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Effects of Methods, Genders, and Interaction to Human Body Temperature Measurement Results Using Tailor-Made Infrared Thermometer and Application Program

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***Abstract*— The 16-temperature measurement site method is holistic but inefficient. This study compared 8 to 16 temperature measurement site methods on seven married couples. The data gathering was obtained using our infrared thermometer, while the data processing was carried out utilizing Two Way ANOVA with Repetition inserted in our developed application program. Unlike the thermometer in general, our thermometer can equally measure the ear canal and forehead temperature equally. Our made application software was used and validated. The result shows no significant difference between 16 and 8 temperature measurement site methods (F method 0.05 < 4.26). There was no significant difference between male and female temperatures (F gender 1.46 < 4.26), and there was no significant interaction between the method and gender (F interaction 1.51 < 4.26). Male and female temperatures, in general, were almost similar, around 0.57 %, but there was a tendency that they were different in detail. The front head (face), lower part arm, hand, thigh, calf, and feet temperatures for men were slightly higher than for women, while the trunk, upper part arm, and back neck temperatures were slightly higher than men's. Based on these findings, eight temperature measurement site methods can replace the 16-temperature measurement site method. A further study should be carried out to obtain the simplest temperature measurement site but with a significant level of accuracy as the 16-temperature measurement site method. Detail differences between male and female temperatures should also be further investigated.**

***Keywords*— Single temperature measurement site method; 8 and 16 temperature measurement site methods; thermoregulation; energy balance; gender; two-way ANOVA with repetition; infrared thermometer.**

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I. INTRODUCTION

Human beings are one kind of homeothermic or warm-blooded living creatures. Their temperatures, mainly due to vibrational and rotational motions in molecules [1], are almost constant irrespective of their ambient temperatures. The human body's thermoregulation controls its temperature homeostasis [2] in a particular range. If the body temperature is lower than the lowest temperature setpoint (36 °C) [3], the body will gain heat due to vasoconstriction that activates the shivering mechanism. On the other hand, when the human body temperature is higher than the highest temperature setpoint (37.5 °C) [3], the body will lose heat due to vasodilatation triggers the sweating mechanism and threshold level

$$Thres_{MBT} = \beta T_{skin} + (1-\beta)T_{core} \quad (1)$$

where $Thres_{MBT}$ = the human sweating (vasodilation) threshold (°C), β= the proporsionality constant (0.05-0.2), T_{skin}= human mean skin temperature (°C), T_{core}= human core temperature (°C) [4].

Human body temperature has some meanings, so body temperature measurements are needed. These measurements have been recognized for more than 150 years as a significant clinical signs such as fever [5], coronavirus [6], [7], and the diabetic foot for signs of inflammation before ulceration [8], when the body temperature is beyond the vasoconstriction or vasodilation threshold levels.

The availability of the body thermoregulation does not mean that the human temperature is uniform on all parts of the human body's skin. Scanning results show that human body temperature varies at various body parts [9], [10], [11]. Hence, it is not always objective to say that a human body temperature can be measured from one point only. This single measurement point might be located on many measurement sites, such as on the axilla [1], forehead [11], rectum [12], and wrist [13].

The more objective temperature measurement is based on the mean measurement of all parts of the human body, such as 16 (1 + 15) and 8 (1 +7) body temperature measurement methods [10]. These methods are comprehensive body temperature measurement methods based on the energy balance of the human body thermoregulation system. The energy balance is a concept where the total energy is zero in equilibrium [14]. The human body temperature is presented in Formula 2.

$$T_{mean\ body} = wT_{core} + (1 - w)T_{mean\ skin} \quad (2)$$

where $w= \geq 0.8$, T_{core}= the core temperature, and $T_{mean\ skin}$= the mean skin temperature on 15 or 7 skin measuring sites [10], so the total number to obtain the mean body temperature is 16 or 8 points.

The core temperature can be measured from natural body orifices or body surfaces [10]. The natural body orifices are the rectum, mouth, ear canal, esophagus, nasopharynx, and gastro-intestinal, while the body surface can be the axilla or forehead [10]. For the sake of comfortability in this study, the core temperature was measured on the respondent's forehead (Model 16A or Model 8A) and ear canal (Model 16B or Model 8B).

The mean skin is skin that represents the interface between the body and the environment [15]. The 15 skin measurement sites are located on the human's head (3 points), arms (2 points), hand (1 point), trunk (4 points), thigh (2 points), calf (2 points), and feet (1 point). The left side was chosen as the measurement site for paired body parts such as hands because all respondents are right-handed. The mean for 15 skin measurement sites is presented in Equation 3 [10].

$$T_{mean\ skin} = 0.07\frac{(A+B+L)_{head}}{3} + 0.14\frac{(D+F)_{arms}}{2} + 0.05G_{hands} + 0.35\frac{(C+E+M+N)_{trunk}}{4} + 0.19\frac{(H+P)_{thigh}}{2} + 0.13\frac{(J+Q)_{calf}}{2} + 0.07K_{feet} \quad (3)$$

where A= bridge of the nose, B= upper cheek, L= nape of the neck, C= chest, E= front waist, M= shoulder blade, N= back waist, H= quadriceps, P= hamstring, J= shinbone, Q= calf, and K= feet.

The 7 skin temperature measurement sites are a simplified version of 15 temperature measurement sites. These sites have been formulated on Equation 3 [10].

$$T_{mean\ skin} = 0.07A + 0.14F + 0.05G + 0.35E + 0.19H + 0.13J + 0.07K \quad (4)$$

Although both methods are comprehensive temperature measurement site methods, they might give different results. This study aimed to obtain the interchangeability of temperature measurement results for both methods on men and women and the interaction between the methods and genders.

II. Materials and Method

A. Materials

The materials used for this study were seven authors and their spouses (7 persons), and they were objects and subjects for the temperature data gathering. Each couple measured each other his or her spouse on 17 measurement sites, two on the core compartment and 15 on the peripheral compartment.

The core and peripheral compartment measurements in this study are related to the surface temperatures of human skin. For this sake, infrared thermometers are accurate [16], quick, [17], inexpensive, easy to use [18], efficient [19], and non-contact [20] thermometers. Our own made infrared thermometer was used to accommodate this research (Fig. 1). It is different from other general infrared thermometers that are not interchangeable [21]; our developed infrared thermometer can be used to measure equally well for the ear canal and forehead.

Fig. 1 A calibrated our own made infrared thermometer was used around 1 cm from the target. Although other general infrared thermometers are not interchangeable [21], this instrument can be used to measure equally well the ear canal and overhead

Rather than ornamental sides, this thermometer pays more attention to technical aspects. Therefore, this infrared thermometer was painted with dominant white color to reduce the ambient temperature impact. This effort was also reinforced using the conical-shaped infrared thermometer design so that the heat dissipation mainly to the air is optimized.

The infrared thermometer was designed for its best operation in the human range temperature, namely between 32° C – 42° C. Its resolution is 0.1° C, accuracy 0,2° C, and can operate for battery between 3.3 VDC – 3.8 VDC recharged from a 5 VDC power supply. When it was calibrated on December 19, 2020, its uncertainty was 0.466 °C for a coverage factor of 95 %. These data are noteworthy because some experts are skeptical about using an infrared thermometer for cutaneous measurements [22]. Hence, regular calibration is essential because medical diagnosis and clinical practice are primarily based on test and measurement instrumentation [23].

Before the measurement step, a briefing or a discussion among all respondents was conducted to make the measurement uniform. This activity is essential because each married couple's temperature measurements were carried out in their own house. Hence, the condition, especially ambient temperature, was set almost the same. Some of the discussions were concerning a measurement set-up and measurement points. Set up variables and conditions of use can influence temperature measurement results [24]. Measurement points were demonstrated in the discussion.

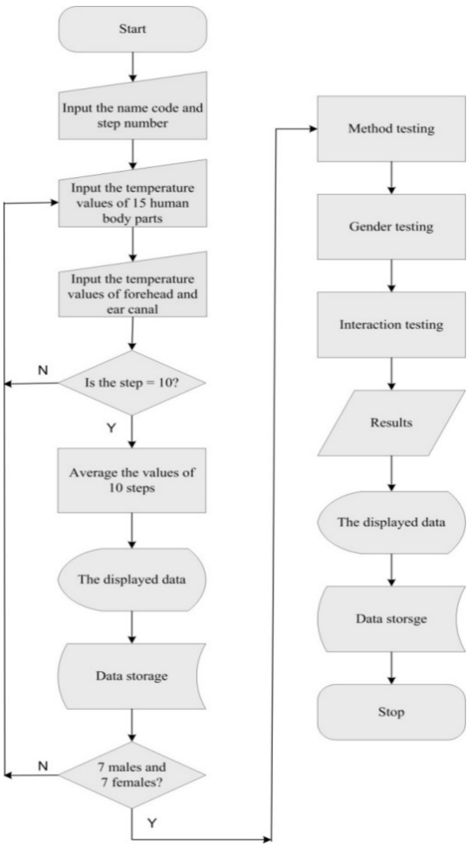

Fig. 2 The flow chart for data gathering and processing

Besides the infrared thermometer, the authors developed an application program for data processing in this study, where all of the above formulas were inserted (Fig. 2). The result of this program was compared with an Excel calculation result. The results from the application program and Excel calculation had to agree. If they were not, recalculation should be carried out to fix the error. The comparison and perhaps the recalculation increased the data processing reliability.

B. Data Gathering

In this paper, 7 from 8 authors and their spouses were the participant (respondents) in the data gathering. Every respondent was measured on 17 measurement sites. 2 and 15 measurement sites were used to obtain core temperature and mean skin temperature, respectively. These data were used for two groups (Forehead Group and Ear Canal Group) and two methods (16 measurement sites and eight measurement site methods). This way was chosen to reduce the data gathering number and eliminate unnecessary factors, particularly sampling errors.

One of the two core temperature measurement sites was located on the body surface (axilla and forehead), while the other was situated on natural body orifices (rectum, mouth, ear canal, esophagus, nasopharynx, and gastro-intestinal) [10]. For the sake of common comfortability for all participants, the forehead and ear canal (tympanic) were chosen to represent the body surface and natural body orifice, respectively. Furthermore, these body measurement sites have the lowest and highest accuracy for measuring body temperature [25]. Forehead and ear temperature measurements are valuable methods for screening purposes [26].

There were 14 (7 male + 7 female) participants for this data gathering. Every participant was measured on 17 (1 forehead + 15 skin + 1 ear canal) temperature measurement sites. Every site was measured ten times. Hence, 2380 (14 x 17 x 10) data were collected (Table I).

TABLE I
DATA GATHERING STEPS

Steps	Data Gathering
Measurement	(7 male + 7 female)(1 forehead +15 skin + 1 ear canal)(10 times)
Data averaging	(7+7)(1+15+1)(1)

The 17 temperature measurement sites (Table 1) were distributed to all human body parts. These measurements represent the core, head, arms, hands, trunk, thigh, calf, and feet. Every human body part for the 8-temperature measurement site method was represented by 1 body part representative, while for 16 temperature measurement site method was represented by 1 representative or 2, 3, or 4 representatives. The data processing used only 238 (14 x 17) samples because the repetitive data during 10 times were averaged first. These averaged data were then utilized as samples. These data were arranged as 14 (rows) x 17 (columns).

C. Data Processing

Nine steps should be conducted during data processing (Table II). These steps should be carried out sequentially from the first step.

TABLE II
DATA PROCESSING STEPS

Steps	Data Processing			
Core splitting	(7+7)(1+15) forehead		(7+7)(15+1) ear canal	
Method splitting	(7+7)(1+15)	(7+7)(1+7)	(7+7)(15+1)	(7+7)(7+1)
Data integration	(7+7)(1)	(7+7)(1)	(7+7)(1)	(7+7)(1)
Method comparison	(1)(1:1)		(1)(1:1)	
Gender comparison	(1:1)(1)		(1:1)(1)	
Factor interaction	(1:1)(1:1)		(1:1)(1:1)	
Method result	Accepted/rejected		Accepted/rejected	
Gender result	Accepted/rejected		Accepted/rejected	
Interaction result	Accepted/rejected		Accepted/rejected	

In the core splitting step, 17 (1 forehead + 15 skin + 1 ear canal) temperature measurement sites were split into two groups. The first was the group where the core compartment was the forehead (1 forehead + 15 skin), and the second was the group where the core compartment was the ear canal (15 skin + 1 ear canal). The 15 temperature measurement sites on the skin were used for both groups.

Each group was disparted into two methods. In group 1, the first method consisted of 16 (1 forehead + 15 skin) temperature measurement sites, while the second method comprised 8 (1 forehead + 7 skin) temperature measurement sites. In group 2, the first method was the 16 (15 skin + 1 ear canal) temperature measurement site method, while the second method was the 8 (7 skin + 1 ear canal) temperature measurement site method. Group 2 was the leading group, and Group 1 was the supportive group. Some researchers do not categorize the forehead as the body core [27], so it was not chosen as the leading group in this study. Due to its location, the ear canal temperature is also more stable than the forehead temperature.

In the data integration step, the core and skin temperature data are entered into their formulas, respectively. As a result, the 16 temperature measurement site method was in Equation 2 and Equation 3, while the 8 temperature measurement site method was in Equation 2 and Equation 4.

Method comparison was used to contras between 16 temperature measurement site method and 8 temperature measurement site method. Male and female data were added based on each method.

Data for both genders were compared. Data obtained from 8 and 16 temperature measurement site methods were summed up for every gender type.

In the factor interaction step, all data were classified into four clusters. Cluster 1 comprised the intersection data between 16 temperature measurement site methods and males; Cluster 2 comprised the intersection data between 8 temperature measurement site methods and males; Cluster 1 comprised the intersection data between 16 temperature measurement site methods and females, and Cluster 4 comprised the intersection data between 8 temperature measurement site method and female (Table III).

The instrument to test all hypotheses was two-way ANOVA (Analysis of Variance) with Repetition [28]. The first way was a method (15A model and 7A model; or 15B model and 7B model), the second way was gender (male and female), and 7 repetitions for both male and female.

TABLE III
BASIC DATA AND FORMULAS FOR DATA PROCESSING

Gender	Method and Model					
	15B		7B		Sum	
M1	X_{11}	$(X_{11})^2$	X_{12}	$(X_{12})^2$	$\sum_{m=1}^{m=2} x_{1m}$	$\sum_{m=1}^{m=2} (x_{1m})^2$
M2	X_{21}	$(X_{21})^2$	X_{22}	$(X_{22})^2$	$\sum_{m=1}^{m=2} x_{2m}$	$\sum_{m=1}^{m=2} (x_{2m})^2$
M3	X_{31}	$(X_{31})^2$	X_{32}	$(X_{32})^2$	$\sum_{m=1}^{m=2} x_{3m}$	$\sum_{m=1}^{m=2} (x_{3m})^2$
M4	X_{41}	$(X_{41})^2$	X_{42}	$(X_{42})^2$	$\sum_{m=1}^{m=2} x_{4m}$	$\sum_{g=1}^{g=2} (x_{4m})^2$
M5	X_{51}	$(X_{51})^2$	X_{52}	$(X_{52})^2$	$\sum_{m=1}^{m=2} x_{5m}$	$\sum_{g=1}^{g=2} (x_{5m})^2$
M6	X_{61}	$(X_{61})^2$	X_{62}	$(X_{62})^2$	$\sum_{m=1}^{m=2} x_{6m}$	$\sum_{m=1}^{m=2} (x_{6m})^2$
M7	X_{71}	$(X_{71})^2$	X_{72}	$(X_{72})^2$	$\sum_{m=1}^{m=2} x_{7m}$	$\sum_{m=1}^{m=2} (x_{7m})^2$
Male	$\sum_{i=1}^{i=7} x_{i1}$	$\sum_{i=1}^{i=7} (x_{i1})^2$	$\sum_{i=1}^{i=7} x_{i2}$	$\sum_{i=1}^{i=7} (x_{i2})^2$	$\sum_{i=1}^{i=7} \sum_{m=1}^{m=2} x_{i}$	$\sum_{i=1}^{i=7} \sum_{m=1}^{m=2} (x_{im})^2$
F1	X_{81}	$(X_{81})^2$	X_{82}	$(X_{82})^2$	$\sum_{m=1}^{m=2} x_{8m}$	$\sum_{m=1}^{m=2} (x_{8m})^2$
F2	X_{91}	$(X_{91})^2$	X_{92}	$(X_{92})^2$	$\sum_{m=1}^{m=2} x_{9m}$	$\sum_{m=1}^{m=2} (x_{9m})^2$
F3	X_{101}	$(X_{101})^2$	X_{102}	$(X_{102})^2$	$\sum_{g=1}^{g=2} x_{10m}$	$\sum_{m=1}^{m=2} (x_{10m})^2$
F4	X_{111}	$(X_{111})^2$	X_{112}	$(X_{112})^2$	$\sum_{g=1}^{g=2} x_{11m}$	$\sum_{m=1}^{m=2} (x_{11m})^2$
F5	X_{121}	$(X_{121})^2$	X_{122}	$(X_{122})^2$	$\sum_{m=1}^{m=2} x_{12m}$	$\sum_{m=1}^{m=2} (x_{12m})^2$
F6	X_{131}	$(X_{131})^2$	X_{132}	$(X_{132})^2$	$\sum_{m=1}^{m=2} x_{13m}$	$\sum_{m=1}^{m=2} (x_{13m})^2$
F7	X_{141}	$(X_{141})^2$	X_{142}	$(X_{142})^2$	$\sum_{m=1}^{m=2} x_{14m}$	$\sum_{g=1}^{m=2} (x_{14m})^2$
Female	$\sum_{i=8}^{i=14} x_{i1}$	$\sum_{i=8}^{i=14} (x_{i1})^2$	$\sum_{i=8}^{i=14} x_{i2}$	$\sum_{i=8}^{i=14} (x_{i2})^2$	$\sum_{i=8}^{i=14} \sum_{m=1}^{m=2} x_{i}$	$\sum_{i=8}^{i=14} \sum_{m=1}^{m=2} (x_{im})^2$
Grand sum	$\sum_{i=1}^{i=14} x_{i1}$	$\sum_{i=1}^{i=14} (x_{i1})^2$	$\sum_{i=1}^{i=14} x_{i2}$	$\sum_{i=1}^{i=14} (x_{i2})^2$	$\sum_{i=1}^{i=14} \sum_{m=1}^{m=2} x_{i}$	$\sum_{i=8}^{i=14} \sum_{m=1}^{m=2} (x_{im})^2$

= Cluster 1, = Cluster 2, = Cluster 3, = Cluster 4.

The ANOVA in this study was used to answer three hypotheses. The first is that there was no significant mean difference among method samples, while the second is that there was no significant mean difference between male and female samples. The third is that there was no significant mean difference due to the interaction between method and gender. These hypotheses were tested using the F test, namely if.

$$F_0 > F_{0.05;\, DF;\, DFW} \tag{5}$$

then the hypothesis is rejected, and if .

$$F_0 \leq F_{0.05;\,DF;\,DFW} \quad (6)$$

then the hypothesis is accepted.

The $F_{0.05;\,DF;\,DFW}$ is the theoretical F for the significant level 0.05. The value of $F_{0.05;\,DF;\,DFW}$ can be obtained from the F distribution (lying to its right-side/right-skewed distribution) table at the related DF (degree of freedom).

The F_0 is the empirical F. There were three F_0in this case. The first was the F for the method (F_A). The second was the F for gender (F_B). The third was the F for the method and gender interaction (F_{AB}). These were presented as follows:

$$F_A = \frac{MSA}{MSW} \quad (7)$$

$$F_B = \frac{MSB}{MSW} \quad (8)$$

$$F_{AB} = \frac{MSAB}{MSW} \quad (9)$$

MSA, MSB, $MSAB$, and MSW were obtained from

$$MSA = \frac{SSA}{DFA} \quad (10)$$

$$MSB = \frac{SSB}{DFB} \quad (11)$$

$$MSAB = \frac{SSAB}{DFAB} \quad (12)$$

$$MSW = \frac{SSW}{DFW} \quad (13)$$

where MSA= mean of squares for the method, MSB= mean of squares for the gender, $MSAB$= mean of squares for the interaction between method and gender, and MSW= mean of squares within the group.

SSA, SSB, $SSAB$, and SSW were attained from

$$SSA = \left(\frac{\left(\sum_{i=1}^{i=14} x_{i1}\right)^2}{i_1} + \frac{\left(\sum_{i=1}^{i=14} x_{i2}\right)^2}{i_2}\right) - \frac{\left(\sum_{i=1}^{i=14}\sum_{m=1}^{m=2} x_{im}\right)^2}{n} \quad (14)$$

$$SSB = \left(\frac{\left(\sum_{i=1}^{i=7}\sum_{m=1}^{m=2} x_{im}\right)^2}{j_1} + \frac{\left(\sum_{i=8}^{i=14}\sum_{m=1}^{m=2} x_{im}\right)^2}{j_2}\right) - \frac{\left(\sum_{i=1}^{i=14}\sum_{m=1}^{m=2} x_{im}\right)^2}{n} \quad (15)$$

$$SSAB = \frac{\left(\sum_{i=1}^{i=7} x_{i1}\right)^2}{k_1} + \frac{\left(\sum_{i=8}^{i=14} x_{i1}\right)^2}{k_2} + \frac{\left(\sum_{i=1}^{i=7} x_{i2}\right)^2}{k_3} + \frac{\left(\sum_{i=8}^{i=14} x_{i2}\right)^2}{k_4} - \frac{\left(\sum_{i=1}^{i=14}\sum_{m=1}^{m=2} x_{im}\right)^2}{n} \quad (16)$$

$$SSW = SSG - SSA - SSB - SSAB \quad (17)$$

$$SSG = \sum_{i=8}^{i=14}\sum_{m=1}^{m=2} (x_{im})^2 - \frac{\left(\sum_{i=1}^{i=14}\sum_{m=1}^{m=2} x_{im}\right)^2}{n} \quad (18)$$

where SSG= the total sum of squares, SSA= between methods sum of squares, SSB= between genders sum of squares, SSAB= the interaction between method and gender sum of squares, SSW= within-samples sum of squares, i_1= i_2= mk= the size of method sample= 14, j_1= j_2= gk= the size of gender sample= 14, k_1= k_2= k_3= k_4= k= the size of interaction sample= 7, m= the size of method= 2, g= the size of gender= 2, n= the size of all sample= 28, and x_{im}= sample temperature value.

DFA, DFB, $DFAB$, DFW, and DFG were attained from

$$DFA = m - 1 = 2 - 1 = 1 \quad (19)$$

$$DFB = g - 1 = 2 - 1 = 1 \quad (20)$$

$$DFAB = DFA * DFB = (m-1)(g-1) = 1 \quad (21)$$

$$DFW = m * g * (k-1) = 2*2*6 = 24 \quad (22)$$

$$DFG = mgk - 1 = (2*2*7) - 1 = 27 \quad (23)$$

where DFA = degrees of freedom for the method, DFB = degrees of freedom for the gender, $DFAB$ = degrees of freedom for the interaction between method and gender, DFW= degrees of freedom within the group, and DFG = degrees of freedom for the group. The DF in $F_{0.05;\,DF;\,DFW}$ was filled with DFA, DFB, or DFAB for the method, gender, or interaction investigation, respectively. In this case, DFA= DFB= DFAB= 1.

III. Result and Discussions

A. Results

The first step of data gathering is measuring the temperature for all respondents. These data were then tabulated for all participants using our developed application program. After 10 times, data were averaged. The presented data, namely data for point A to point K, were the means of each temperature measurement point. The 10 repetitions were used to improve data quality. This data averaging step was repeated for other participants.

Every participant finally has only two integrated data, namely temperature data for model A and Model B. Model B was processed first because it was the leading model. The output from data gathering was used as the basis for data processing.

Data were analyzed using Two Way ANOVA with Repetition available in our developed application program. The data analysis result (Fig. 3) shows that all empirical F was smaller than theoretical F. This finding was supported using an Excel calculation. Both data processing methods were in agreement. It means that the data analysis was correct.

B. Discussion

Equation 2 is a powerful formula due to at least two reasons. First, it is based on the Energy Balance concept. Second, it is an identical couple with Equation 1. They have the same format but are different in their arrangement, and their opposite working principle causes these. Equation 1 is a formula for dissipating heat, while Equation 2 stores heat.

Based on the results presented in Fig. 3, it is clear that the difference between 16 and 8 measurement site methods was nonsignificant, the difference between male and female temperature was nonsignificant, and the interaction between the temperature measurement site method and gender was nonsignificant. Therefore, all three null hypotheses were accepted. Let us take a look one by one at why these results occurred.

Equations 3 and 4 show that both equations are almost similar and detailed versions of Equation 2. They comprise the same body parts and constants. They are different, however, in their detail of body parts. Whatever it is, 80 % of both methods are determined by body core temperature. They are precisely the same (37.23 °C) for the ear canal as the body core compartment. The remaining depends on the mean skin temperature, namely 34.92 °C for Equation 3 (method 1) and 35.11 °C for Equation 4 (method 2). The mean body temperatures were 36.77 °C and 36.80 °C for the 16 and 8 temperature measurement site methods (method 1 and method 2). In other words, their difference was less than 0.1 %. Hence, this difference was nonsignificant for the theoretical $F_{0.05, 1, 24}$ (4.26) [29].

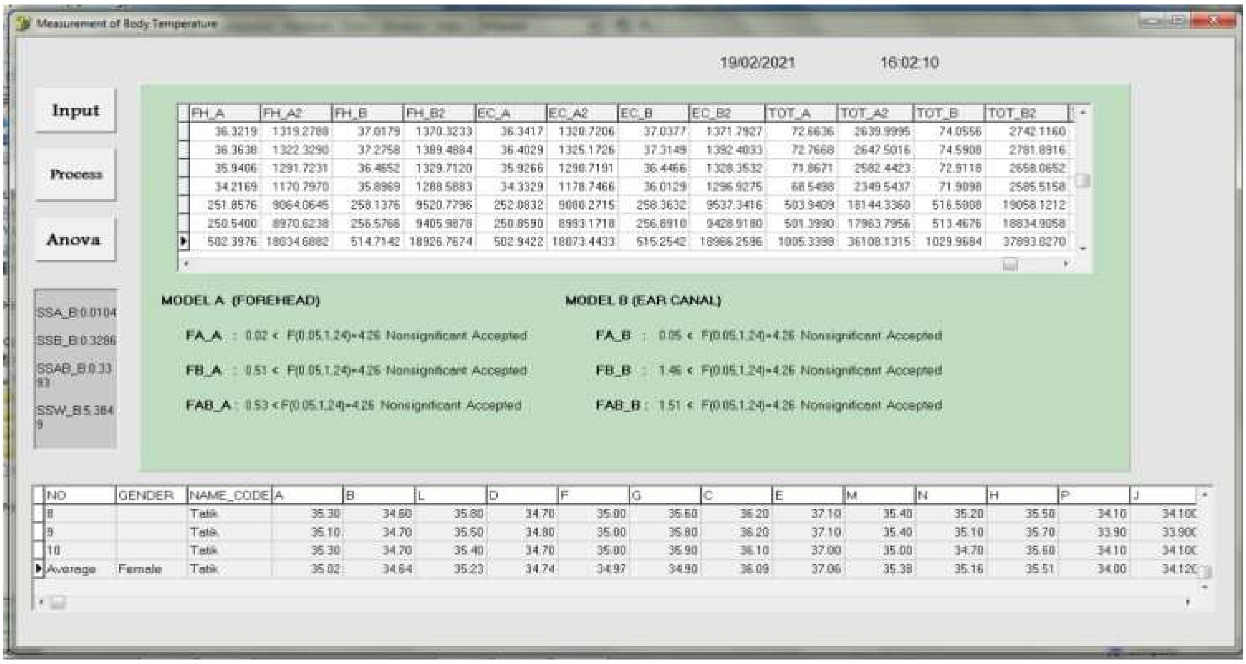

Fig. 3 Results of data analysis

Male body temperatures were varied from 36.26 °C to 37.50 °C, while female body temperatures fluctuated between 35.9 °C and 37.06 °C. Mean body temperatures for male and female groups were 36.89 °C and 36.68 °C, respectively, or the mean female body temperature was around 0.57 % lower than the male body temperature. Men generally move more than women, and every movement will generate heat. Although, in general, the male temperature was a little bit higher (0.21 °C), there was a possibility that a man's body temperature (36.26 °C, for example) was lower than a woman's body temperature (37.06 °C, for example). Hence, this difference (0.57 %) as a whole was still nonsignificant.

Even though man and woman temperatures generally have no significant difference, they seem different in certain body parts. Men had temperatures that were slightly higher on points A, B, F, G, H, P, J (if it was not rounded), Q, K, ear canal, and forehead, while women on points L, D, C, E, M, N (Fig. 4). It means that there was a tendency that front head (face), lower part arm, hand, thigh, calf, and feet temperatures for men were slightly higher than women; while the trunk, upper part arm, and back neck temperatures for women were a little bit higher than men (Fig. 4). Besides, men are more active than women, while women wear thicker clothes than men and have longer hairs to protect heat releases from the body. Furthermore, women have a lower sweat output in heat stress than men [30].

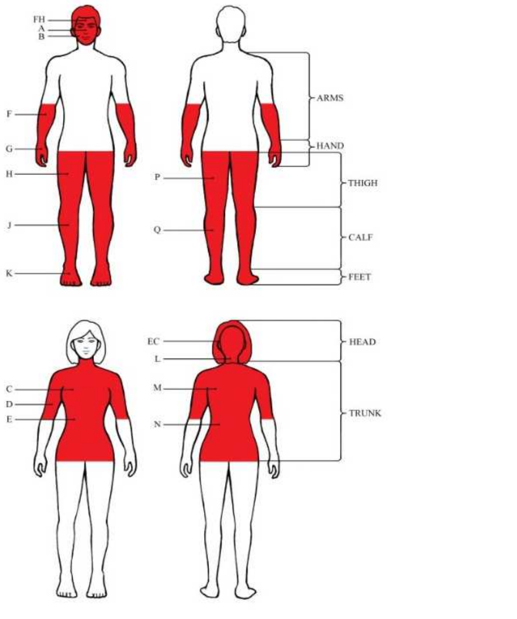

Fig 4 Temperature measurement results lead to a hypothesis that men have warmer temperature than women on the red colour man body parts, while women have warmer temperature than men on the red colour woman body parts. Two of 17 temperature measurement sites were located on the core compartment, while the rest were situated on the skin surfaces, namely the human's head (3 points, A, B, and L), arms (2 points, D and F), hand (1 point, G), trunk (4 points, C, E, M, and N), thigh (2 points, H and P), calf (2 points, J and Q), and feet (1 point, K).

The interaction may strengthen the difference between two variables or factors (method and gender). The empirical F for method (0.05) and F for gender (1.46) in this case, however, were very nonsignificant (< 4.26). Therefore like the two former hypotheses, the interaction F (1.51) was also nonsignificant. All three hypotheses were accepted. Another investigation amplified these statements, namely ear canal on the core compartment was replaced with the forehead. The empirical Fs, in this case, was 0.02, 0.11, and 0.13, respectively. Hence all three hypotheses were accepted. The above investigations show that although classified as core compartments, the ear canal (37.23 °C) and forehead (36.13 °C) mean temperatures differed significantly. The difference was valid for the investigations in 16 measurement site methods and 8 measurement site methods.

Based on the above hypothesis testings, it is clear that the developed tools for this study worked well. The infrared thermometer could measure temperature on many body measurement sites convincingly. This system, however, is still a stand-alone instrument with a small display. It is better if this instrument is made as a telemetering system. The developed application program should be embedded in the instrument. The measurement distance is also so near (around 1 cm) that it is uncomfortable for someone who would like to be measured.

IV. Conclusion

There were three main findings of this study. First, our developed infrared thermometers could be used to measure equally well for the ear canal and overhead. Second, our developed application program to analyze data worked well as it was designed. Third, the 8 measurement site method had the same quality result as the 16 measurement site method, both for males and females.

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