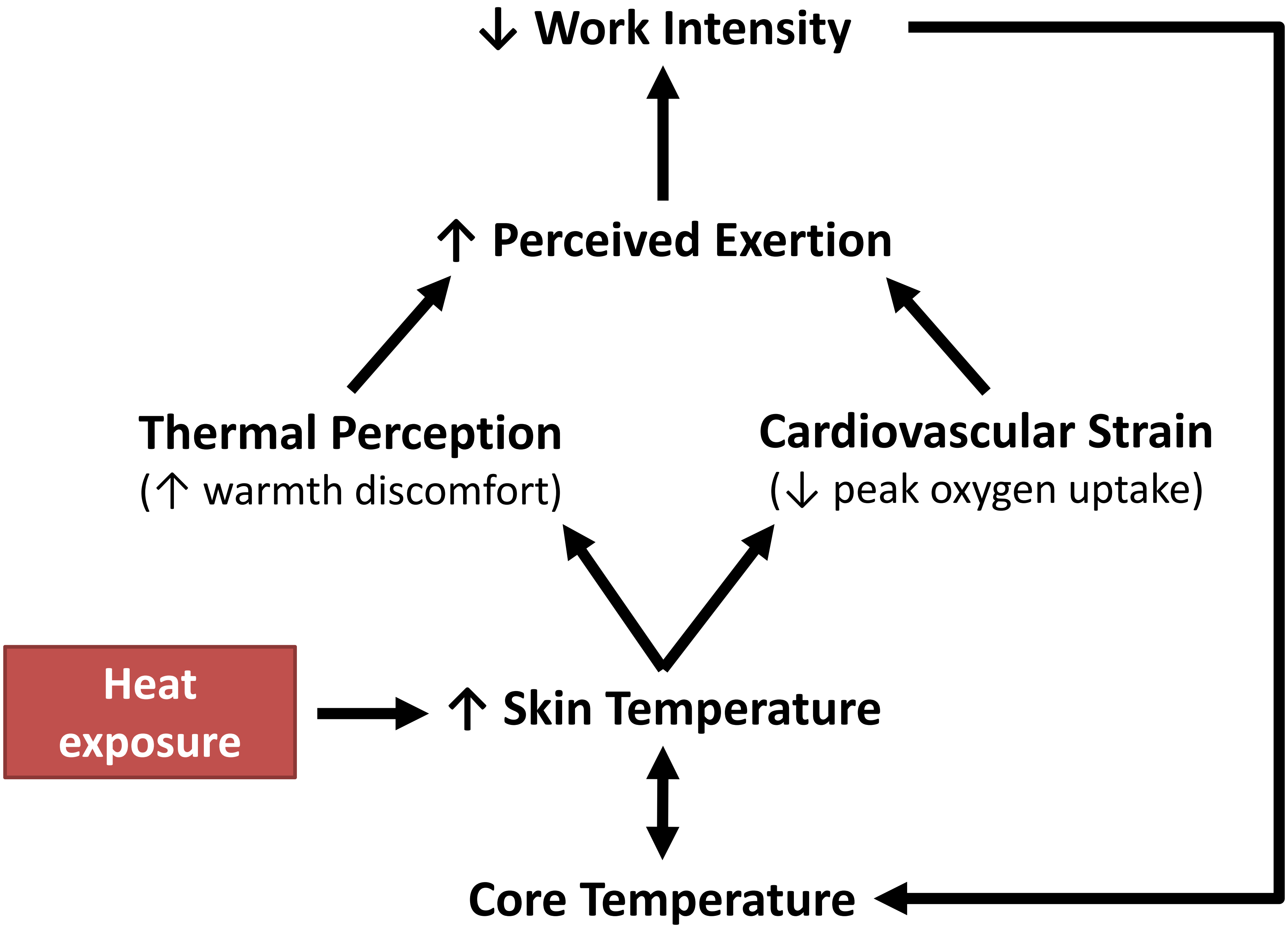
Schlader et al., Physiol Behav, 2011

THERMAL VS. NON-THERMAL STIMULI

- **Facial temperature** and **thermal perception** are capable modulators of behavioural thermoregulation and work output

- Physical (thermal) temperature change is **not** a necessary requirement for the initiation of thermoregulatory behaviour

Schlader et al., Physiol Behav, 2011



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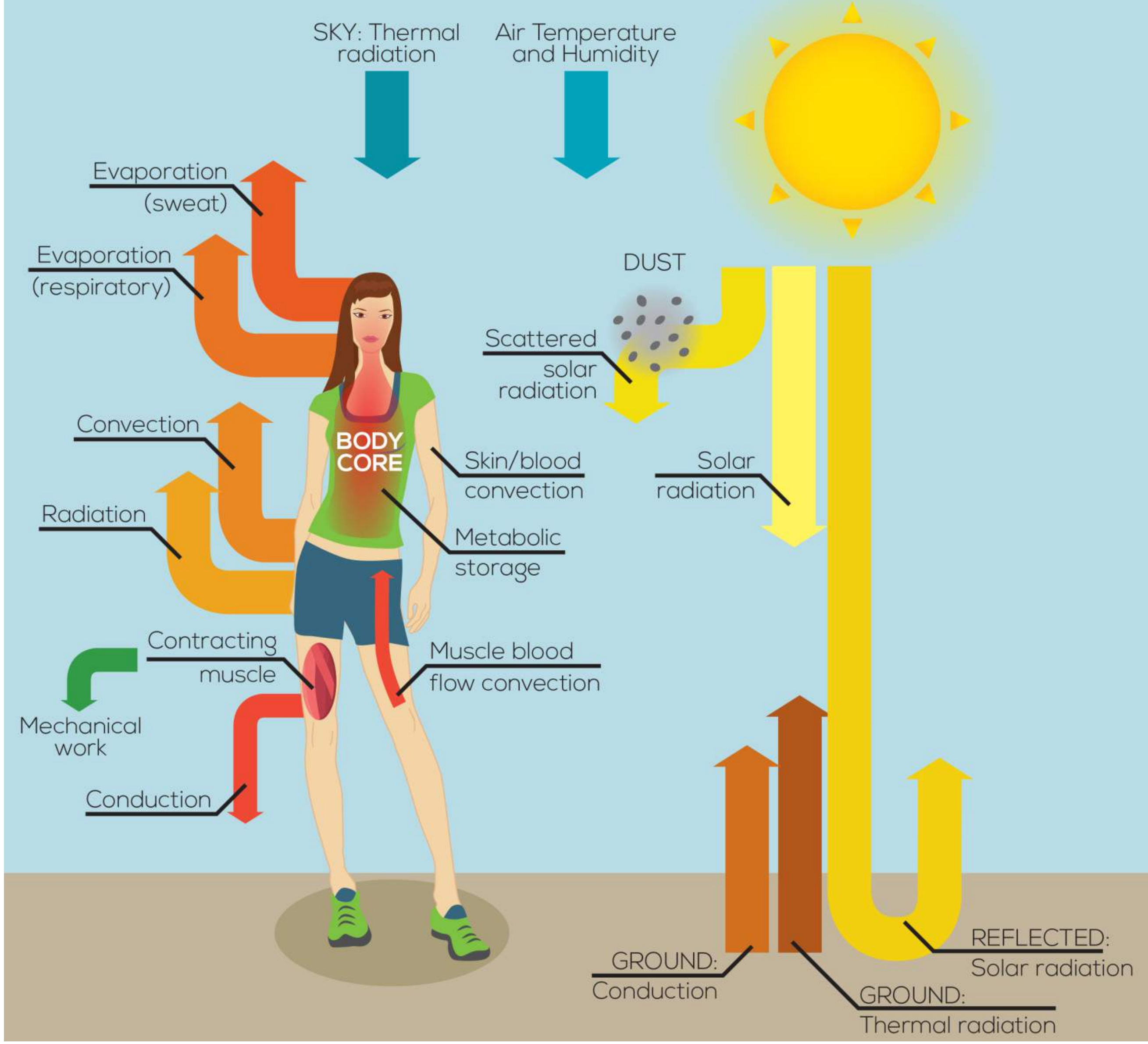

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