HEAT LOAD LIMITATIONS UNDER NORMAL AND STRESS CONDITIONS

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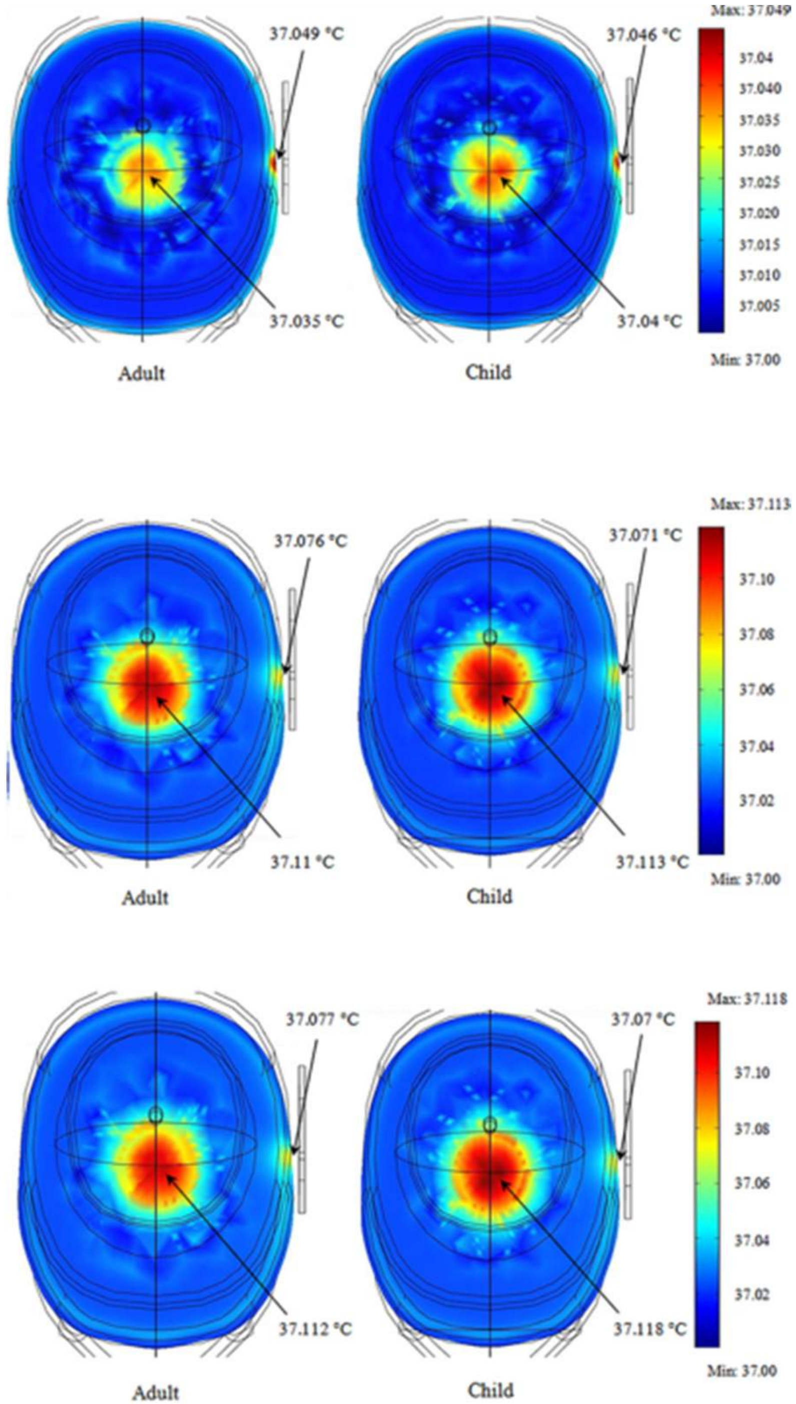


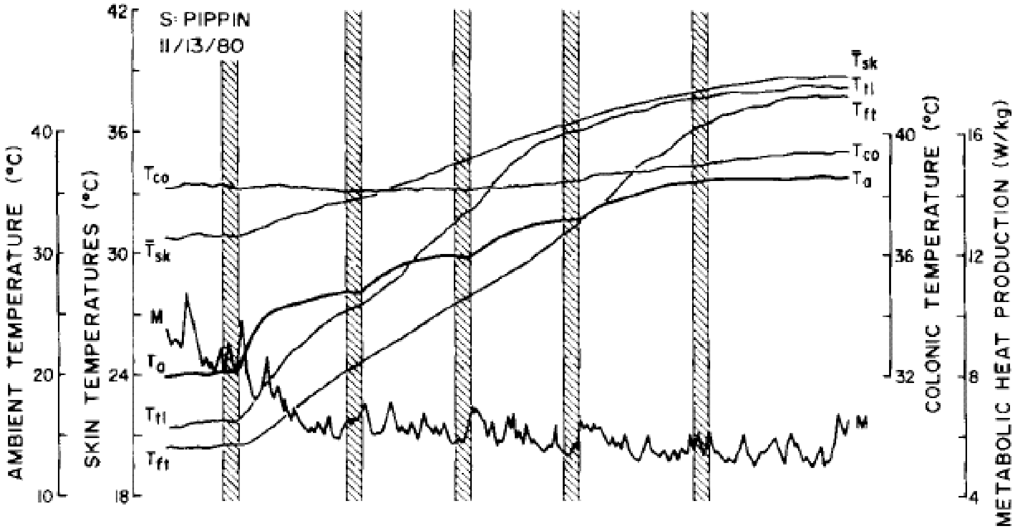
HEALTH EFFECTS OF HEAT STRESS

- Functional exhaustion of thermoregulatory mechanisms is typically manifested via two pathological conditions:
  - **thermal exhaustion**
  - **heat stroke**
    - **work/exercise induced**
      - **Tc: >40°C**
      - **neurological dysfunction**

Gabrielle Andersen, Los Angeles, 1984

EFFECTS OF MICROWAVE EXPOSURE

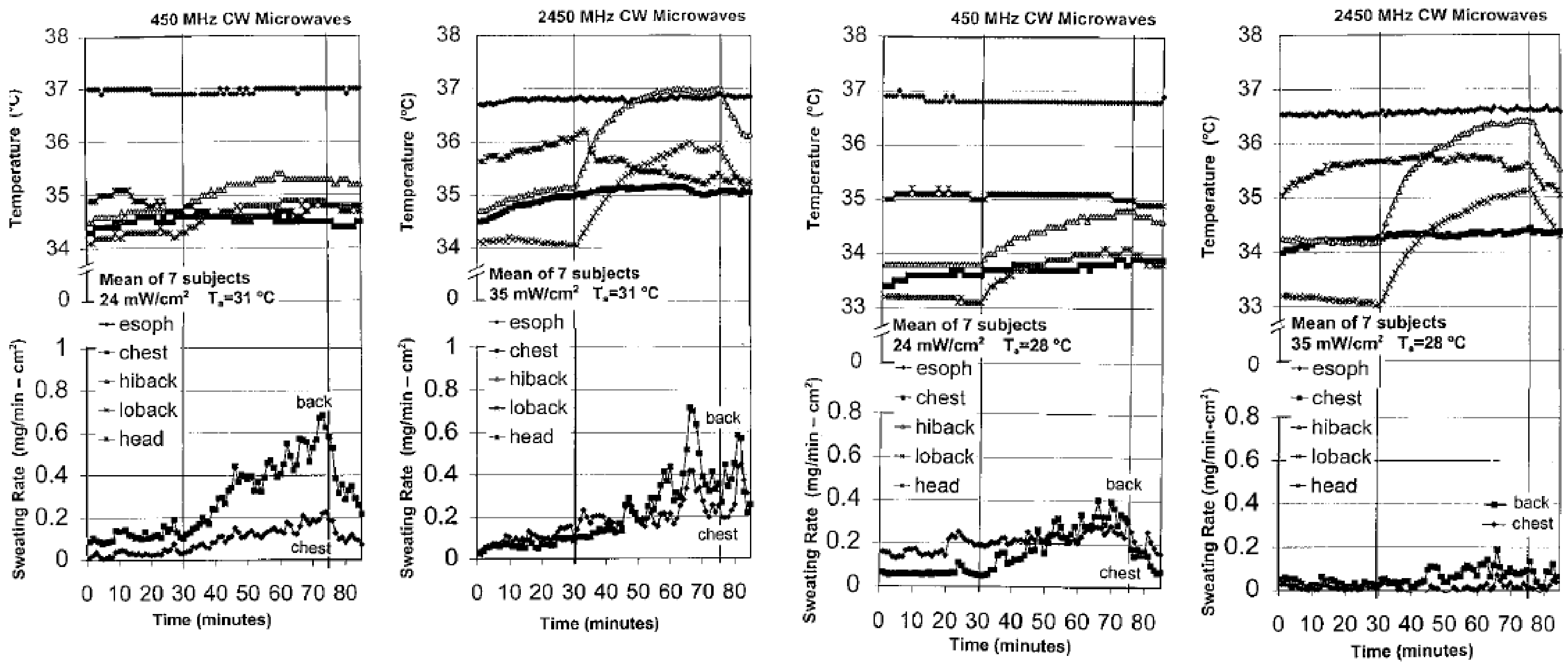
- Squirrel monkeys exposed to 2450-MHz continuous-wave microwaves for 40 h/week for 15 weeks



Adair et al., Bioelectromagnetics, 1985

- **No effect** of microwave exposure :
  - – metabolic rate, core temperature, sweating
- **Significant effect** of microwave exposure:
  - – skin temperature

EFFECTS OF RADIOFREQUENCY EXPOSURE

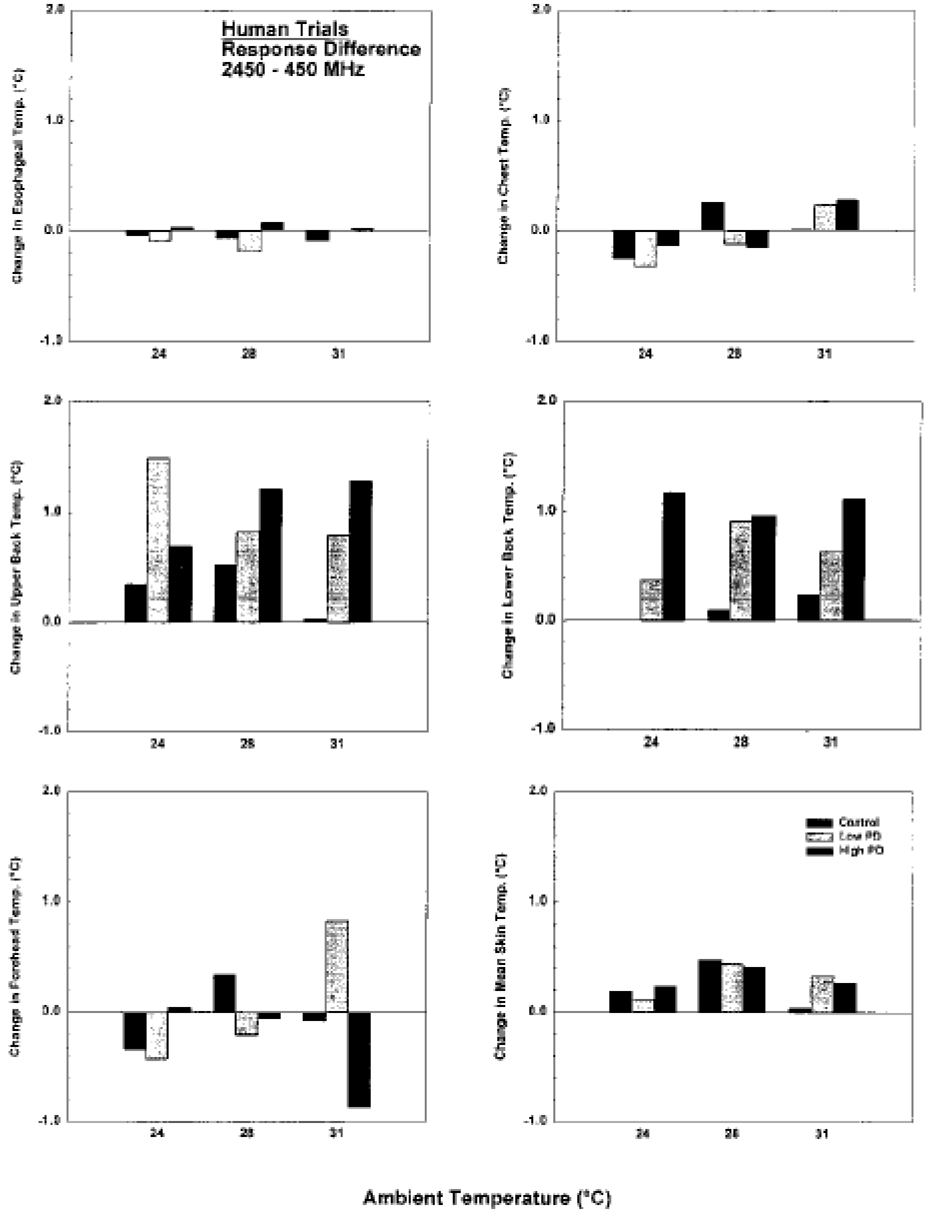


- 45-min dorsal exposure to 450 and 2450 MHz continuous-wave radio-frequency energy
  - 7 adults
  - 24°C, 28°C, and 31°C
  - 2 peak power densities (equivalent to normalized peak surface SARs of 6.0 and 7.7 W/kg)

Adair et al., Bioelectromagnetics, 1998-99

EFFECTS OF RADIOFREQUENCY EXPOSURE

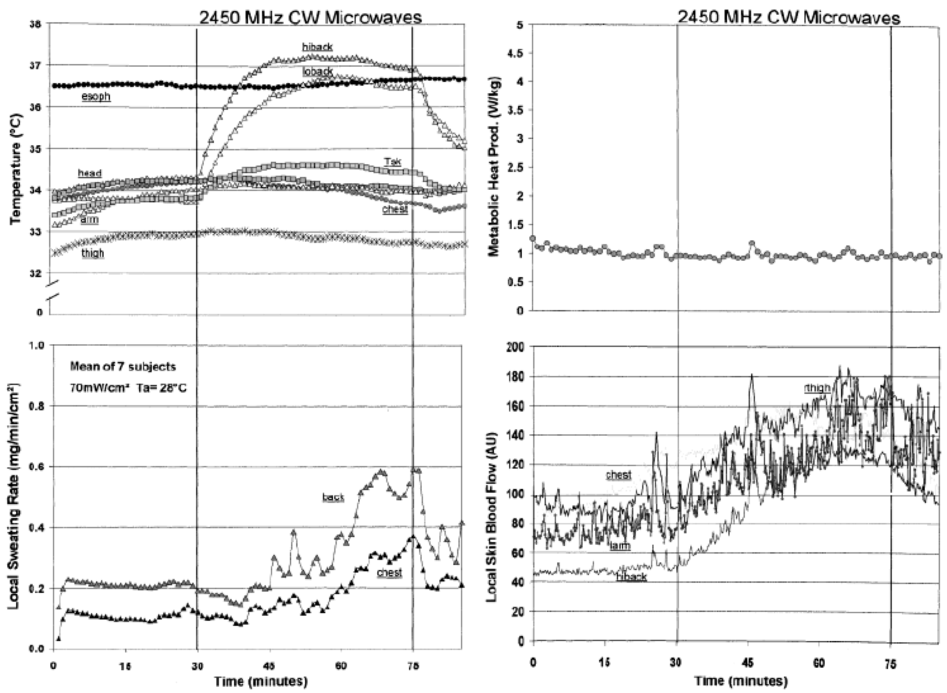
- **No effect** of radiofrequency:
  - metabolic heat production
  - esophageal temperature
- **Significant effect** of radiofrequency:
  - skin temperature



Adair et al., Bioelectromagnetics, 1998-99

EFFECTS OF RADIOFREQUENCY EXPOSURE

- 45-min dorsal exposure to 2450 MHz CW radio-frequency energy
  - 7 adults
  - 24°C, 28°C, and 31°C
  - 2 peak power densities (equivalent to normalized peak surface SARs of 11 and 15.4 W/kg)

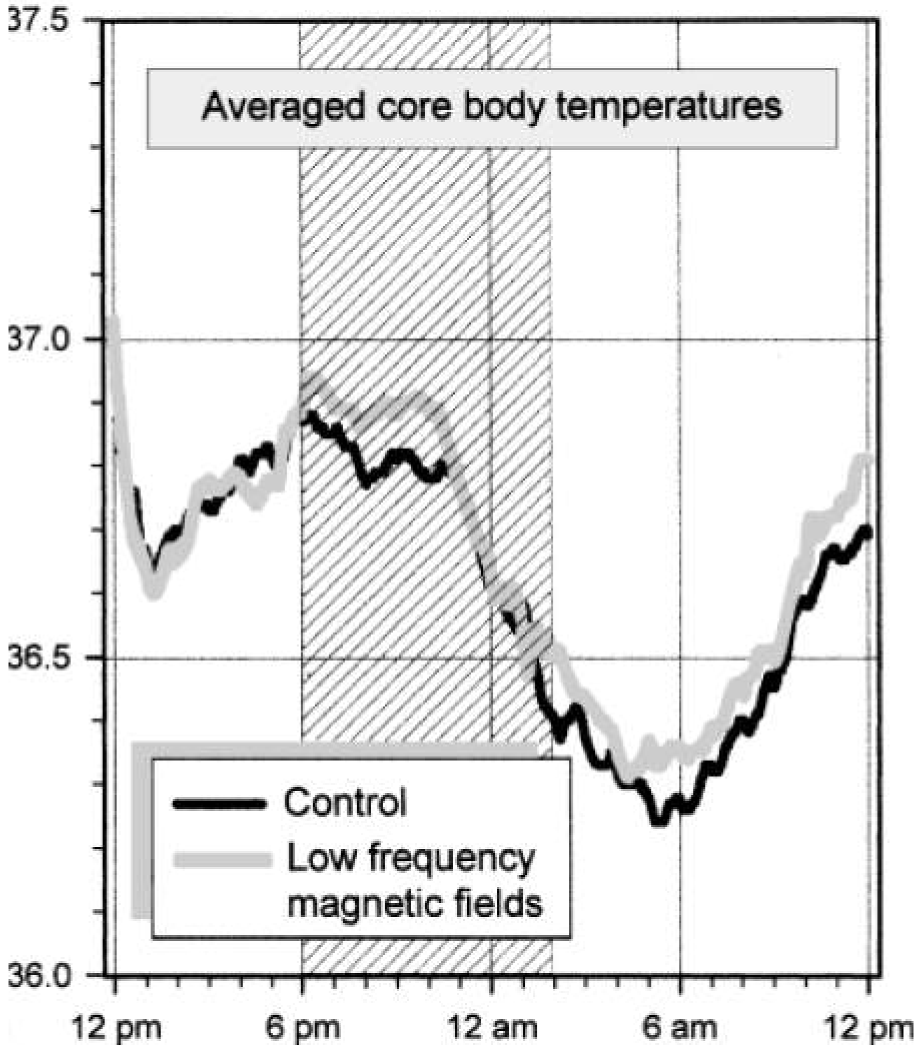


Adair et al., Bioelectromagnetics, 2001

EFFECTS OF MAGNETIC FIELD EXPOSURE

- 7 healthy young males
- Strong extremely low frequency magnetic field (16.7 Hz, 0.2 mT) continuously applied between 6 pm and 2 am

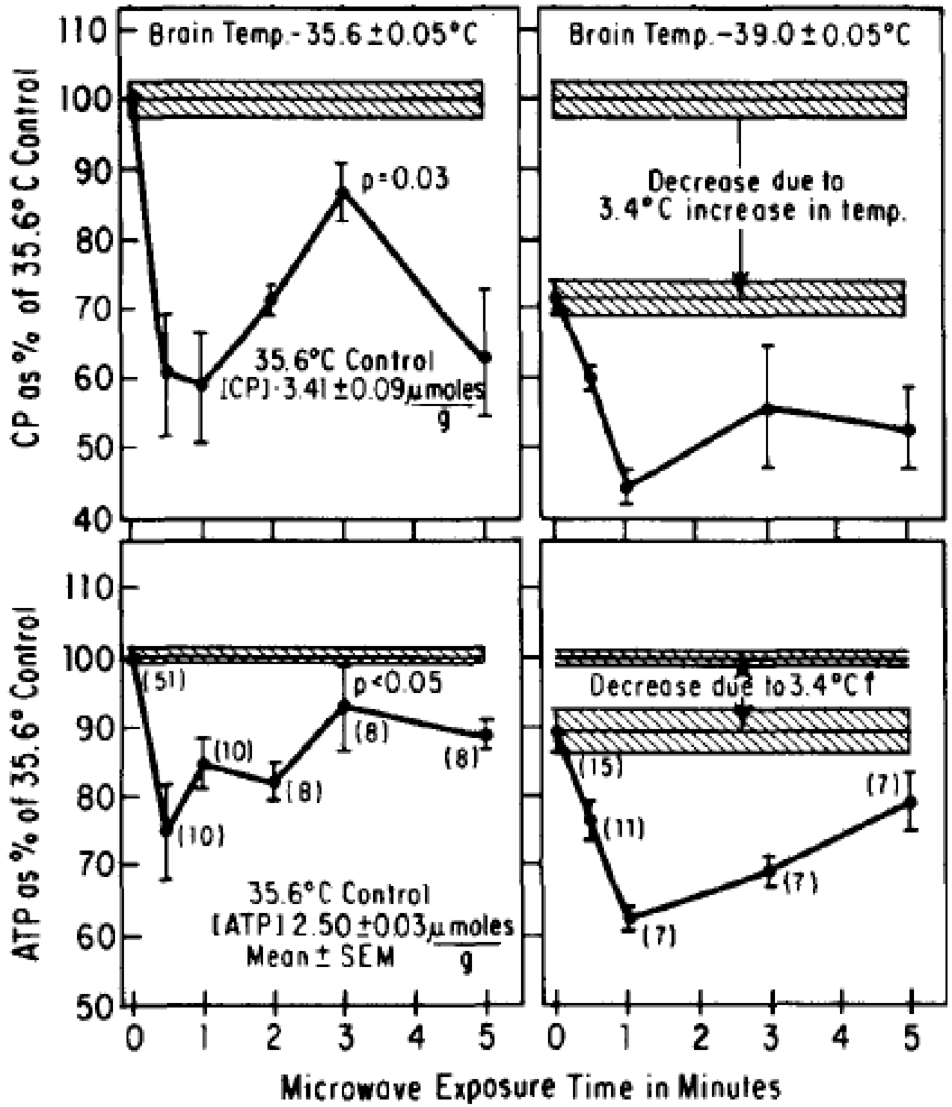
- **No effect** on core temperature



Griefahn et al., Bioelectromagnetics, 2001

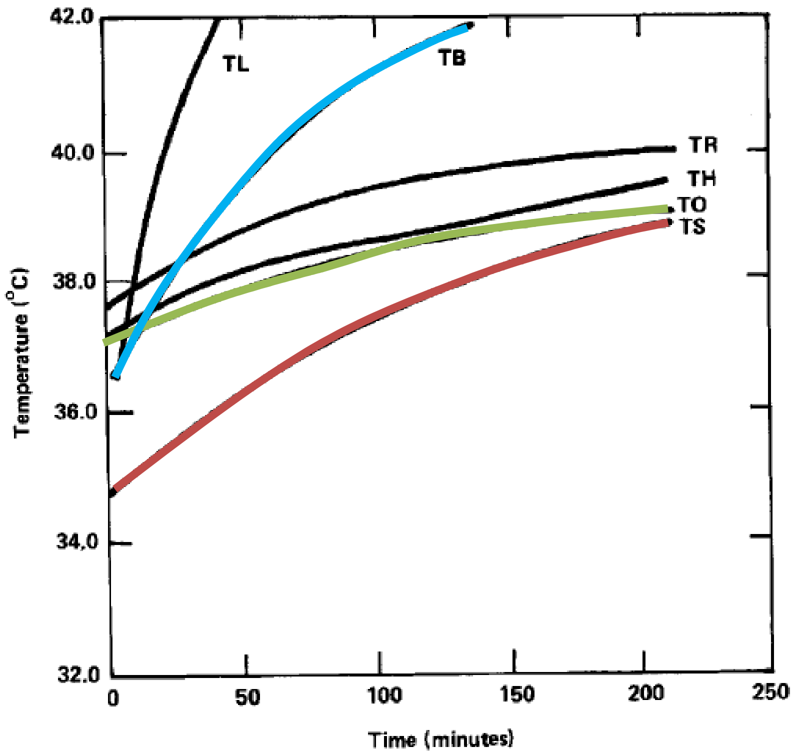
MICROWAVE EXPOSURE & BRAIN METABOLISM

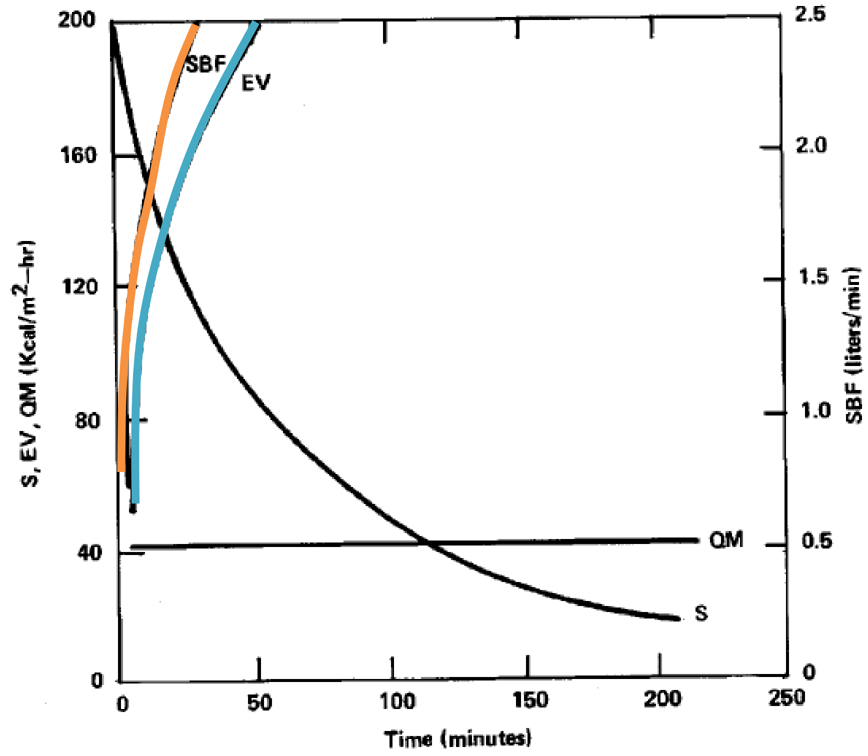
- Exposure to 591 MHz radiation at 13.8 mW/cm² for 0.5, 1.0, 3.0, and 5.0 min
- **No effect** on brain temperature
- **Significant effects** on CP and ATP



Sanders et al., Bioelectromagnetics, 1984

THERMAL EFFECTS OF EMF EXPOSURE





- Human model subjected to an 80-MHz EMF at a power density of 32.5 mW/cm^2

Spiegel et al., Bioelectromagnetics, 1980

EXISTING PRACTICE

- The American Conference of Governmental Industrial Hygienists proposed the **Threshold Limit Values** to manage the level of thermal strain experienced by workers
  - work-rest allocations that consider environmental conditions (WBGT) adjusted for activity level and clothing insulation
  - <u>primary goal</u>: preventing **core temperature** from exceeding predefined thresholds which are adjusted to account for the acclimation status of the worker
    - upper limit Tc allowed in non-acclimated workers: **38.0˚C**
    - upper limit Tc allowed in acclimated workers: **38.5˚C**

ACGIH, 2007

EXISTING PRACTICE

ACGIH TLV's for hot environments for physically fit and acclimatized individuals wearing light summer clothing

	Work Load		
Work-Rest Regimen	**Light**	**Moderate**	**Heavy**
Continuous Work	30 °C	26.67 °C	25 °C
75% Work 25% Rest, each hour	30.56 °C	27.78 °C	25.56 °C
50% Work 50% Rest, each hour	31.67 °C	29.44 °C	27.78 °C
25% Work 75% Rest, each hour	32.2 °C	31.11 °C	30 °C

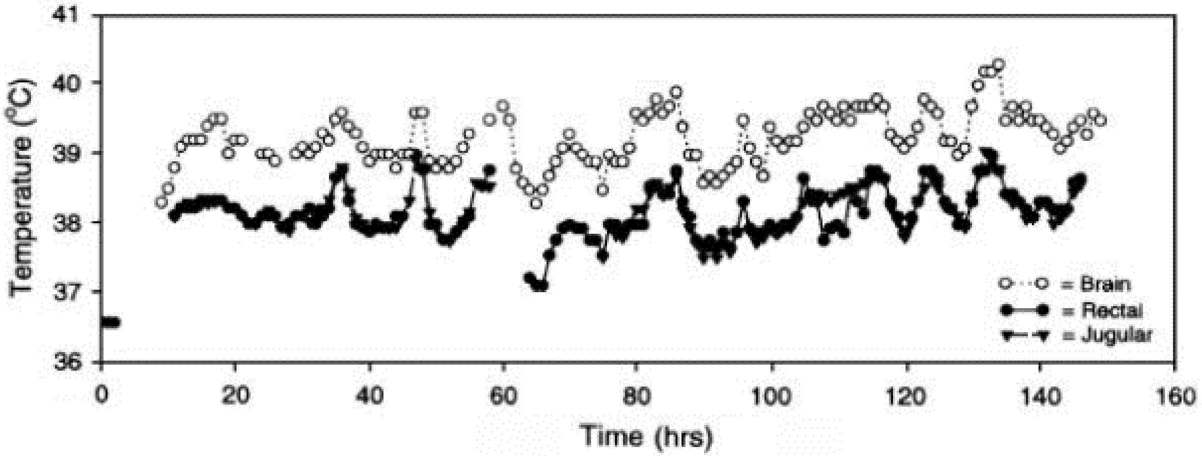
ACGIH, 2007

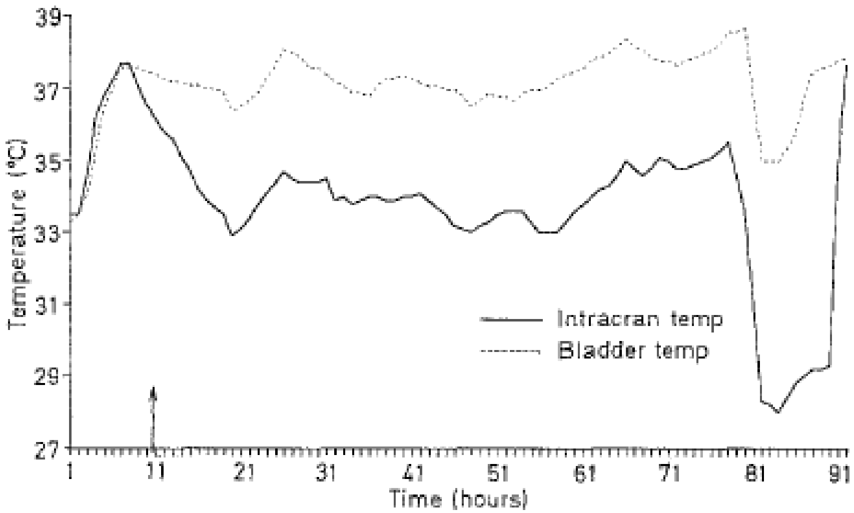
CORE TEMPERATURE

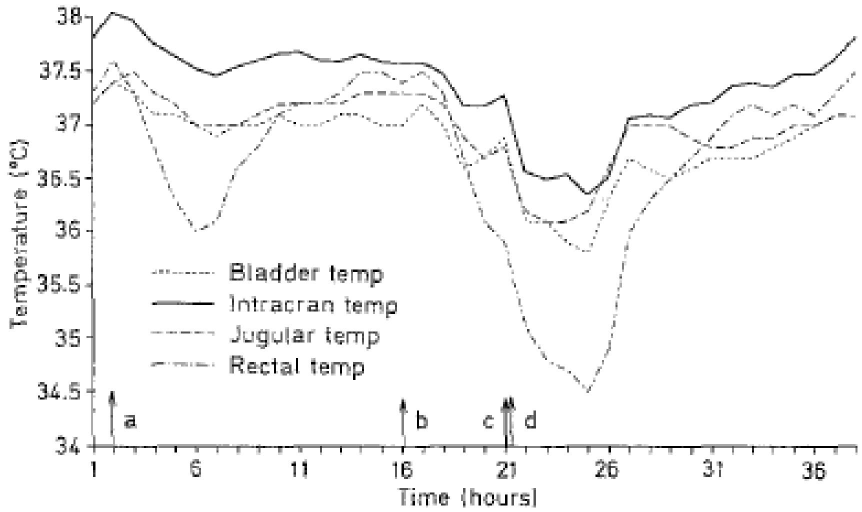
- Core temperature is the temperature of deep structures of the body such as the liver
  - measurement in the **rectum** is the traditional gold standard measurement, however it responds with a significant time delay
  - **esophageal** temperature is preferable due to its fast response time, however it is relatively invasive
  - **visceral** temperature is used infrequently and responds with a time delay
  - **brain**, **jugular**, and **bladder** temperatures are rarely used due to their invasiveness

VARIATION IN CORE TEMPERATURE

Rumana et al., Crit Care Med, 1998

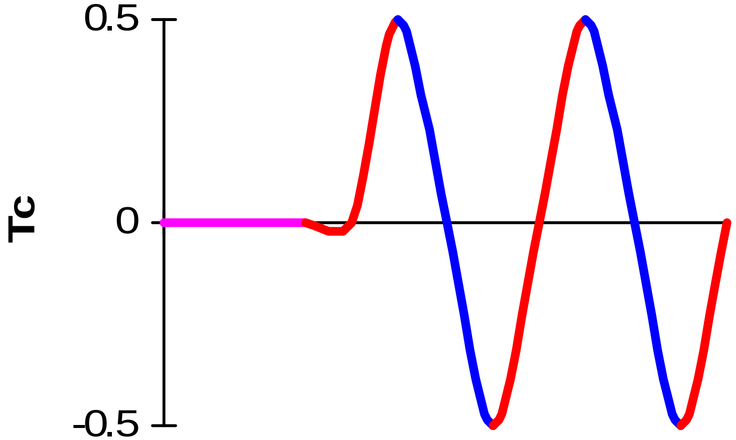






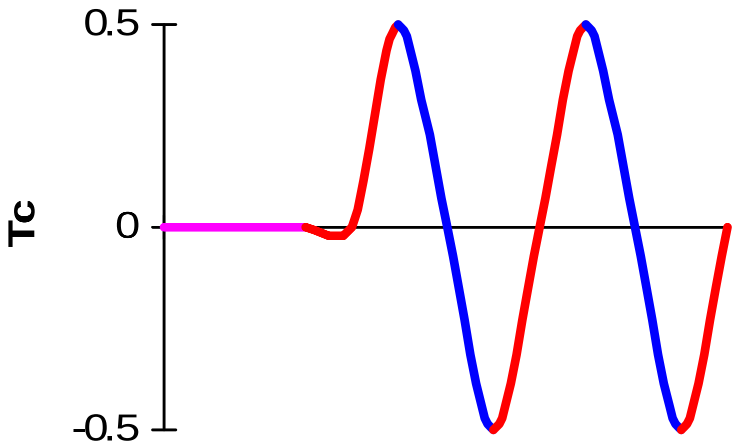
Verlooy et al., Acta Neurochir, 1995

CHANGES IN CORE TEMPERATURE

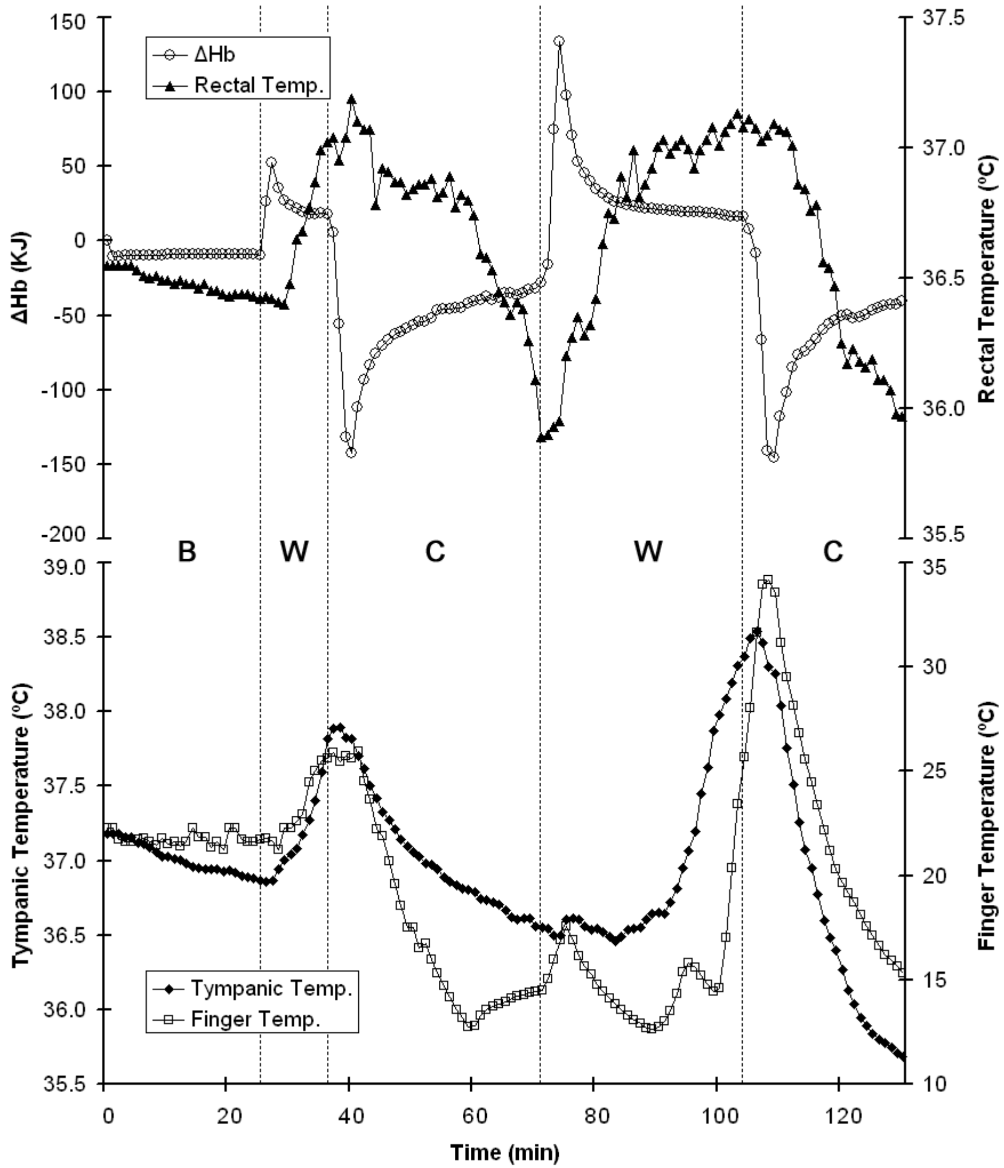


Flouris & Cheung, JAP, 2009

CHANGES IN CORE TEMPERATURE



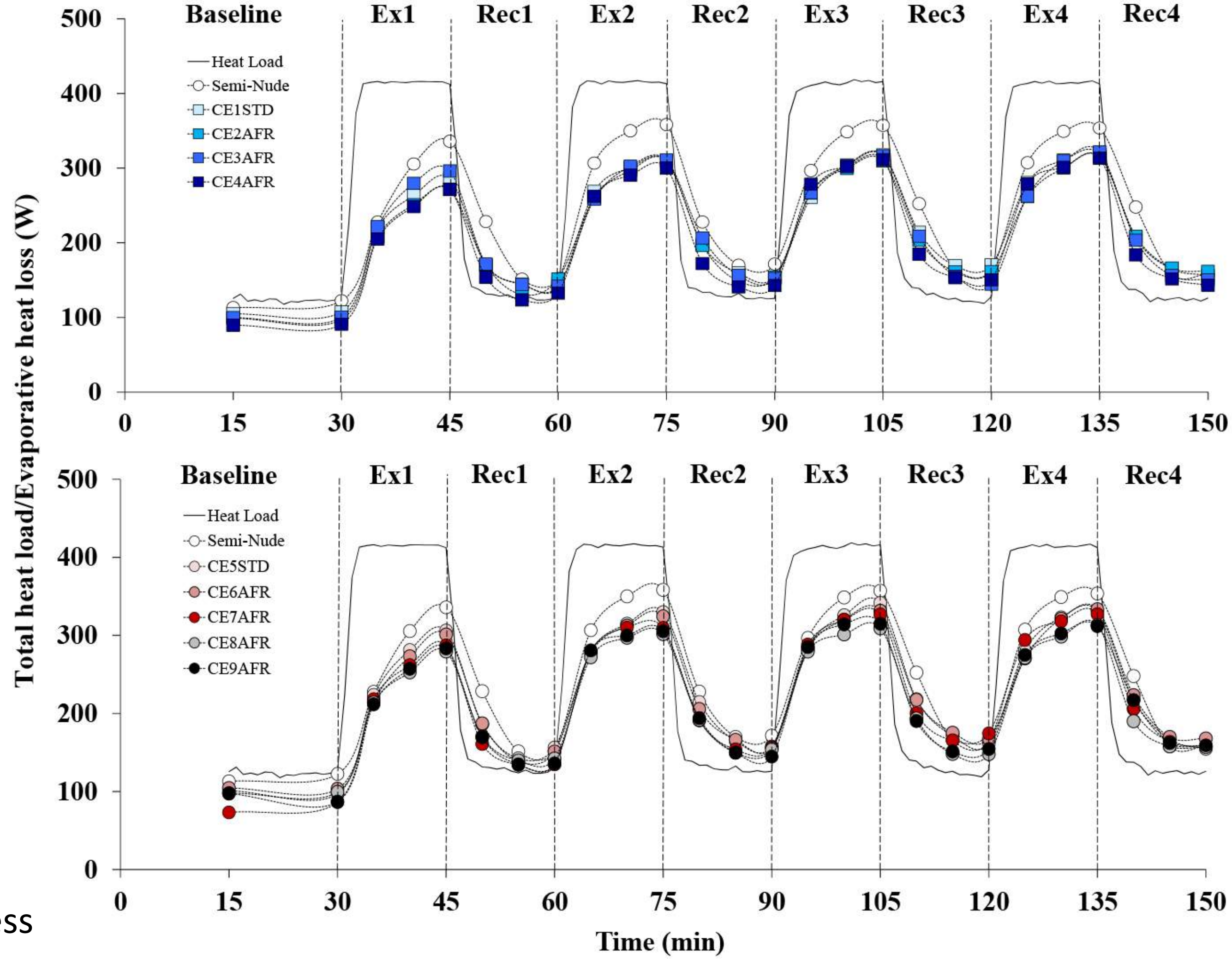
Flouris & Cheung, JAP, 2009



CLOTHING

- 4x15 min work bouts at 400 W

35 °C
15% RH



 Poirier et al., JOEH, In Press

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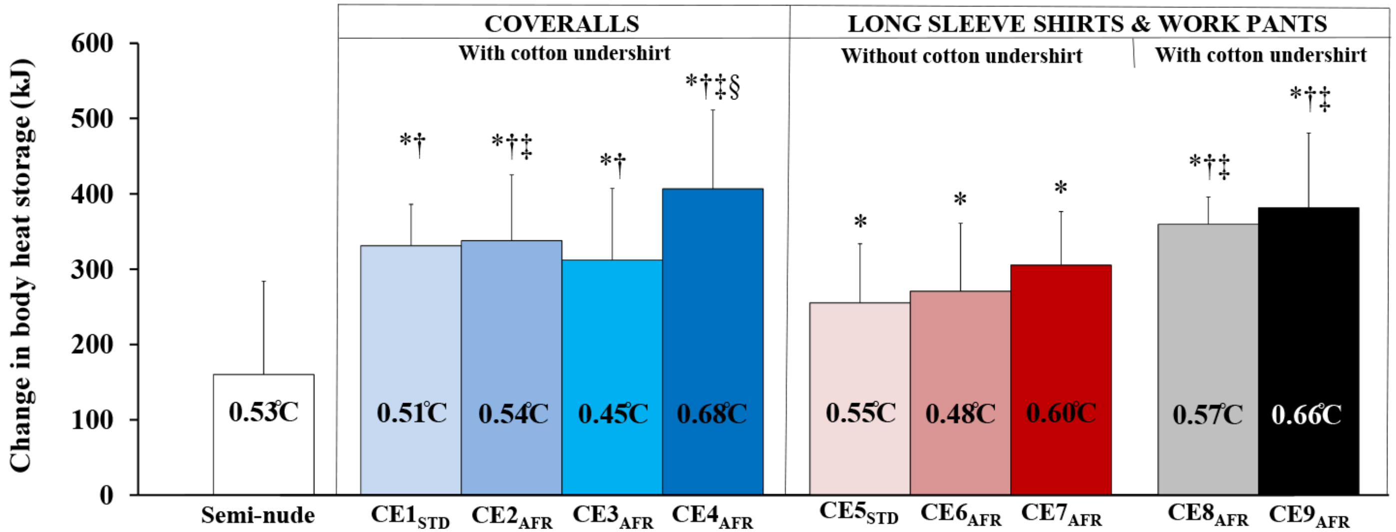
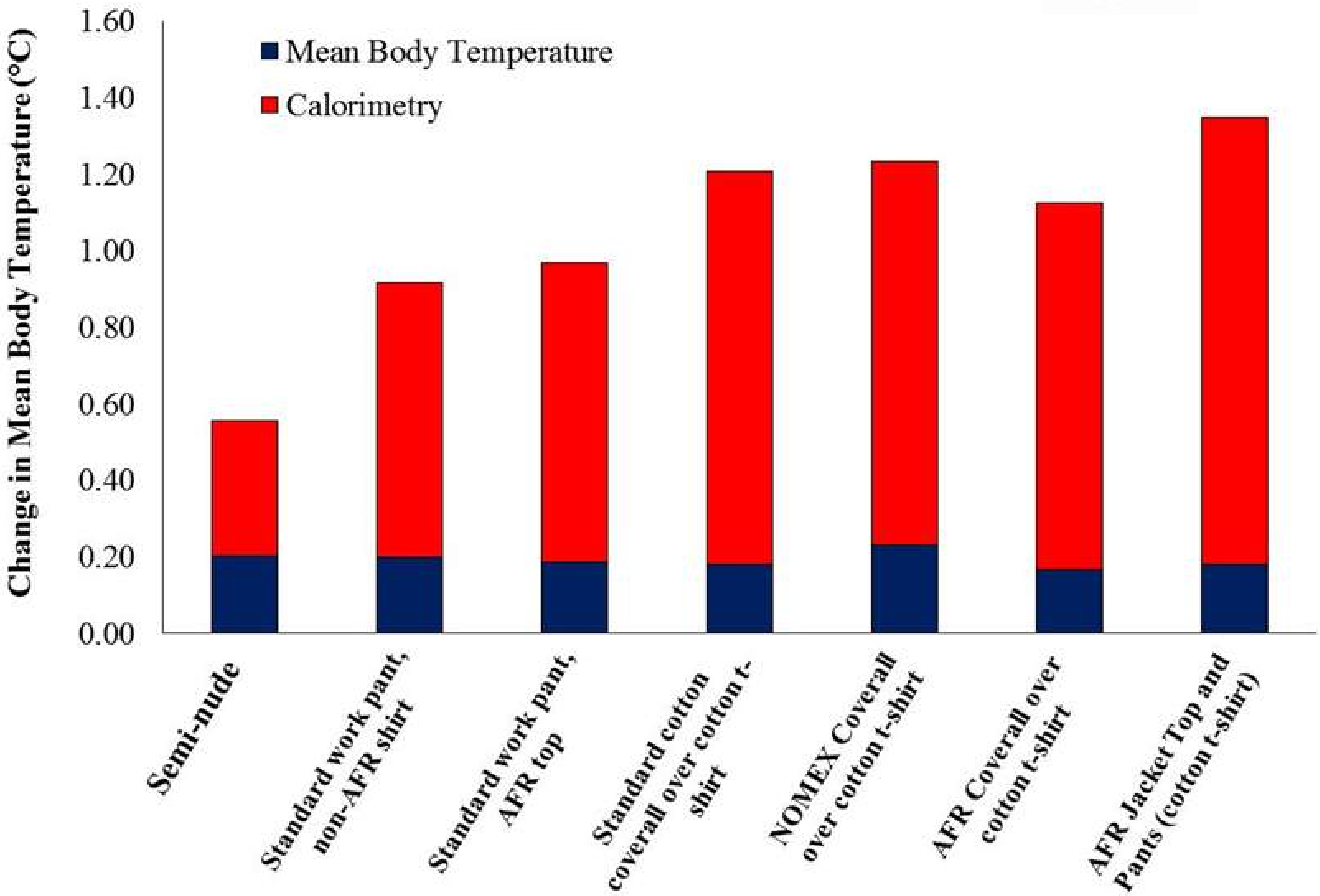


Poirier et al., JOEH, In Press

Do we really understand the risk using core temperature? Raising a red flag!



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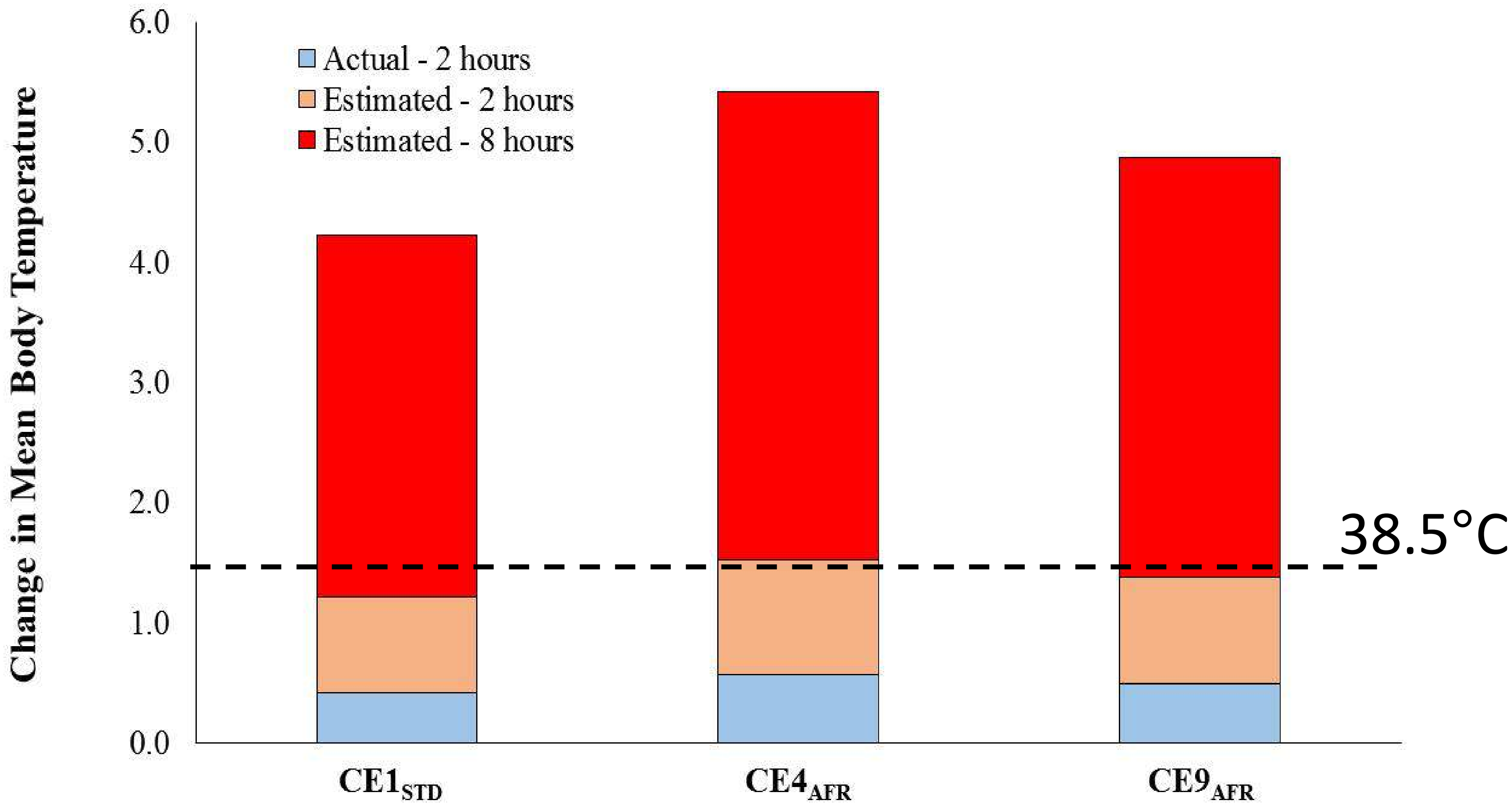
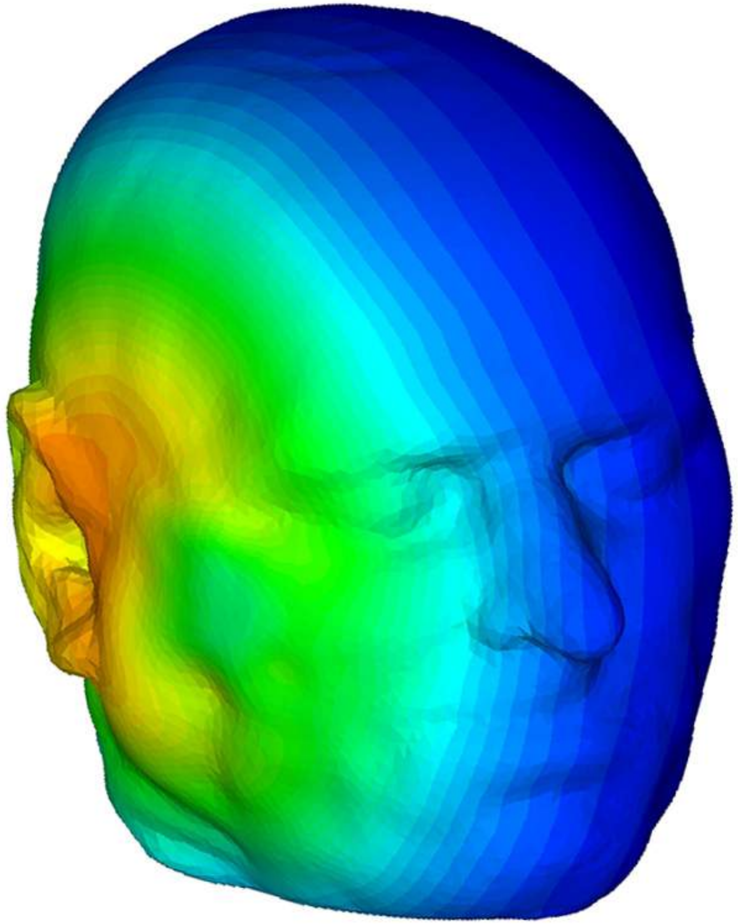
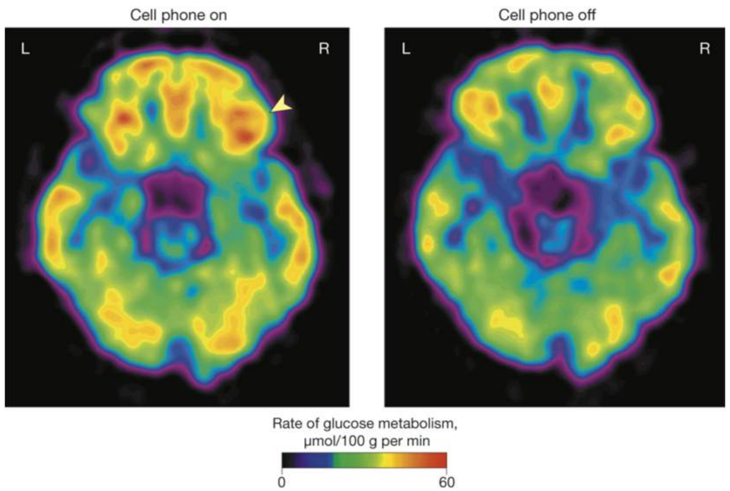
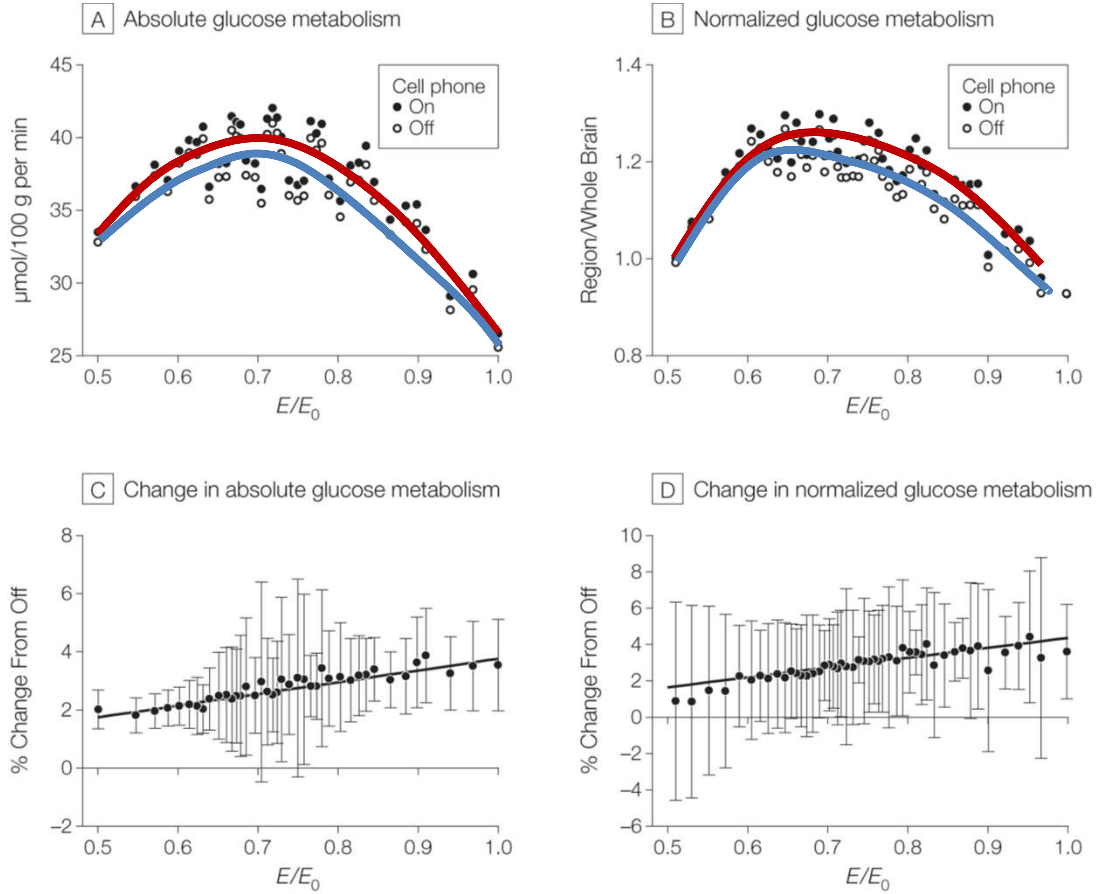


HEAD THERMOREGULATION



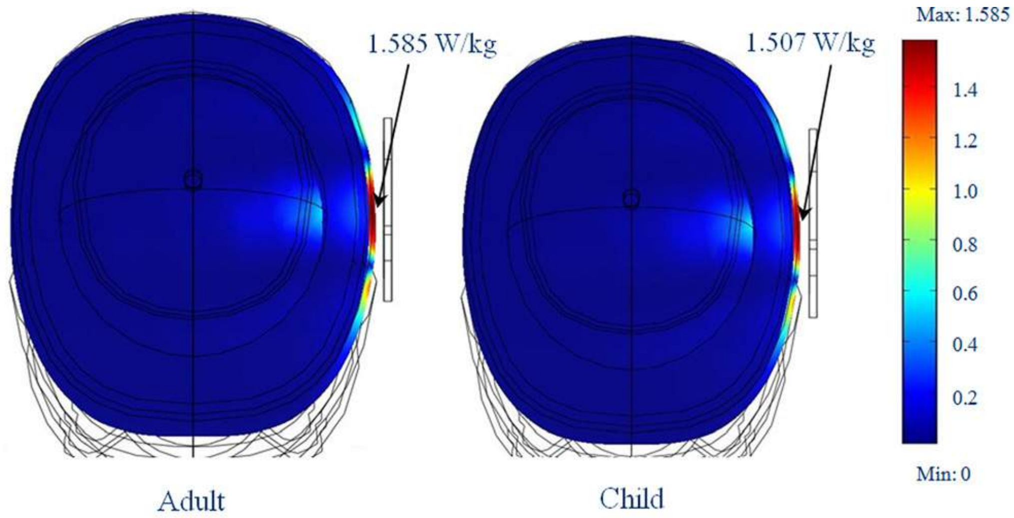
RADIOFREQUENCY & BRAIN METABOLISM

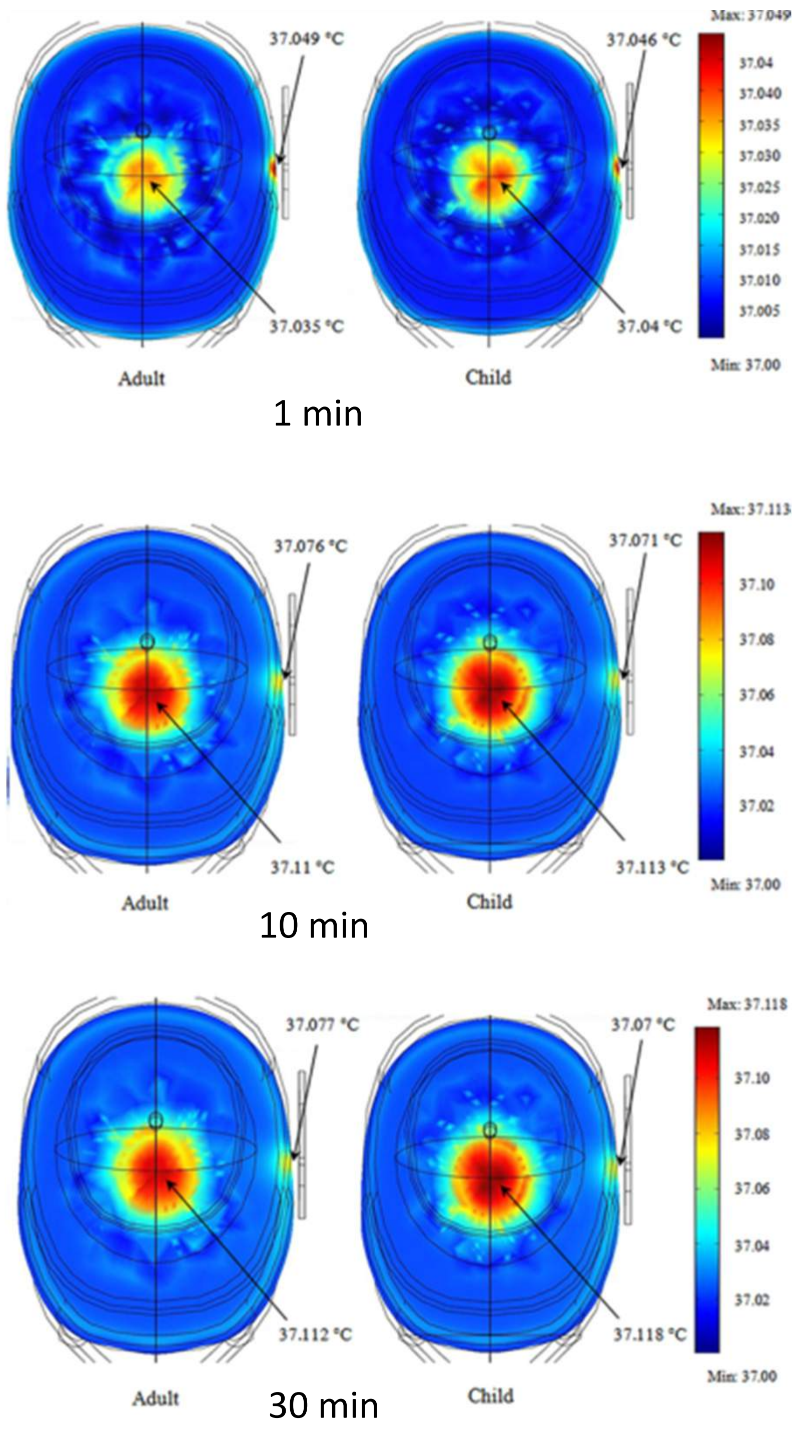




Volkow et al., JAMA, 2011

RADIOFREQUENCY & HEAD THERMOREGULATION





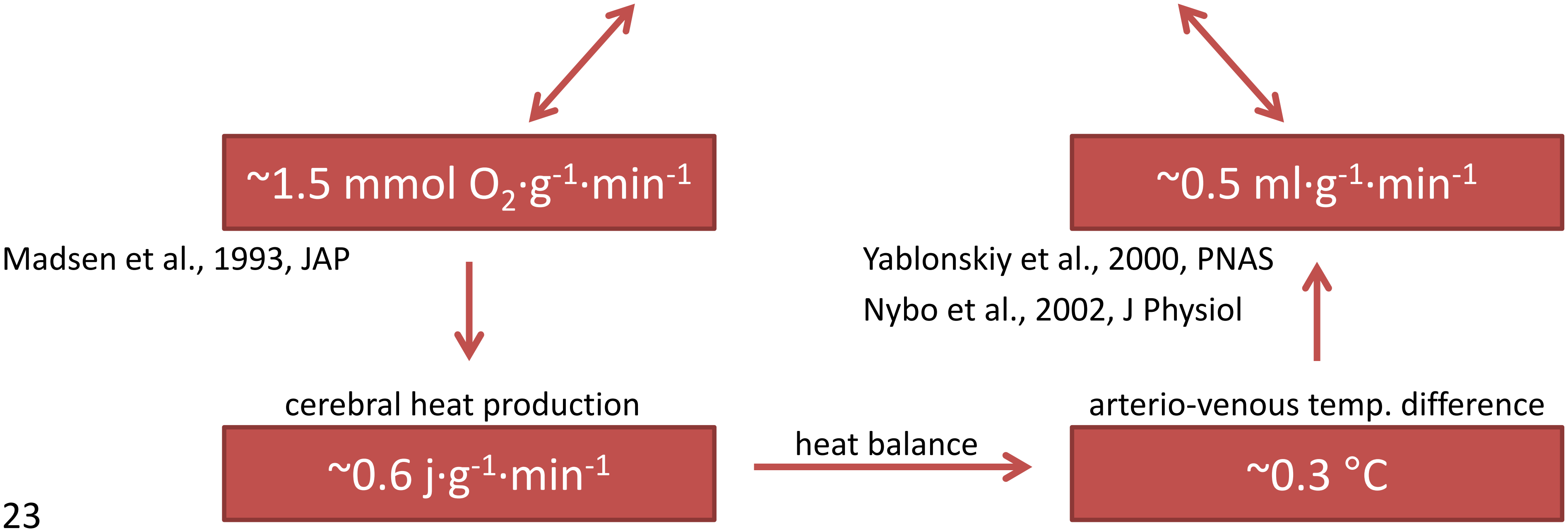
- Highest temperature after 30 min radiation exposure:
  - adult brain: 37.112°C
  - child brain: 37.118°C

Wessapan et al., JHT, 2012

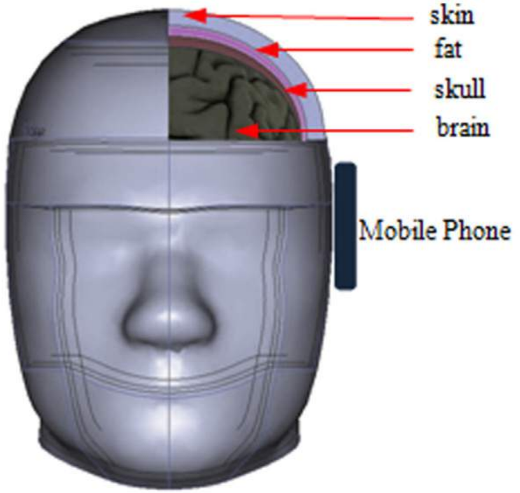
HEAD THERMOREGULATION AT REST

- Average brain temperature at rest: ~37°C
  - heat is heterogeneously distributed in the brain

    Mariak et al., 1999, JAP
  - local temperature depends on the proportion between the regional **metabolic rate** and **cerebral blood flow**



CONSIDERATIONS



Head dimensions

	Adult (cm)	7 years old child (cm)
Head length	18.8	17.3
Head breadth	16	14.9
Head height	23.7	20.8

Dielectric properties of tissues at 900 MHz

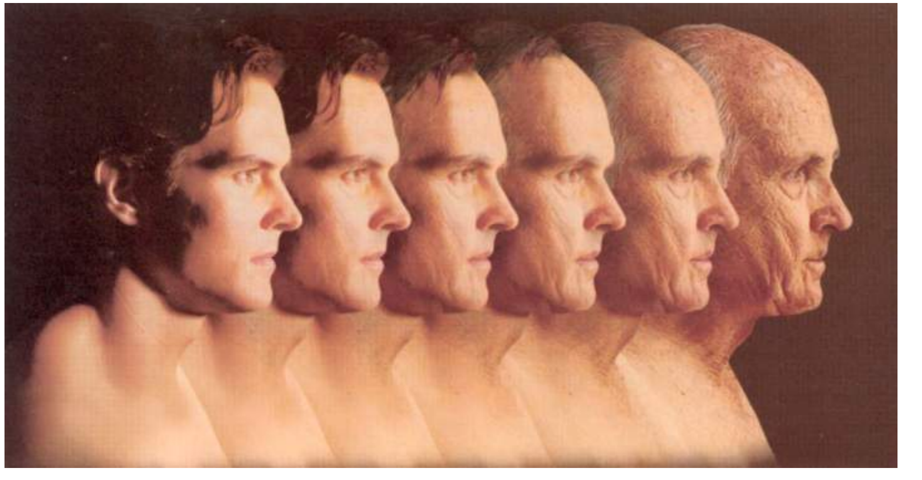
	Adults		7 years old	
Type of tissue	ε_r	σ (S/m)	ε_r	σ (S/m)
Skin	41.41	0.87	42.47	0.89
Fat	11.33	0.11	12.29	0.12
Bone	20.79	0.34	21.97	0.36
Brain	45.805	0.765	46.75	0.78

Thermal properties of tissues

Tissue	ρ (kg/m^3)	k (W/m°C)	C (J/kg°C)	Q_{met} (W/m^3)	ω_b (1/s)
Skin	1125	0.42	3600	1620	0.02
Fat	916	0.25	3000	300	4.58×10^{-4}
Bone	1990	0.37	3100	610	4.36×10^{-4}
Brain	1038	0.535	3650	7100	8.83×10^{-3}

Wessapan et al., JHT, 2012

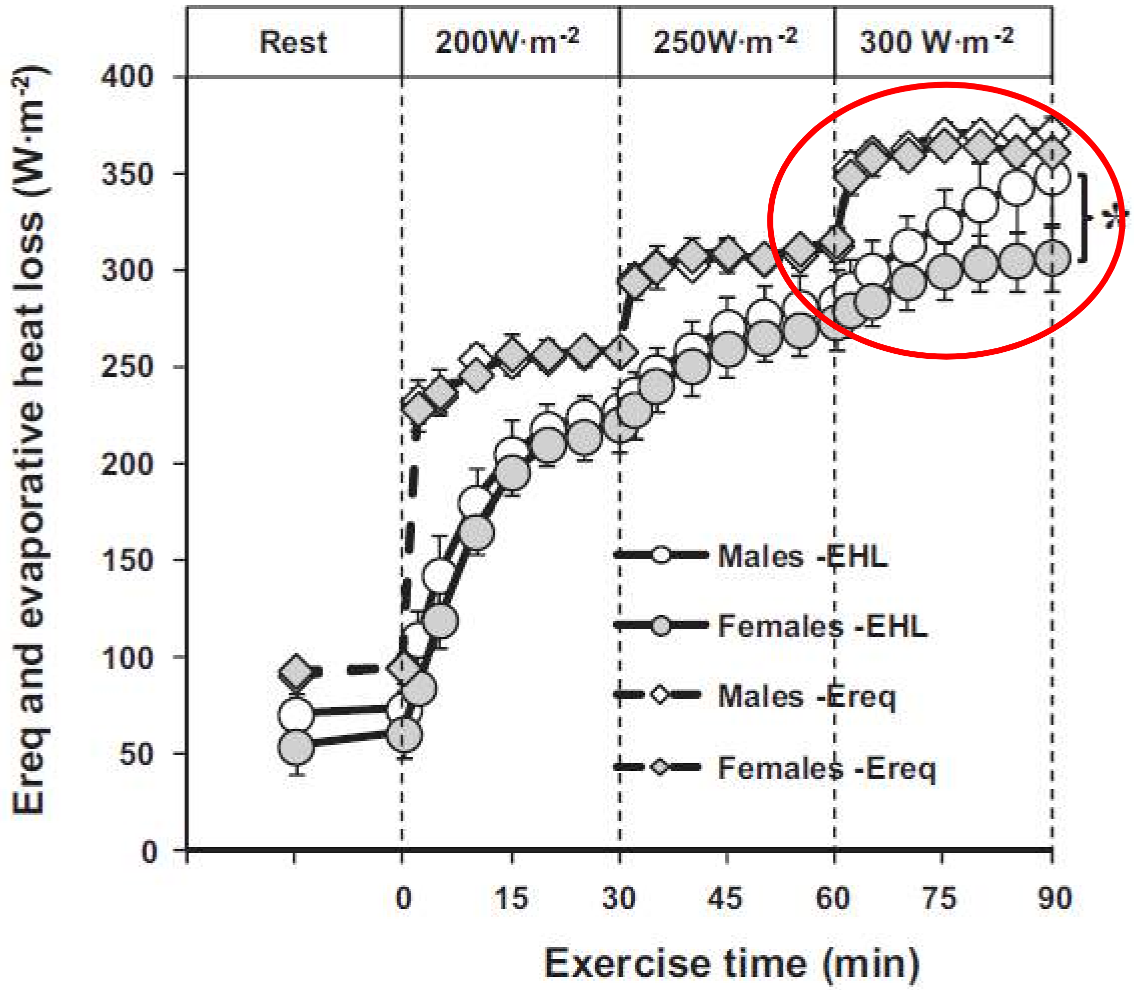
EFFECTS OF SEX, AGE, FITNESS AND DISEASE THERMOREGULATION



Sex differences in thermoeffector responses during exercise at fixed requirements for heat loss

Daniel Gagnon and Glen P. Kenny

J Appl Physiol 113: 746–757, 2012.



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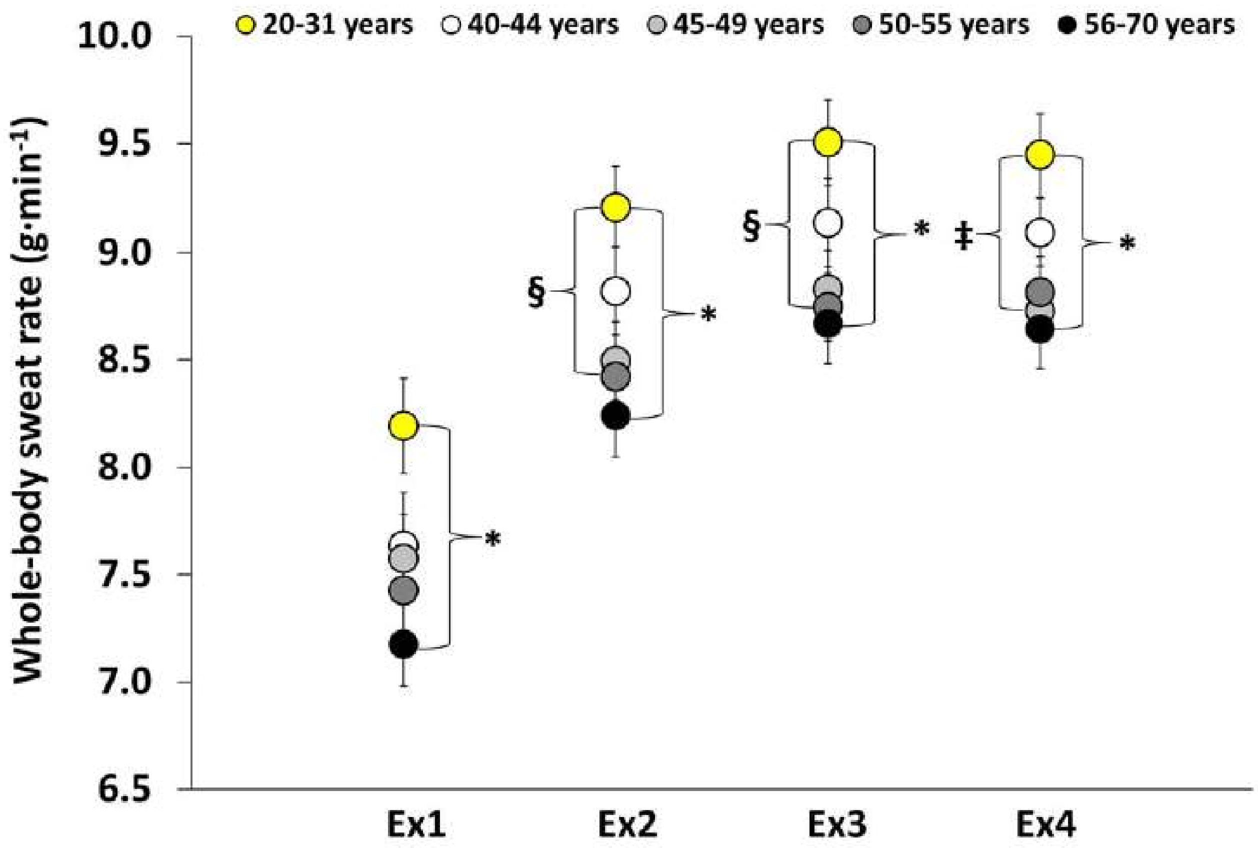
PLOS | ONE

Age-Related Decrements in Heat Dissipation during Physical Activity Occur as Early as the Age of 40

Joanie Larose[1], Pierre Boulay[2], Ronald J. Sigal[3,4], Heather E. Wright[1], Glen P. Kenny[1*]

PLoS ONE 8(12): e83148. doi:10.1371/journal.pone.0083148



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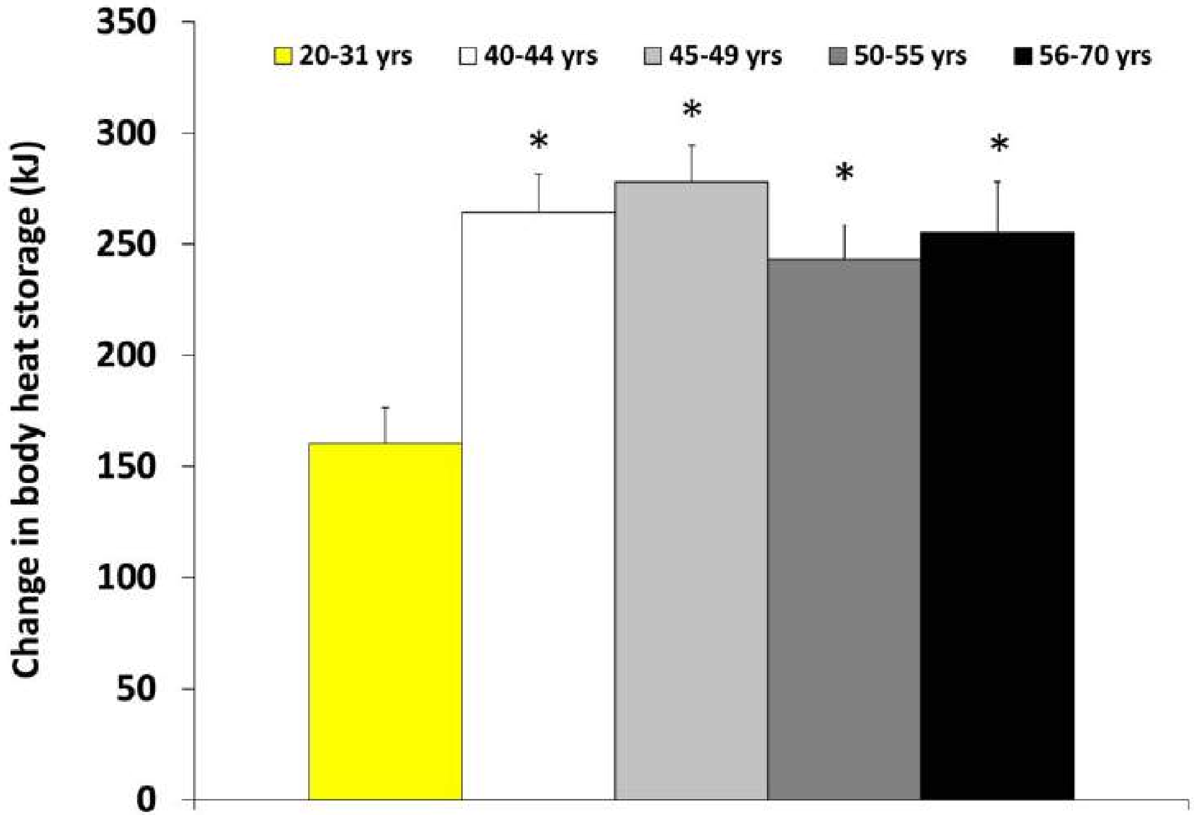
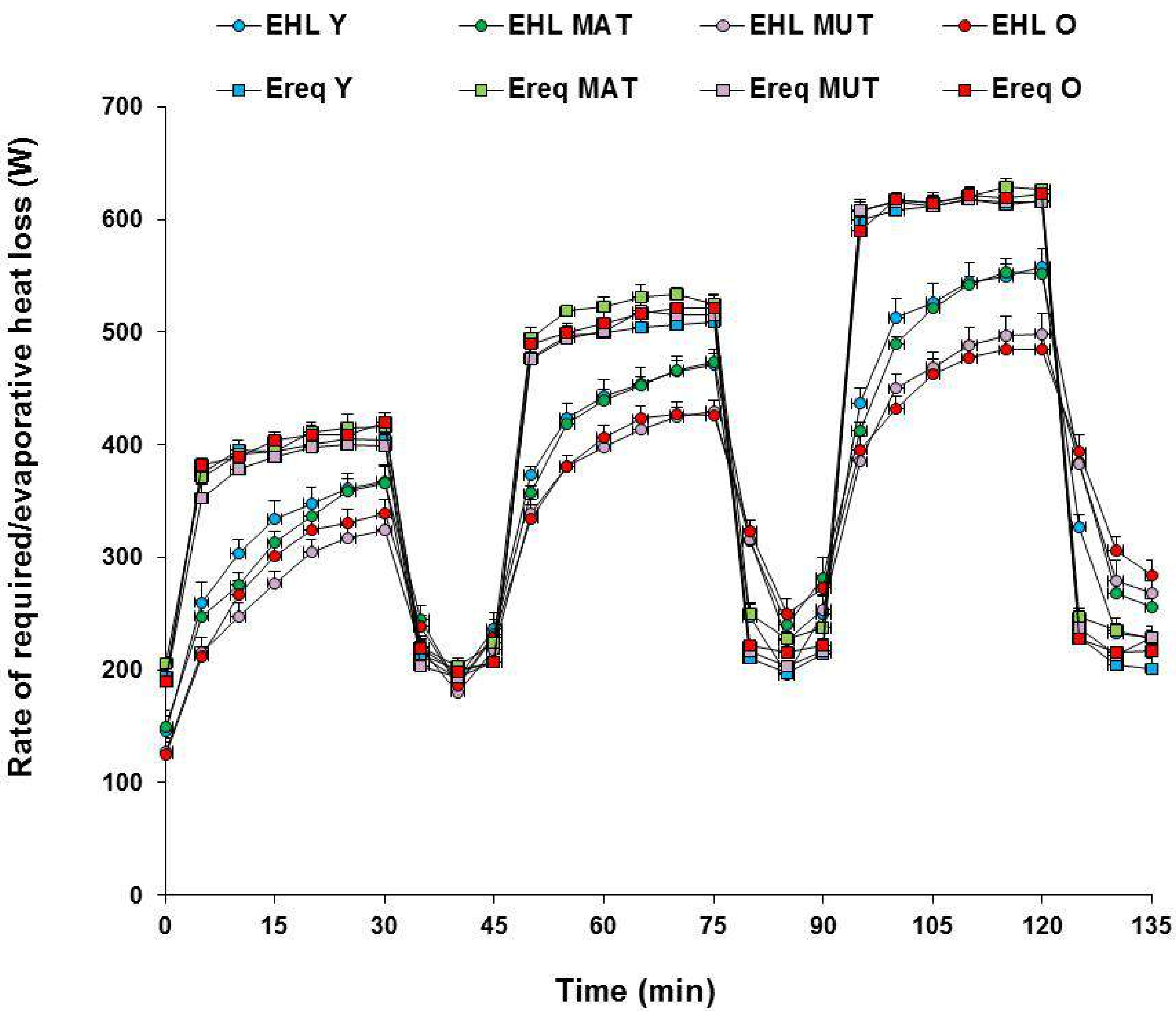


Aging impairs heat loss, but when does it matter?

Jill M. Stapleton,[1] Martin P. Poirier,[1] Andreas D. Flouris,[2] Pierre Boulay,[3] Ronald J. Sigal,[4]
Janine Malcolm,[5] and Glen P. Kenny[1]



AGE & DIABETES

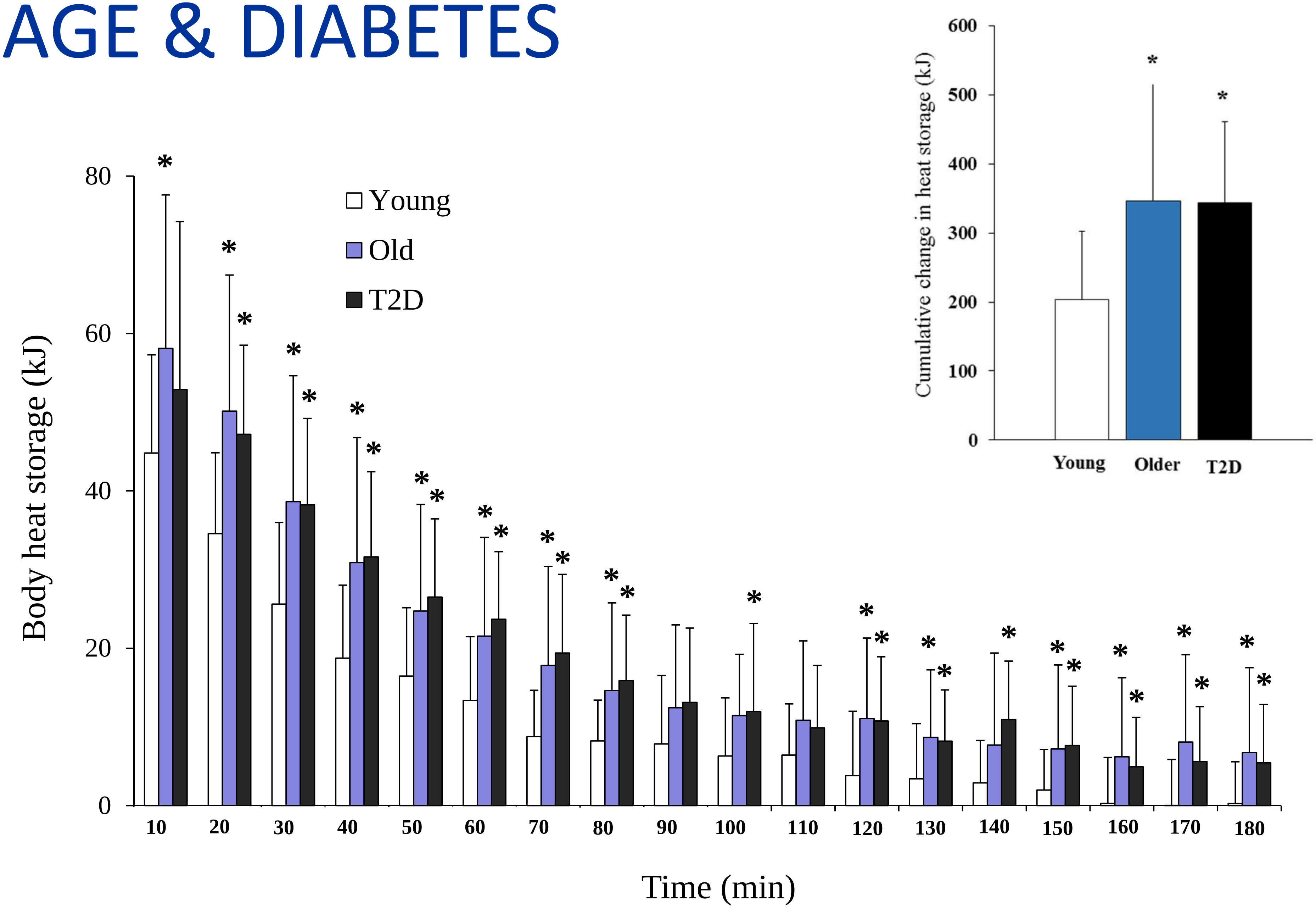
- 26 young (23±3 years)
- 25 older (63±5 years)
- 11 T2D (59±9 years)

3 hours

43 °C
30% RH

Kenny et al., Under Preparation

AGE & DIABETES



Kenny et al., Under Preparation

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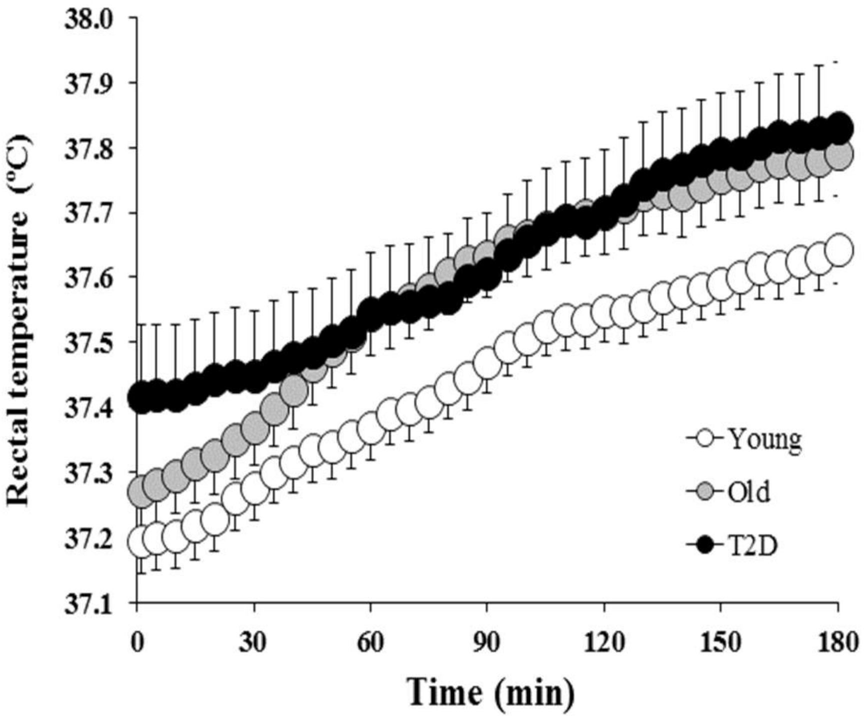
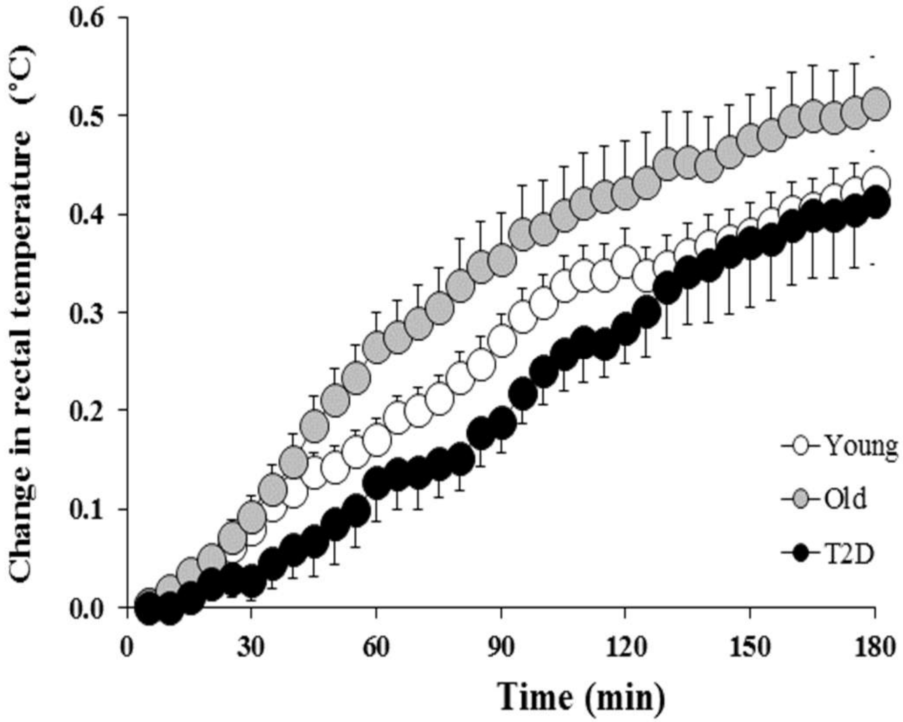




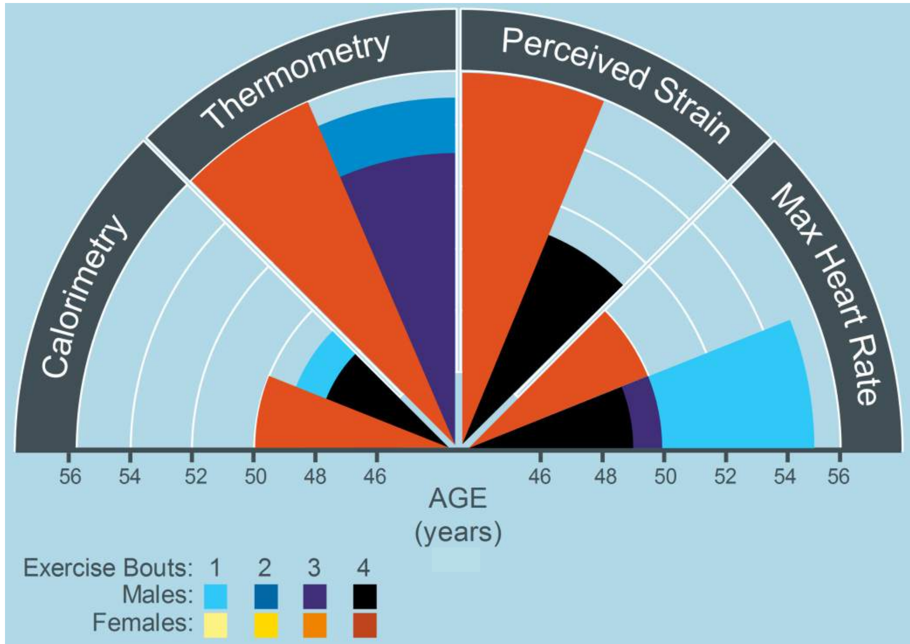
Kenny et al., Under Preparation

THRESHOLDS FOR WORK IN THE HEAT

- 87 men
- 24 women

- 4x15 min work bouts at 400 W

35 °C
40% RH



Flouris et al., Under Preparation

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