Mathematical Model of Thermal Reception and Integration and its Combination with Prediction System of Whole Body Temperatures

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INTRODUCTION

We have developed a computer program for the numerical analysis of thermal conditions of all segments and blood circulatory systems in the human body. The advantages of the present program were larger numbers of blood temperature variables and the controlling outputs of thermoregulation model expressing local characteristics as compared to the previous models.

The present paper describes a mathematical model of thermal reception and integration mechanism, which combined with our prediction computer program of whole body temperature, and two application results of physiological and psychological reaction under the thermal transients : (1) ramp(27.5→14.5℃) and (2) step(29→17.5→29℃) change of ambient temperature (in (1) also changing subject's clothes). The calculated results agree well with the experimental results of body temperature and thermal sensation.

PREDICTION SYSTEM OF WHOLE BODY TEMPERATURES

Firstly we presented an anatomical and physiological model expressing local characteristics of each segment of the human body, which fitted to the average Japanese male subject (Yokoyama, 1993). In the model each segment is concentric cylindrical shape, which consists of internal multi-layers. For the prediction of body temperatures and heat fluxes in the human body a solving procedure of heat

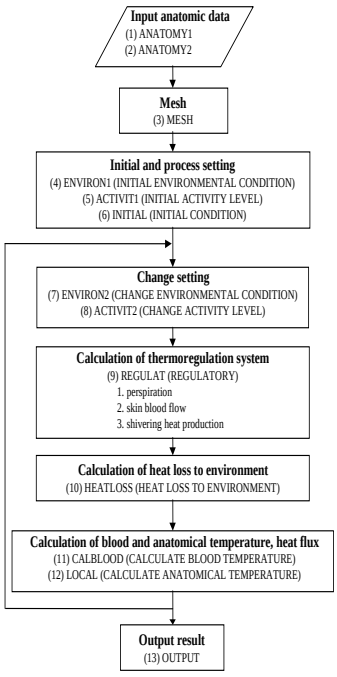

Figure 1 Flowchart for the present computer program.

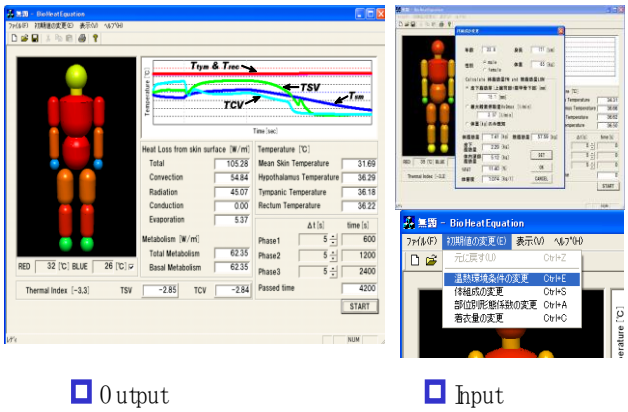

Figure 2 Outline of Prediction System

transfer equation of each segment in the human body is required. For saving computing time we developed an algorithm for heat transfer equation of each segment in the human body (Yokoyama et al., 1997). The algorithm is perfectly adequate for the present concentric cylindrical model for the segment. Using the present algorithm we showed several examples of calculated body temperatures and heat fluxes under the assumption that the arterial blood temperature entering to a segment is known. The present program also included a subroutine of calculation of thermoregulatory responses (Yokoyama et al., 2000a; 200b). Figure 1 shows the flowchart for the present computer program (Yokoyama et al., 2007). Figure 2 shows the outline of the present prediction system

MATHEMATICAL MODEL OF THERMAL RECEPTION AND INTEGRATION

According to the previous neuroanatomy and neurophysiology including fMRI and PET research results we introduced a mathematical model of thermal reception and integration mechanism. Table 1 summarizes the reports concerning evoked activity regions with thermal stimuli.

Figure 3 shows a neural network model for thermal sensation vote (TSV). We also introduced a neural network model for thermal comfort vote (TCV). The weight coefficients between units were tuned by the error back propagation method (Rumelhart et al., 1986; Chauvin and Rumelhart, 1995). The teacher's data sets were provided from our previous experimental researches (Yokoyama et al., 2002).

These models were combined with our computer prediction computer program of whole body temperatures.

Table 1 Summary of the reports concerning evoked activity regions with thermal stimuli.

Modarity		Warm sensation								Cold sensation				Thermal comf
Number of subjects		16	16	27	8	12	13	10	10	12	13	10	-	8
Body part		forearm	forearm	forearm	hand	hand	hand	hand	hand	hand	hand	hand	hand	whole body
Stimulation temp. [℃]		35 vs. r.	35 vs. r.	43 vs. 36	41 vs. 35	44 vs. 35	43 vs.35	40 vs.34	laser	20 vs. 32	20 vs. 32	20 vs. 34	20 vs. 33	(T_{air}) 8 vs.2
Stimulation period [sec]		5 × 6	5 × 6	5	29	42	44	60	1 [msec] × 100	36	34	60	45 ~60	22 [min]
Stimulation area [cm^2]		3.14 × 6	3.14 × 6	2.54	9	digit	9	280	0.79 × 100	digit	9	280	-	whole body
Imaging Method		PET	PET	PET	fMRI	PET	fMRI	PET	fMRI	PET	fMRI	PET	PET	fMRI
S I		■	■		■	-		■	■	-				
S II		■	■		■					-		■	■	
Thalamus		■	■	■	■	■	■	-		■	■	-	■	
Insula	ant.	■	■		■	■		■		■		■	■	
	mid.	■	■		■			■				■	■	
	post.	■	■		■	■				■			■	
Frontal gyrus		■			■	-		-		-		-		
Temporal gyrus			-		■	-		-		-		-		
Precentral gyrus (M1)					■	-		-		-	■	-		
SMA (M2)			■				■			-	■			
Prefrontal cortex		■	■	■		-		-	■			-		
Limbic forebrain	Amygdala					-		-	□ *	-		-		□
	Orbitofrontal cortex					-		-		-		-	■	
	CC ant. (ACC)		■		■	-	■		■	-	■			
	CC mid.					-		-		-		-	■	
	CC post.				■	-	■	-		-	■	-		
Basal ganglia		■		■		■		-		■		-	■	

COMPARISON OF EXPERIMENTAL AND CALCULATED RESULTS

By using a new computer program thermal physiological and psychological responses at transient state were simulated. The subject was a Japanese healthy male (163cm; 53kg) rested at Ta 27.5℃ and RH 50% and wore heavy suits. After 20 min the room temperature was

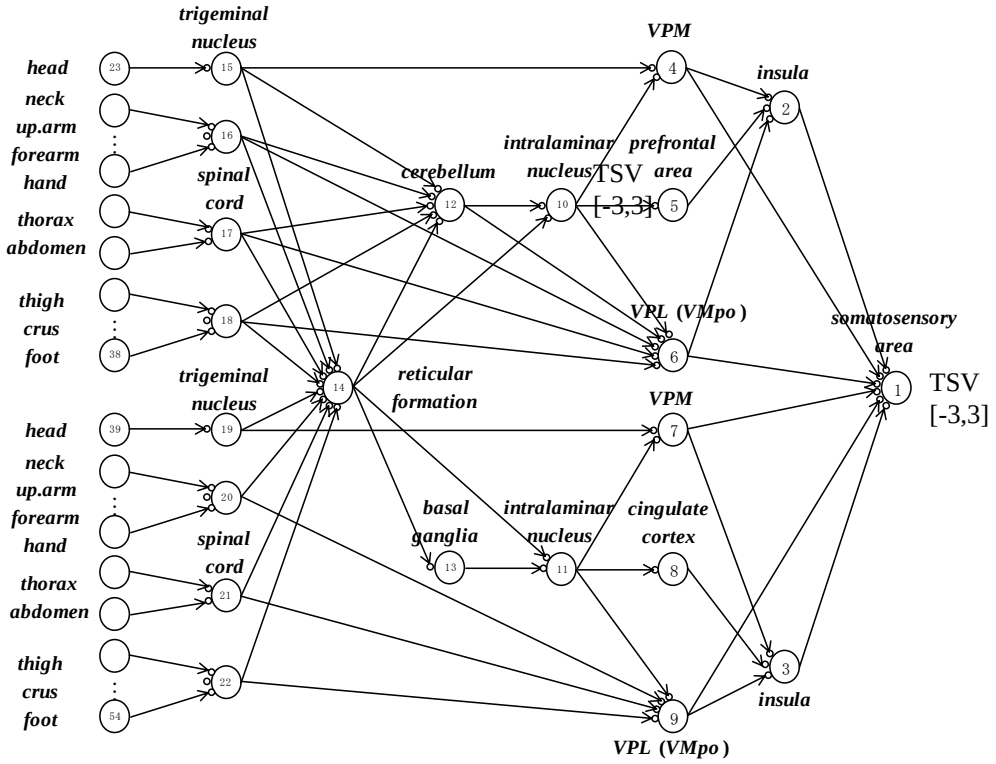

Figure 3 Neural network model for thermal sensation vote (TSV)

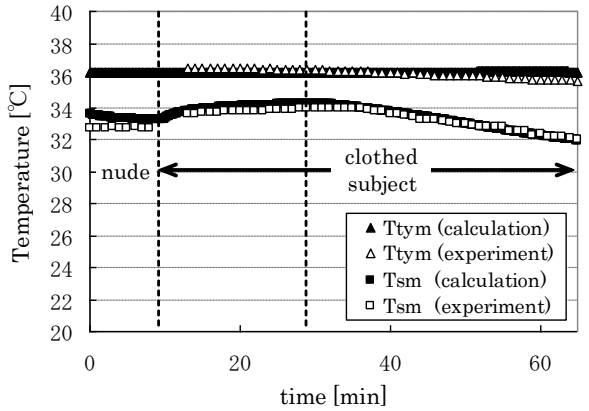

Figure 4 Calculated and measured results of tympanic and mean skin temperature

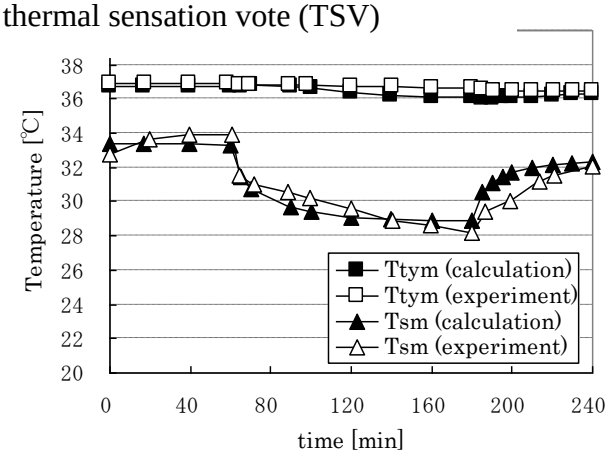

Figure 6 Calculated and measured results of tympanic and mean skin temperature

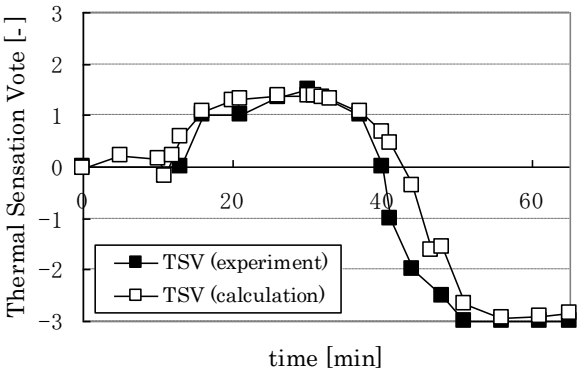

Figure 5 Calculated and measured results of thermal sensation vote (TSV)

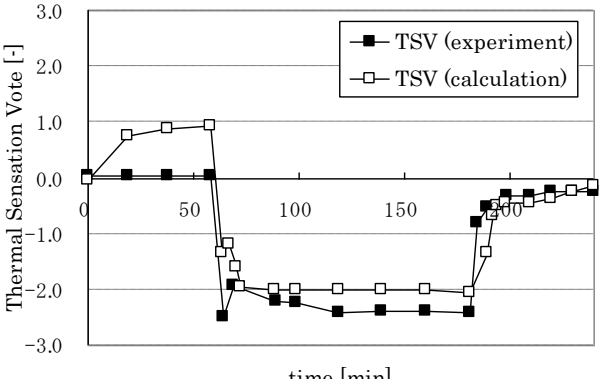

Figure 7 Calculated and measured results of thermal sensation vote (TSV)

cooled down to 14.5℃ during 30min. The calculated and experimental results of body temperatures are shown in Figure 4. Figure 5 shows the calculated and experimental results of thermal sensation votes. In Figure 5. ‘‘+1’’, ‘‘0’’, and ‘‘-3’’ correspond ‘‘slightly warm’’, ‘‘neutral’’ and ‘‘cold’’ sensation, respectively. These calculated results suggested the validity of the present thermal physiological and psychological prediction based on thermoregulation model expressing local characteristics of each segment.

The next case is a simulation of the step-wise change of transient state. The subject was an American health male (190cm; 84.8kg) rested at Ta 29℃ and RH 40% and was exposed cold environmental condition (Ta17.5℃; RH 35%) during 120min. After then the subjects stayed at Ta 29℃ and RH 40% (Gagge et al., 1967).

Figure 6 shows the calculated and experimental results of the tympanic and mean skin temperature. Calculated values of both tympanic and mean skin temperature reproduced measured values accurately. In Figure 7 the calculated and experimental values of TSV (Thermal Sensation Vote) are shown. The scores were the same in Figure 5. These calculated results also suggested the validity of the present thermal and psychological prediction system based on thermoregulation model expressing local characteristics of each segment and mathematical model of thermal reception and integration process with neural network.

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