

FDTD analysis of body-core temperature elevation in children and adults for whole-body exposure

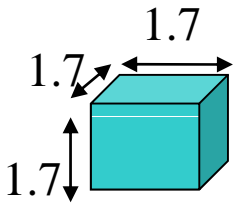
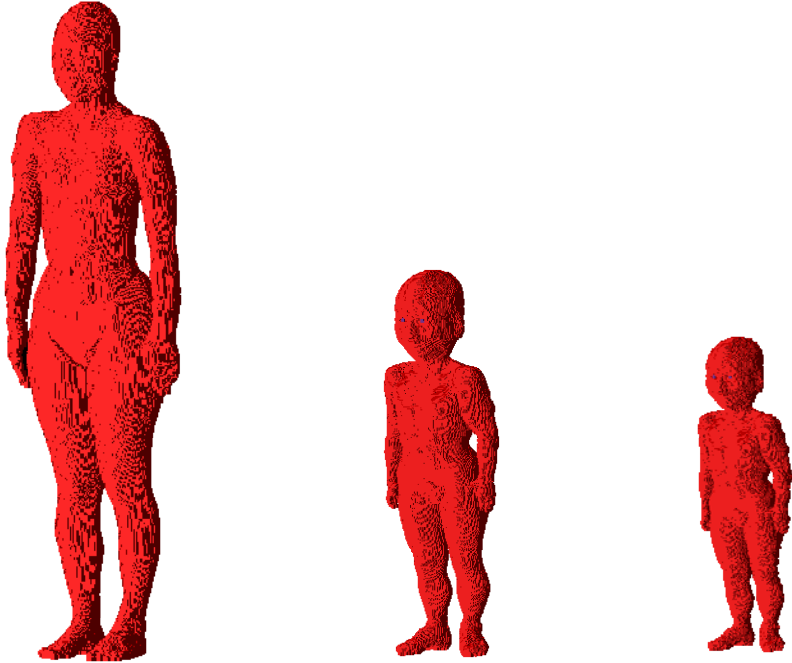
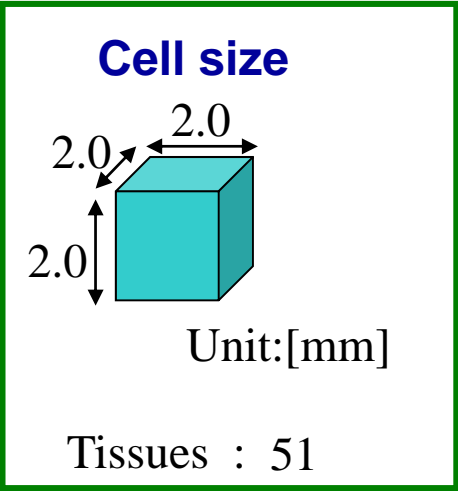
A. Hirata, T. Asano, and O. Fujiwara

Phys. Med. Biol., vol.53, pp.5223-5238,
2008

ahirata@nitech.ac.jp



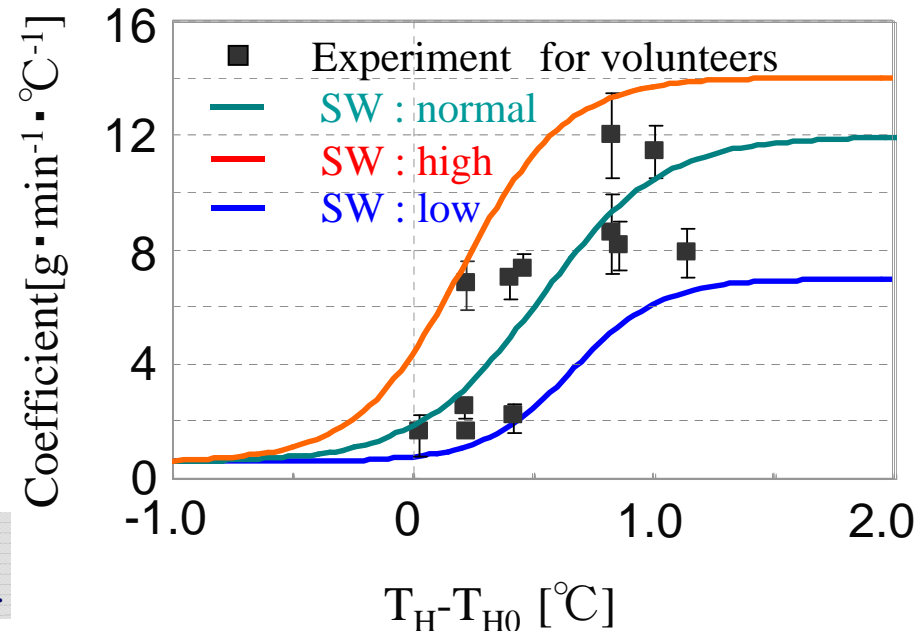
Anatomically-based Human models



| | 22years (Female) | 3years (Male) | 9month |
|-------------------------|---------------------|------------------|--------|
| Height [m] | 1.61 | 0.90 | 0.75 |
| Weight [kg] | 53 | 13 | 9 |
| S_M [m ²] | 2.08 | 0.79 | 0.58 |

S_M : Model surface area

Perspiration coefficient versus core temperature



J.A.J. Stolwijk,
NASA CR-1855, (1971)

D. Fiala, et al, Int J,
Biometeorol., (2001.5).

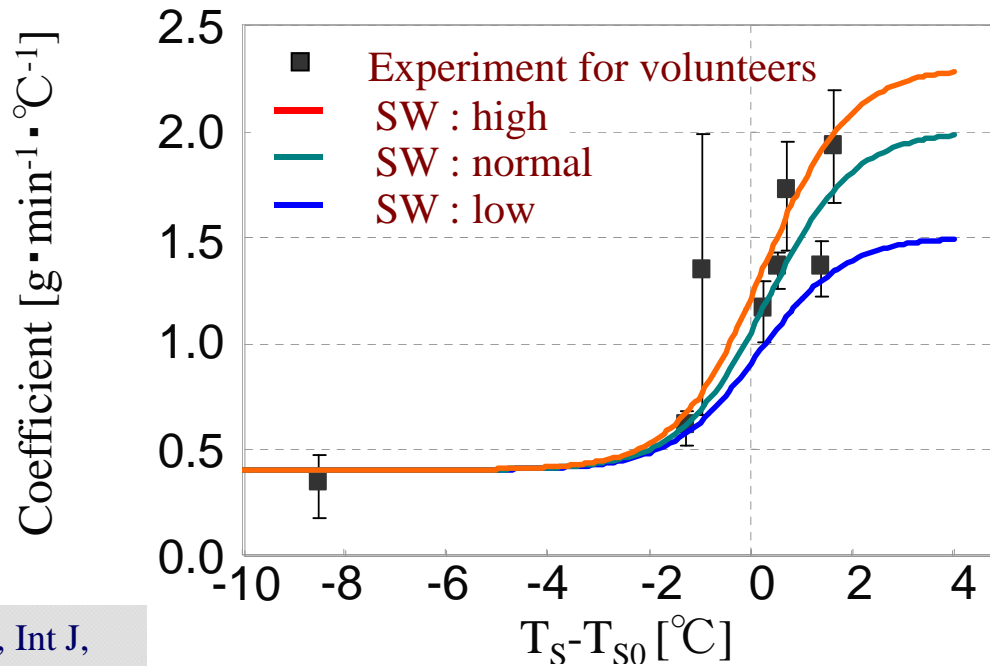
$$\left[\alpha_{21} \tanh \left(\beta_{21} (T_H - T_{H,0}) - \beta_{20} \right) + \alpha_{20} \right]$$

$$\begin{matrix} \alpha_{20}=6.30 & \beta_{20}=1.03 \\ \alpha_{21}=5.70 & \beta_{21}=1.98 \end{matrix}$$

$$\begin{matrix} \alpha_{20}=7.30 & \beta_{20}=0.47 \\ \alpha_{21}=6.70 & \beta_{21}=2.30 \end{matrix}$$

$$\begin{matrix} \alpha_{20}=3.80 & \beta_{20}=1.80 \\ \alpha_{21}=3.20 & \beta_{21}=2.70 \end{matrix}$$

Perspiration coefficient versus skin temperature



J.A.J. Stolwijk,
NASA CR-1855, (1971)

D. Fiala, et al, Int J,
Biometeorol., (2001.5).

$$\left[\alpha_{11} \tanh \left(\beta_{11} (T_S - T_{S,0}) - \beta_{10} \right) + \alpha_{10} \right]$$

$$\alpha_{10}=1.20 \quad \beta_{10}=0.19$$

$$\alpha_{11}=0.80 \quad \beta_{11}=0.59$$

$$\alpha_{10}=1.35 \quad \beta_{10}=0.15$$

$$\alpha_{11}=0.95 \quad \beta_{11}=0.59$$

$$\alpha_{10}=0.95 \quad \beta_{10}=0.09$$

$$\alpha_{11}=0.55 \quad \beta_{11}=0.59$$

Modeling of Perspiration

$$-K(\vec{r}) \frac{\partial T(\vec{r}, t)}{\partial n} S = H \cdot (T_s(\vec{r}, t) - T_a) + SW(\vec{r}, T(\vec{r}, t))$$

$$SW(\vec{r}, t) = \left\{ \begin{aligned} & \left[\alpha_{10} \tanh(\beta_{11} 0.59(T_s - T_{s,0}) - \beta_{10}) + \alpha_{11} \right] (T_s - T_{s,0}) \\ & + \left[\alpha_{20} \tanh(\beta_{21}(T_H - T_{H,0}) - \beta_{20}) + \alpha_{21} \right] (T_H - T_{H,0}) \end{aligned} \right\} \\ \times \left\{ (0.58 \times 4.2 \times 10^3 + PI) / (S \times 60) \right\}$$

D. Fiala, et al, Int J, Biometeorol., (2001.5).

T_s : skin temperature [°C]

T_H : hypothalamus temperature [°C]

T_{s0} : set skin temperature [°C]

T_{H0} : set skin temperature [°C]

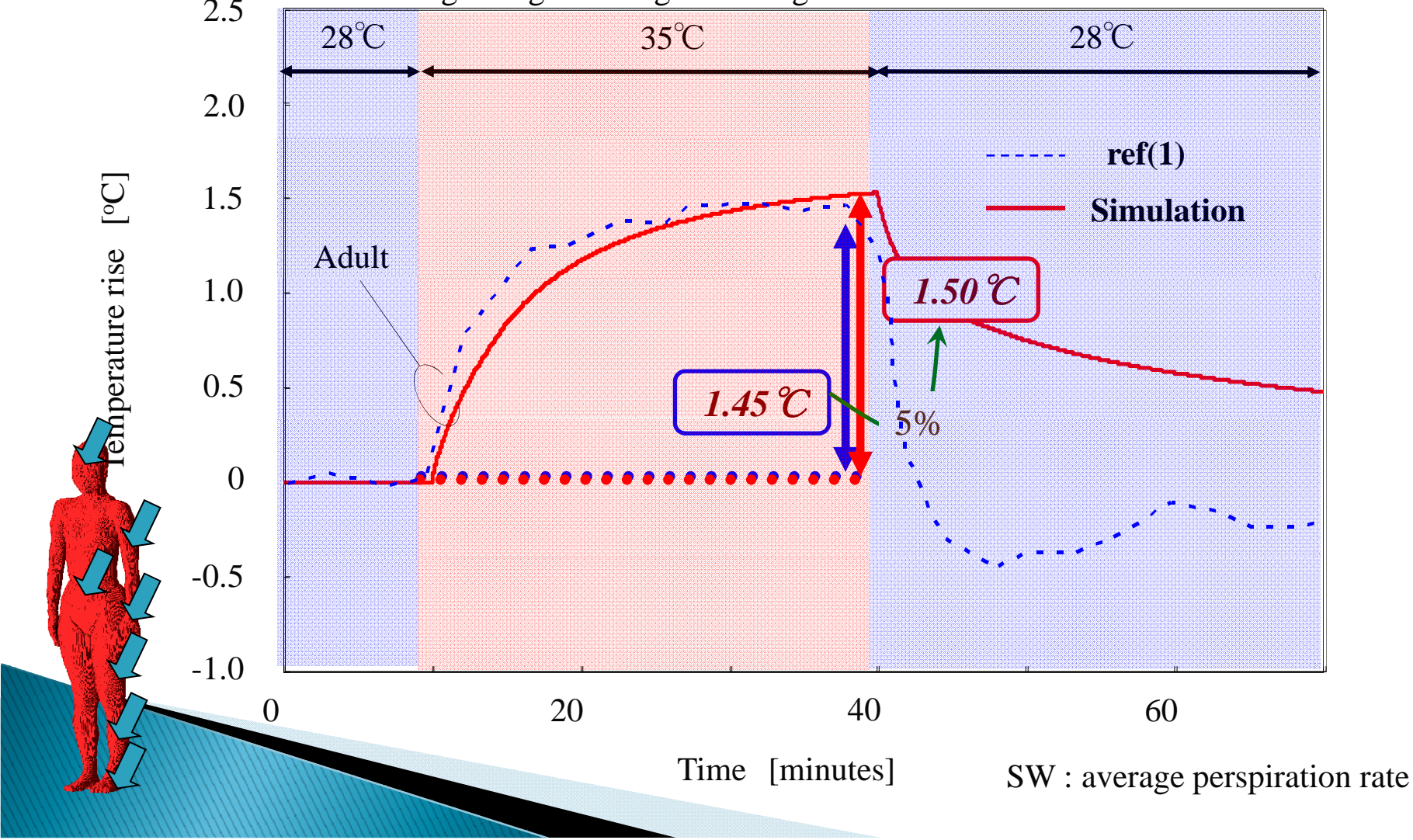
S : body surface area [m²]

PI : evaporative loss [W/m²]

Skin temperature variation for different ambient temperatures

Tsuzuki et al, J. Appl. Physiol.1998.

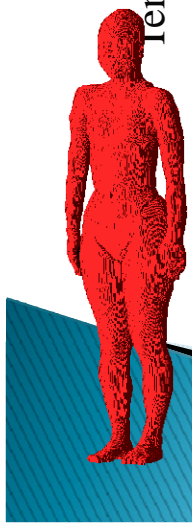
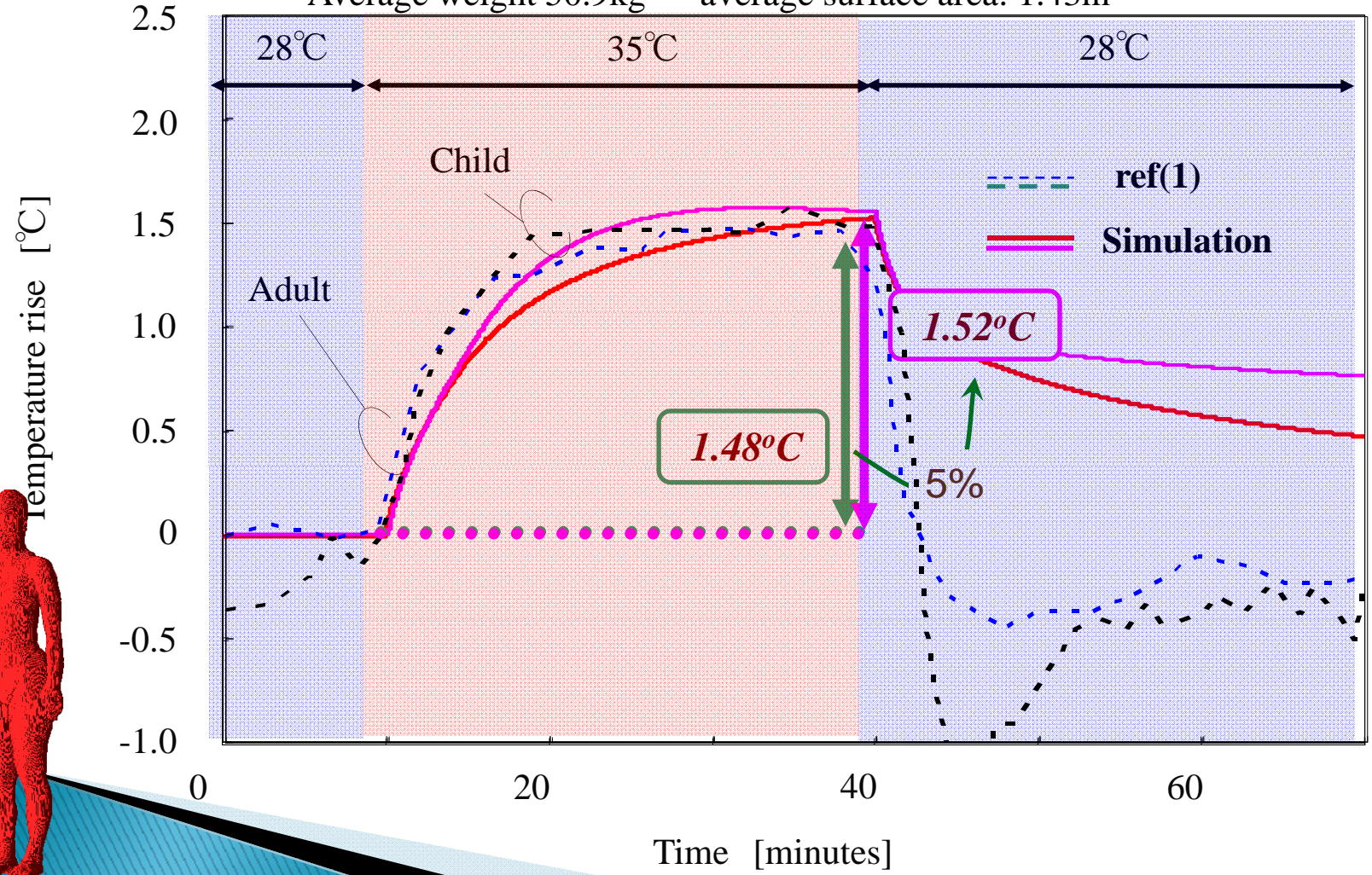
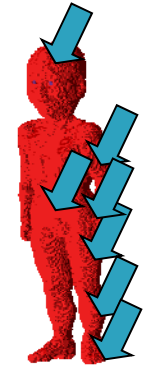
Volunteers: 8 age: 31 average height: 154 cm
 Average weight 50.9kg average surface area: 1.43m²



Skin temperature variation for different ambient temperatures

Tsuzuki et al, J. Appl. Physiol. 1998.

Volunteers: 8 age: 31 average height: 154 cm
 Average weight 50.9kg average surface area: 1.43m²

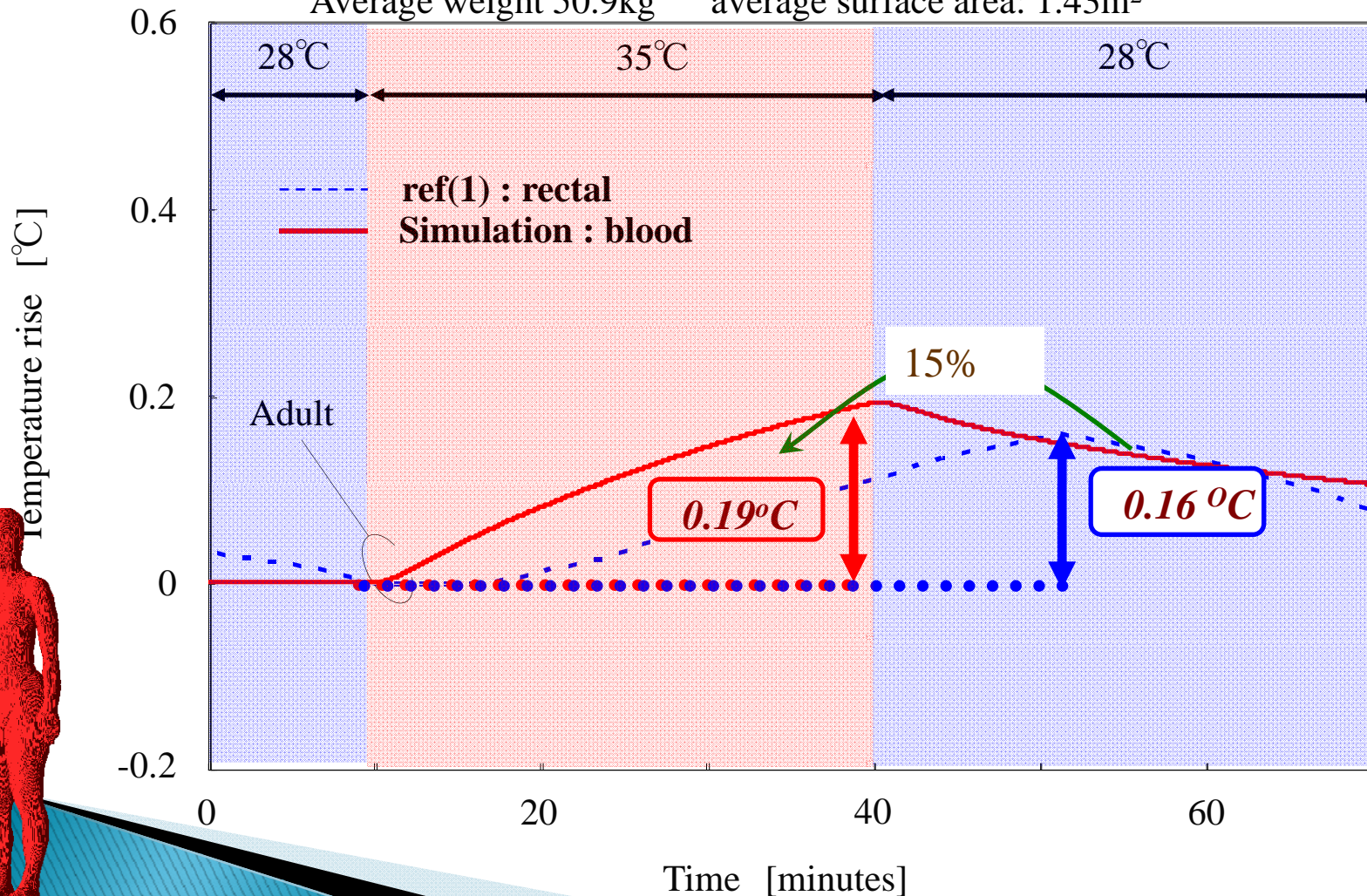


SW : average perspiration rate

Core temperature variation for different ambient temperatures

Tsuzuki et al, J. Appl. Physiol.1998.

Volunteers: 8 age: 31 average height: 154 cm
Average weight 50.9kg average surface area: 1.43m²

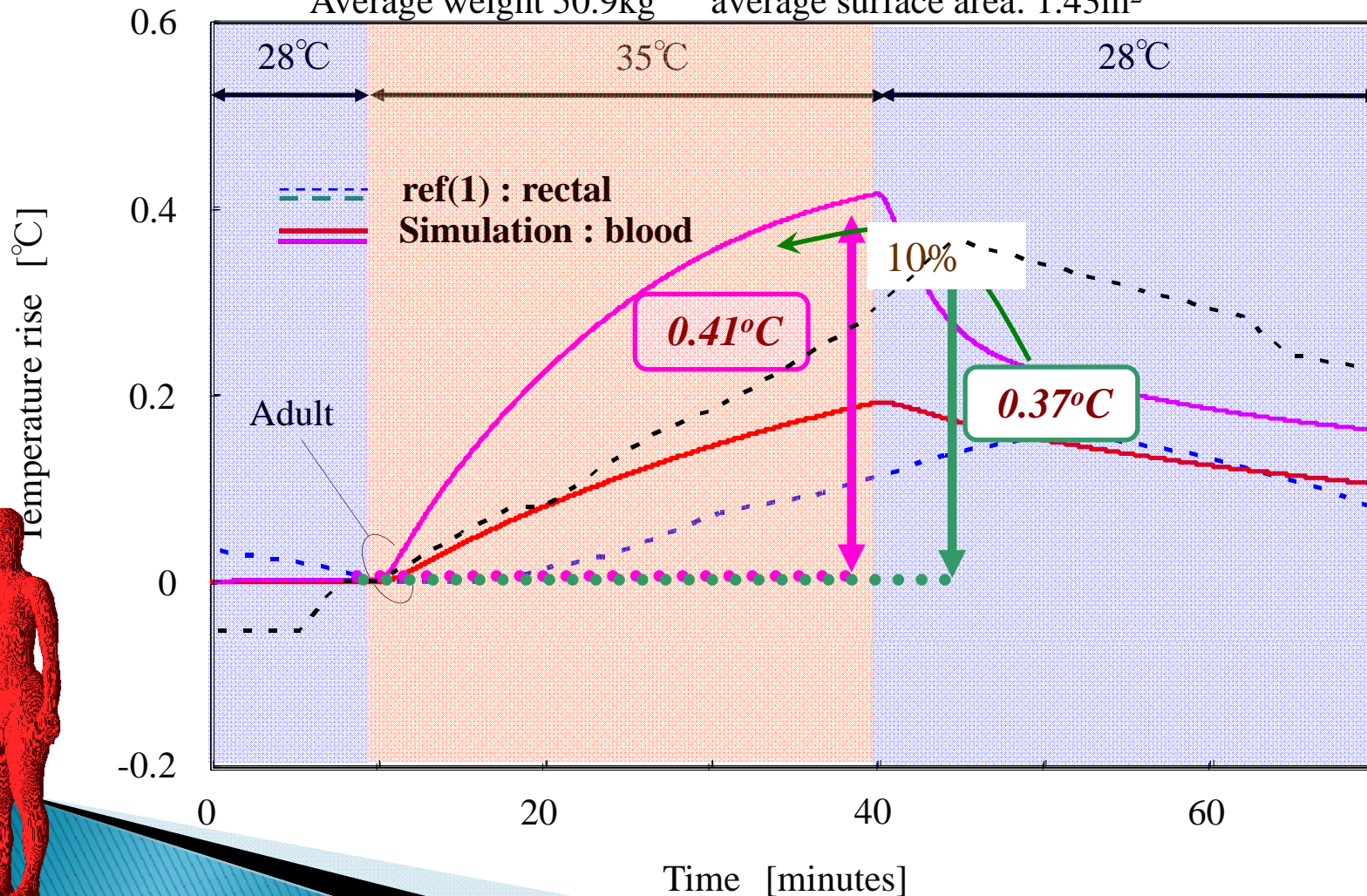


SW : average perspiration rate

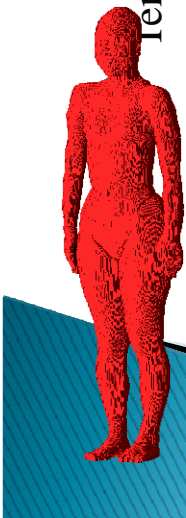
Core temperature variation in different ambient temperatures

Tsuzuki et al, J. Appl. Physiol.1998.

Volunteers: 8 age: 31 average height: 154 cm
Average weight 50.9kg average surface area: 1.43m²



SW : average perspiration rate

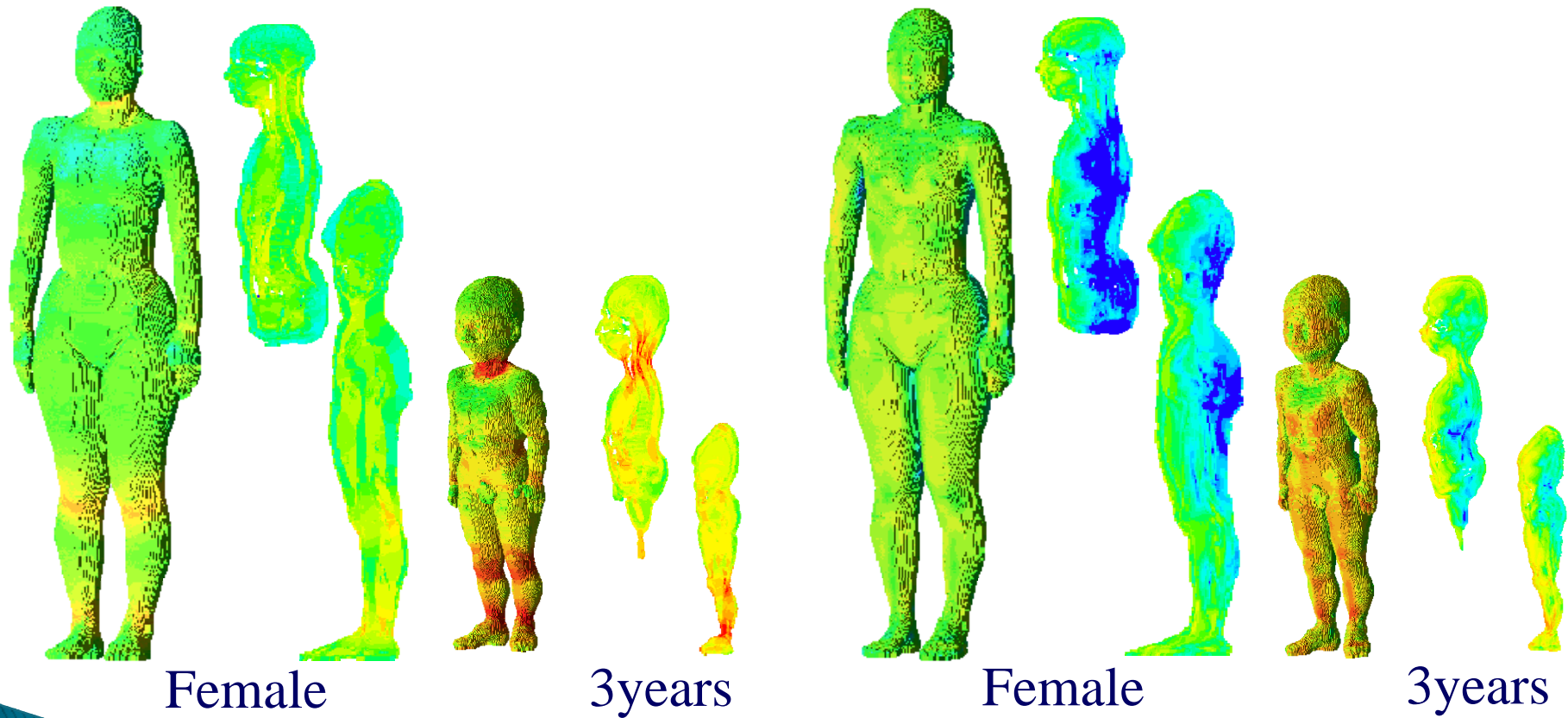


SAR Distribution

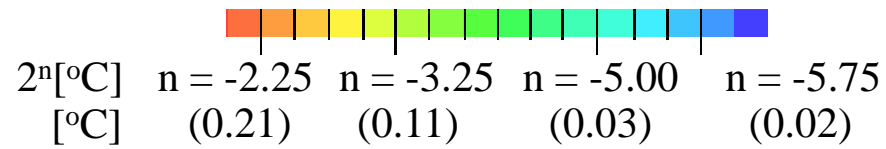
2^n [W/kg] $n = 5$
[W/kg] (32.0)

$n = -10$
(9.8×10^{-4})

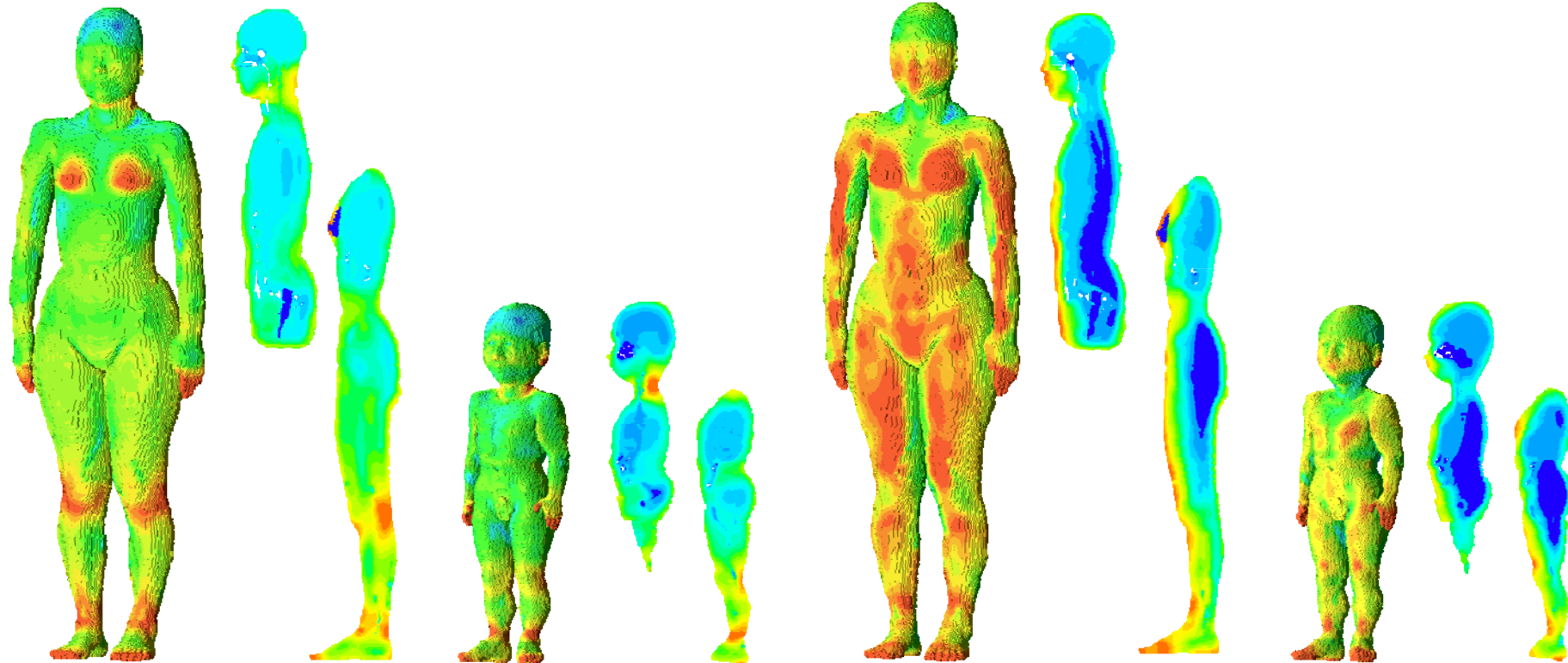
WBSAR : 0.08W/kg



Temperature Elevation Distribution



WBSAR : 0.08W/kg



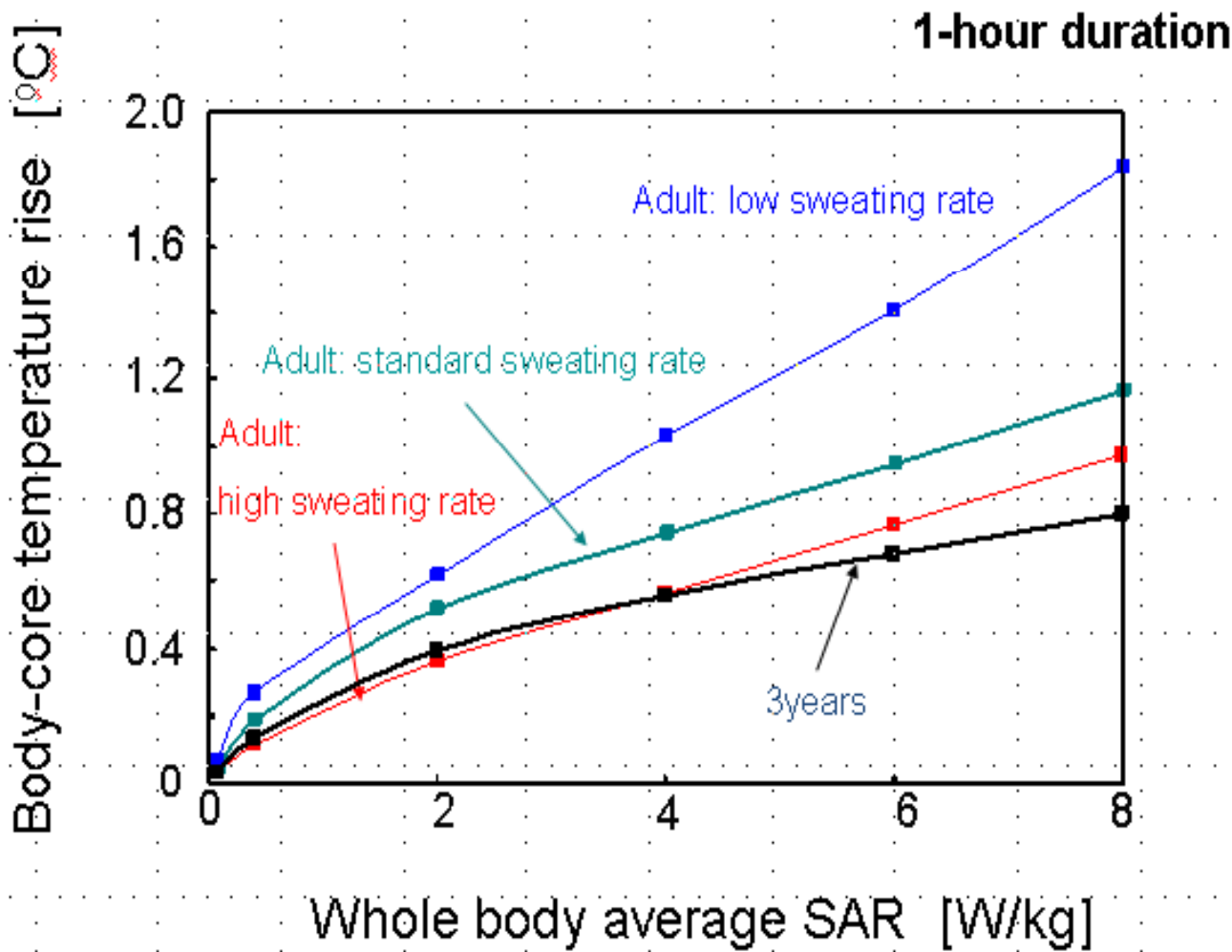
Female

3years

Female

3years

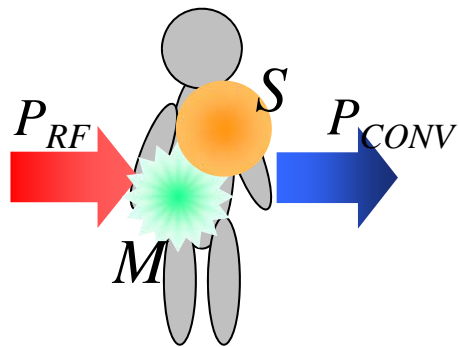
Core Temperature Rise vs WBSAR



Dominant Factor Influencing Core Temperature Elevation

E. Adair and D. Black, Bioelectromag. Suppl., vol.6, S17-S38, 2003

S. Ebert, et al., Phys. Med. Biol., vol.50, pp.5203-5215, 2005



$$M + P_{RF} - P_{CONV} = S$$

M : Basal Metabolism

P_{RF} : RF power Absorption

P_{CONV} : Heat Convection to Air

S : Power stored in Human

Derived Formula

$$T(t) = T_0 + \frac{W \cdot SAR_{WBave}}{\int_S H(\vec{r})dS + \int_S sw(t)dS} \left(1 - \varepsilon \frac{\int_S H(\vec{r})dS + \int_S sw(t)dS}{W \cdot C_{WBave}} t \right)$$

W : Model Weight [kg]

H : Heat Transfer Coefficient [W/m²·°C]

SAR_{WBave} : WBA-SAR[W/kg]

C_{WBave} : Specific Heat Averaged Over Body [J/kg·°C]

sw : Perspiration Coefficient[W/m² °C]

A. Hirata et al., Prog. In Electromag. Res., vol.99, pp.53-70, 2009.

Summary

When coefficients of perspiration rate in children is assumed to be identical to those of adults, computational results are in good agreement with measurements. (Computation vs measurements)

For RF exposures, core temperature elevation in the children is expected to be smaller than those in adults due to larger surface area-to-weight ratio. (Computational estimation)

