ICNIRP
INTERNATIONAL COMMISSION ON
NON-IONIZING RADIATION PROTECTION

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Radiofrequency fields and thermophysiology

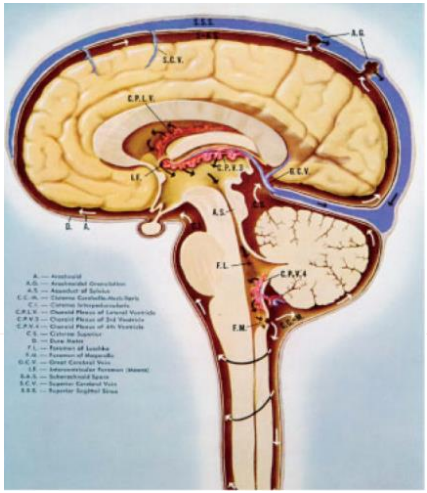
Zenon Sienkiewicz
ICNIRP

Overview

Section 1 — Overview of thermophysiology in humans
- Heat balance

Section 2 — Summary of studies of RF-exposed volunteers (WHO EHC)
- Experimental studies of Eleanor Adair
- Studies using MRI
- Studies with phone handsets

Section 3 — Conclusions



Maintain thermal homeostasis

System strives to maintain temperature within optimal biological range

behavioural and physiological

Average body core temperature ~ 37 C

individual differences 36 - 38 C

circadian variation ± 0.5 C

Elevated core temperature above average (hyperthermia)

heat stress (reversible, headache, dizziness, increased accident rates) > 38 C

heat stroke (severe, unconsciousness) >41 C

death > 43°C

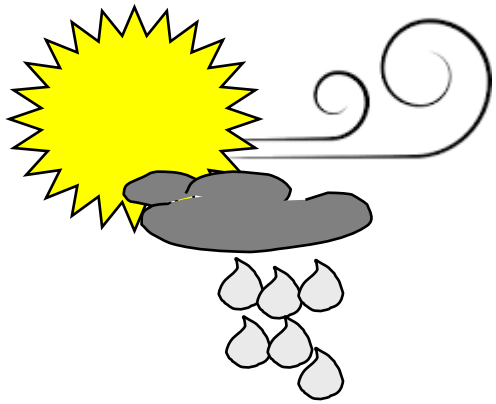
Minimum core temperature

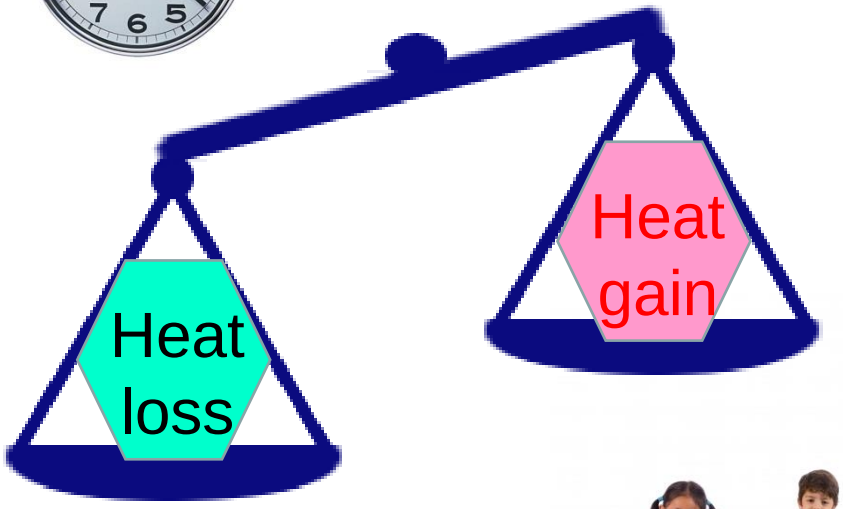
shivering as core temperature drops

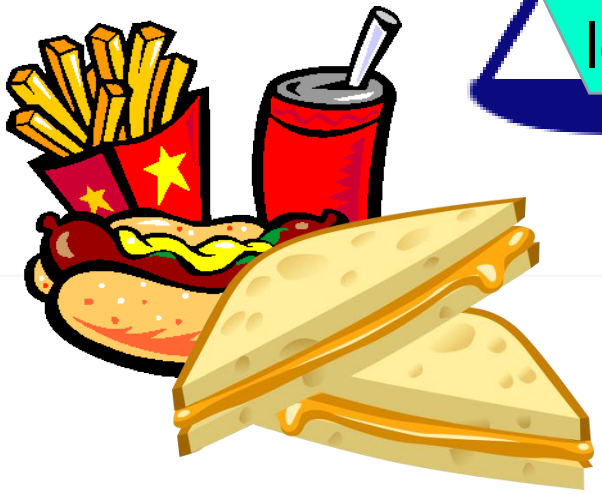
shivering stops below about 33 C, unconsciousness

death >25°C

A very labile system







Generalised heat balance equation

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

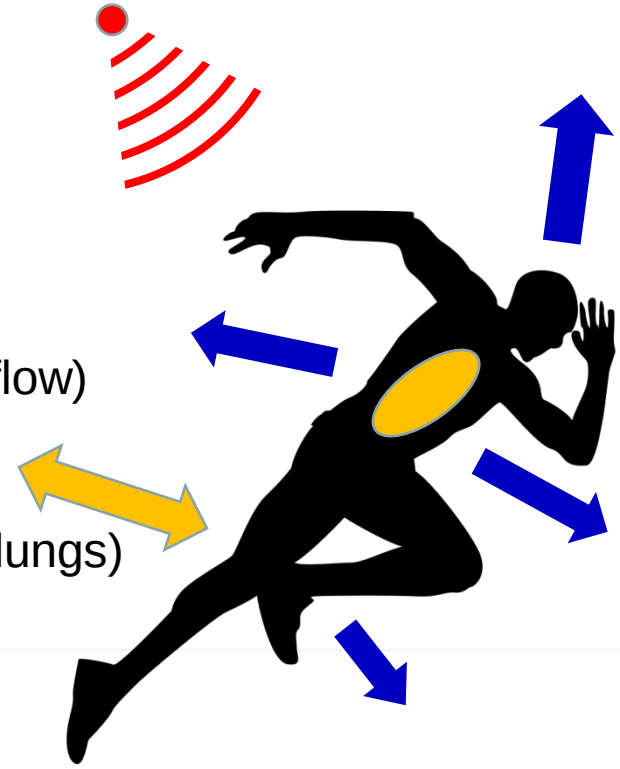
S is rate of heat storage (ideally, close to zero)

M is metabolic heat production
W is mechanical work by/on body

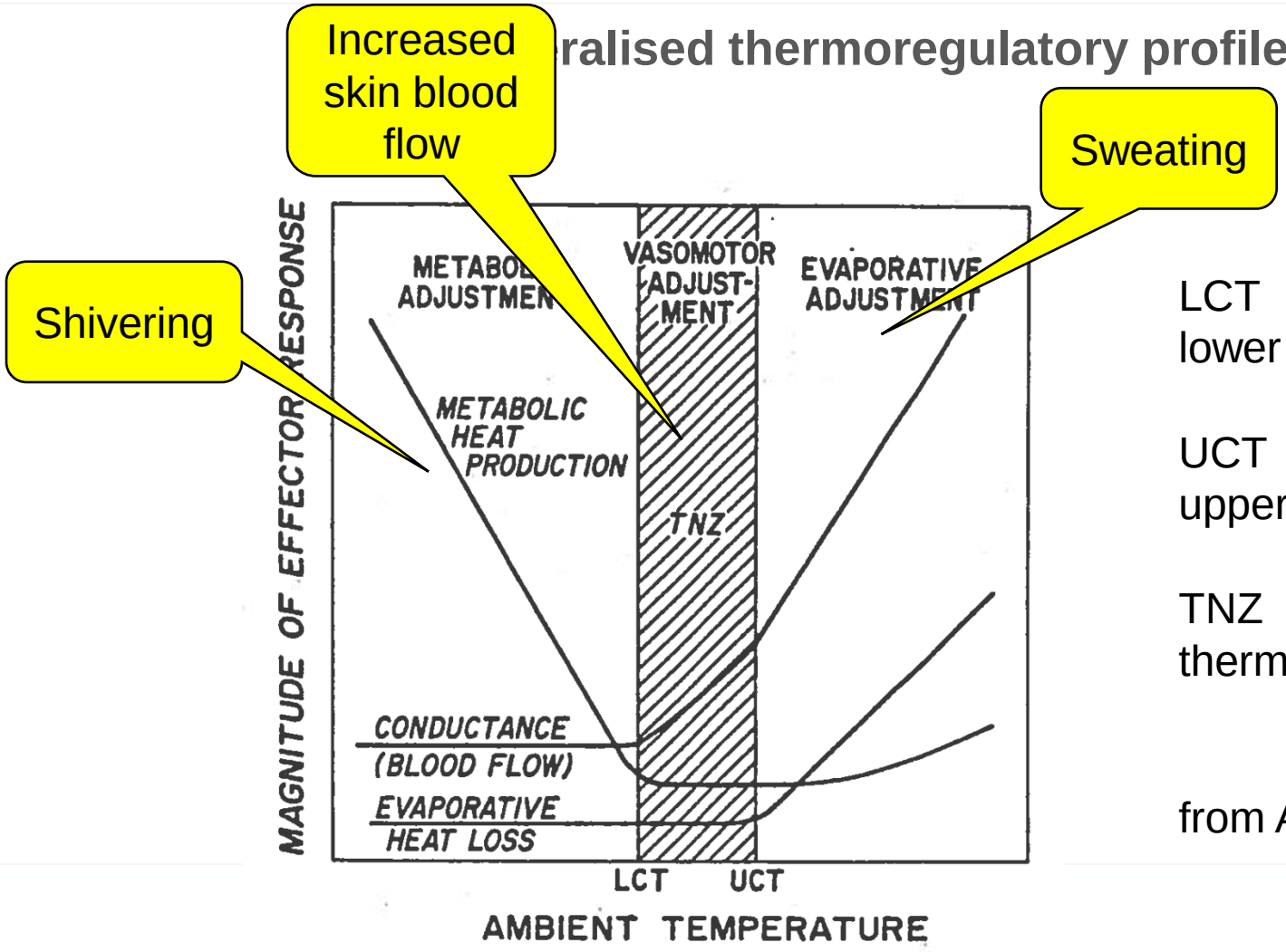
R is heat exchange via radiation
C is heat exchange via convection (skin blood flow)
K is heat exchange via conduction

E is heat exchange via evaporation (sweating, lungs)

RF is rate of absorbed RF energy (SAR)



ralised thermoregulatory profile



LCT
lower critical temperature

UCT
upper critical temperature

TNZ
thermoneutral zone

from Adair and Black (2003)

Temperature control mechanisms

Negative feedback control system with a set point

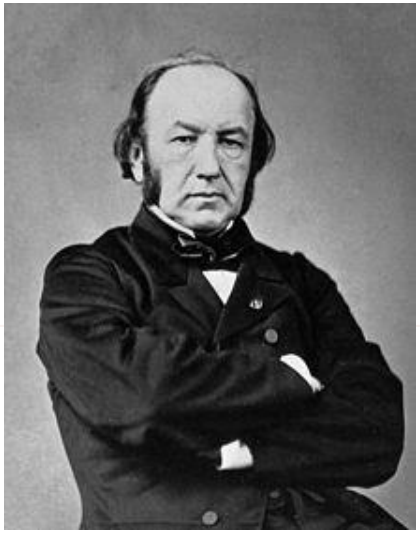
Central thermostat in preoptic/anterior hypothalamus

Sensors in core (cortex, midbrain, spinal cord, deep abdominal structures), and periphery (skin), to provide tempertaure information

Inputs are integrated, compared to set point, and error signal produced to offset original input

- heat production increased if temperature lower than set point
- heat production decreased if temperature is higher than set point

Magnitude of response is proportional to error signal



Heat stress index

Heat loss critically depends on evaporative loss, E

Ratio E_{req}/E_{max} is heat stress index, HSI (Belding and Hatch, 1955)

$E_{req} < E_{max}$ heat storage becomes positive and temperature will rise as

HSI <20% thermal comfort

30 - 60% uncomfortable but tolerable for shorter times, interference with concentration and fine motor skills

60 to 100% severe, intolerable conditions

Thermoregulation in RF-exposed volunteers

Series of six studies by Eleanor Adair and colleagues (1998-2005)

- healthy adults, male and female, n = 7 or 6, seated in bathing suits
- exposed in anechoic test chamber for 45 min, low humidity, constant air flow
- ambient temperature of 24, 28 or 31 C
- used dipole or horn antenna at 450 or 2450 MHz, behind subject, partial body exposure on head, trunk, upper arms
- used dipole in corner reflector at 100 or 220 MHz, behind subject, whole-body exposure

Physiological parameters measured before during and after exposure

- oesophageal (core) and local skin temperature
- metabolic heat production
- sweating rates
- local skin blood flow
- heart rate (in latter studies)

Summary of exposure conditions

Reference	Exposure (MHz)	Peak local SAR in skin (W/kg)	WBA SAR (W/kg)
Adair et al 1998	450 CW	0, 6.0, 7.7	
Adair et al 1999	2450 CW	0, 5.9, 7.7	
Adair et al 2001a	2450 CW	0, 11.0, 15.4	
Adair et al 2002b	2450 PM	0, 5.9, 7.7	
Adair et al 2003	100 CW		0, 0.27, 0.41, 0.54
Adair et al 2005	220 CW		0, 0.41, 0.54, 0.68

Summary of Adair's results

Compared last 10 min of 30 min acclimation period with last 10 min of exposure

Overall, magnitude of responses depend on ambient temperature and SAR
But great variability between individual subjects
Results are mainly descriptive, few statistical analyses

- no measurable effects on metabolic heat production
- small changes in body core temperature (~ 0.1 to ~ 0.3 C, peak 0.48 C)
- local skin temperature increased (~1.5 to ~ 4 C), plateau reached after ~15 to 30 min only at higher ambient temperatures
- 100 and 220 MHz (resonance) produced hot spots in top of foot, front of ankle, base of skull, back of knee
- also skin blood flow, sweat rates increased with increasing SAR at 28 or 31 C
- Moderate effects on heart rate (<15% increase)

Results were consistent with expected thermoregulatory changes

Conclusions on Adair's studies

These studies suggest that the thermoregulatory system can well cope with acute exposure to RF fields at whole body SARs of up to 0.68 W/kg at 220 MHz or local SARs of up to 15.4 W/kg at 2450 MHz in ambient temperatures of up to 31 C

Small changes in body core temperature reflect activation of increased heat loss mechanisms, skin blood flow and sweating as well as cardiovascular changes

Consistent with physiological responses to conventional thermal stress

MRI studies with volunteers

Studies have investigated thermoregulation using MRI, although some studies did not include a sham control or volunteers were not blind to exposure conditions

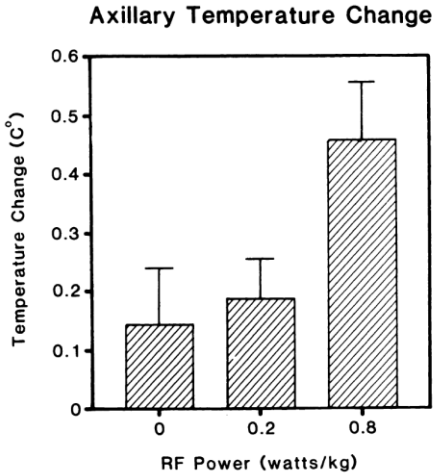
- suggest exposures used only caused small rises in core temperature, acceptable rises in local skin temperature

Kido et al (1987)

- used a 1.5 T system, sham had no RF just static and gradient fields
- axillar temperature measured by thermistor probe before and after exposure (17 min)

- 13 subjects exposed to head scan, at 0.02 or 0.06 W/kg
  no significant increase in temperature
  heart rate decreased (>3 bpm) at higher SAR

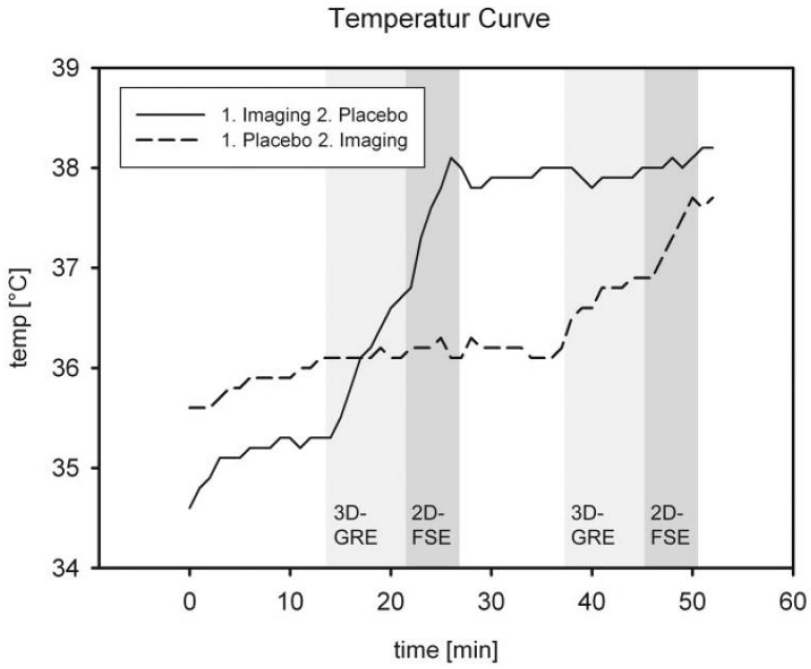
- 14 subjects exposed to lumbar scan at 0.2 or 0.8 W/kg
  temperature increased by 0.2 C and 0.5 C
  heart rate increased (3 bpm) at higher SAR



Boss et al (2007)

- used a 3 T system, sham had no RF just static and gradient fields
- skin temperature measured by fibre-optic sensors or IR camera for 10min before and during exposures (6 and 4 min)
- 18 subjects, exposed to 3D gradient-echo sequence and 2D fast spin-echo sequence of pelvis (WBA SAR 1.6 or 2.9 W/kg), head (1.2 or 2.5 W/kg), or knee (0.2 or 4.8 W/kg)
- mean skin temperatures all increased
  - ~ 1 C for pelvis
  - ~ 0.5 C for head
  - ~ 0.3 C for knee
- no effect on heart rate or blood pressure

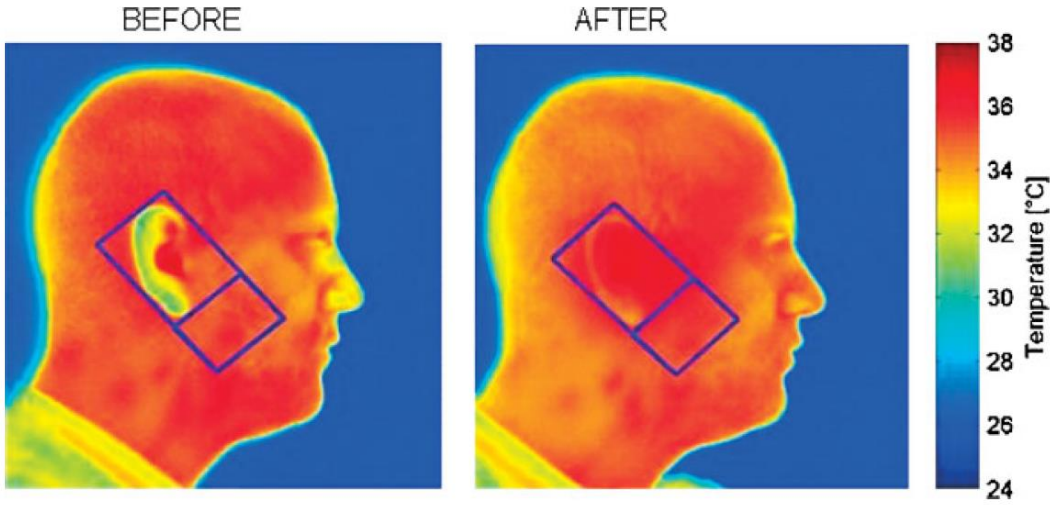
- "…may be regarded as safe, even in patients with cardiovascular disease."



Mobile phone handsets

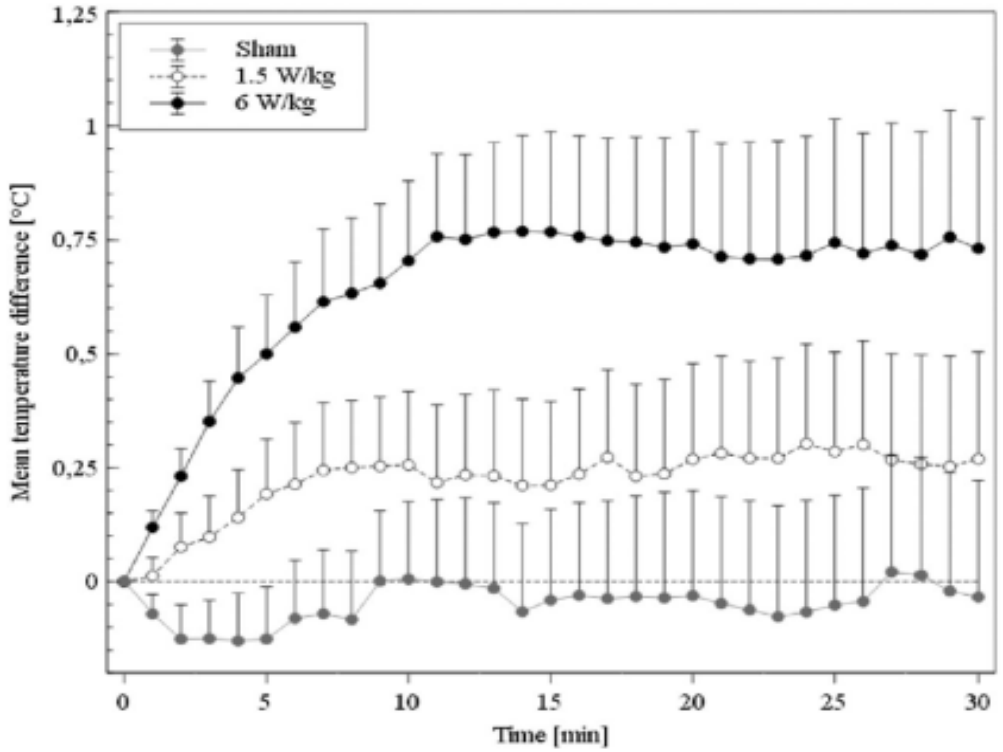
Straume et al (2005)

- measured temperatures in ear and cheek by IR camera in one male
- GSM 900 MHz signal at 0.21 W (~ 0.8 W/kg) or signal to load, or turned off
- after 15 and 30 min, compared to non phone side,
- temperature rise of ~ 1.5 C due to insulation, ~ 0.7 C due to electrical power dissipation
- no additional effects of RF



Dorn et al (2014)

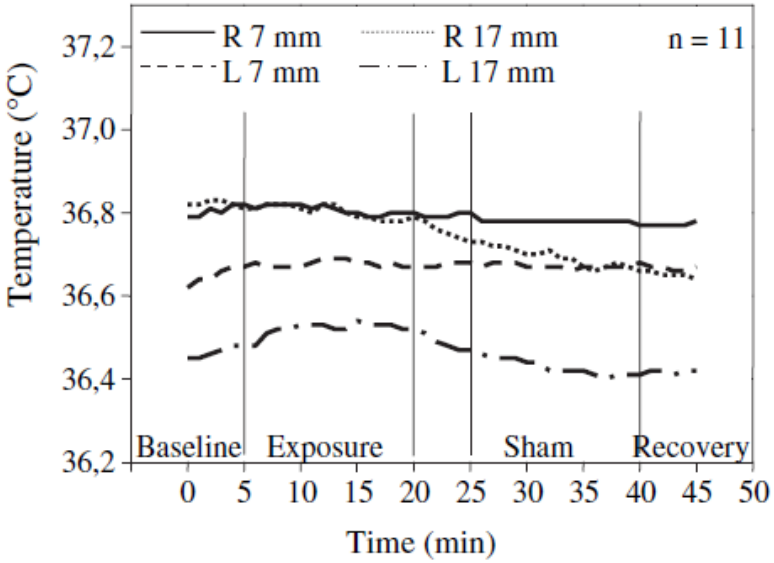
- measured temperature using probes in 15 males
- TETRA 385 MHz via antenna fixed at left ear
- heating of antenna of ~ 0.2 C
- non-significant temperature increases at 1.5 W/g of ~ 0.3 C
- significant temperature increases at 6 W/kg of ~ 0.8 C

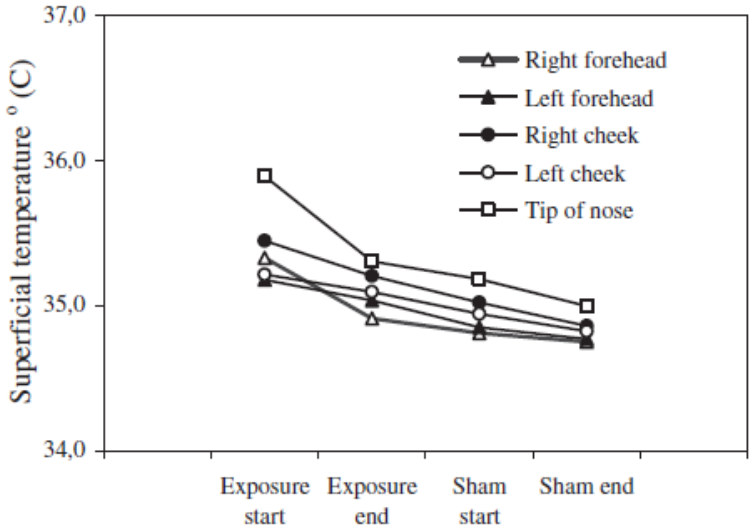


Position of non perturbing fluoro-optical glass probes

Lindholm et al (2011)

- measured temperature in ear canal and on face in 23 males, 14-15 years, using thermistors and IR camera
- GSM 902 MHz, battery/speaker removed, via coaxial cable from another phone, 4 cm from right ear (dummy phone on left)
- average SAR of 2.0 W/kg in head , 0.66 W/kg in brain
- no significant increase in temperature in ear or on face
- also no effect on cerebral blood flow, heart rate or mean arterial pressure





Conclusions

Healthy people are able to maintain core body temperatures very effectively and efficiently under a range of thermal loads

- behaviour, skin blood flow, sweating

Laboratory studies with volunteers exposed to RF fields suggest

- skin temperatures may increase
- but core body temperature is minimally increased
- thermoregulatory mechanisms are working well
- and no adverse health effects

Overall, responses are consistent with conventional heat stress or exercise

- but studies used small number of resting subjects
- need studies with larger numbers and performing physical activity
- a wider range of ambient conditions and exposures

Thank you for your attention

Any questions?