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Original Article

Effects of Various Protective Clothing and Thermal Environments on Heat Strain of Unacclimated Men: the PHS (predicted heat strain) Model Revisited

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Abstract: Five protective garments (light summer clothing L, high visibility clothing HV, military clothing MIL, climber coverall CLM and firefighting clothing FIRE) were assessed on eight unacclimated male subjects at two environments: moderate warm environment with high humidity (MWH, 20.0°C, 86% relative humidity) and warm environment with moderate humidity (WMH, 30.0°C, 47% relative humidity). The thermophysiological responses and subjective sensations were reported. The PHS model (ISO7933) was used for predicting thermophysiological responses for each testing scenario. It was found that there were significant differences between clothing FIRE and other clothing on thermal sensation (p<0.05). Significant differences were found on skin humidity sensation between FIRE and L, HV or MIL (p<0.001). The RPE value in FIRE is significantly different with L and HV (p<0.05). In MWH, the post-exercise mean skin temperatures increased by 0.59 and 1.29°C in MIL and CLM. In contrast, mean skin temperatures in L, HV, MIL, CLM and FIRE in WMH increased by 1.7, 2.1, 2.1, 2.8 and 3.3°C, respectively. The PHS model presented good performance on predicted mean skin temperatures in MIL and CLM at the two studied environments. However, the skin temperature prediction with light clothing in WMH was weak. For thick protective clothing, the prediction on rectal temperature was protective. It is thus concluded that the results generated by the PHS model for high insulating clothing and measurements performed in high humidity environments should be explained with caution.

Key words: Heat stress, Heat strain, PHS model, Thermophysiological response, Protective clothing

Introduction

People who are doing open air mining, power line construction, military training, and firefighting jobs are frequently exposed to severe heat stress, which may deteriorate their productivity or even threaten body survival[1, 2]. Heat strain arises from different physical activities, clothing ensembles and thermal environments, which results in a rise in both body core and skin temperatures[3]. The physical activity contributes to the total heat stress of the work by generating metabolic heat in human body in proportion to work intensity. The heat and moisture transfer characteristics of clothing worn affect the amount of heat stress by changing the dry and evaporative heat exchange

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rates between body surface and environment[4]. Thermal environmental factors such as air temperature, air velocity, water vapour pressure and radiation also contribute to the total heat stress[5, 6].

Assessment of heat stress may be conducted by measuring climatic and physical parameters of thermal environment and following evaluation of their impacts on human body by using a single heat stress index or more indices. The Predicted Heat strain (PHS) model[8] was developed based on heat balance equation, which made predicted physiological states consistent with heat transfer theory. This model was derived from an in-depth revision of the previous Required Sweat Rate index[7, 9] and new algorithms were created based on scientific literature concerning, convection, evaporative heat transfer, rectal and skin temperatures. As a rational model, it was adopted by the ISO 7933[10] and was used as a tool to predict human thermophysiological responses of a standard person exposed in hot environments. More detailed information about the present PHS model can be found in papers authored by Malchaire *et al.* and also, the international standard ISO 7933[8, 10, 11].

In our previous paper, we have validated the PHS model by human trials conducted in hot environments. We found that the PHS model generated unreasonable physiological data for subjects who wore high insulating protective clothing[12]. Nevertheless, the performance of this model has not been thoroughly examined in various warm environments yet. In order to further check its applicability and prediction accuracy, eight unacclimated men in five vocational clothing performed 64 trials under warm/moderate warm conditions. Their physiological responses and perceptions were reported. The PHS model was used to check its prediction accuracy on such physiological parameters as rectal temperature, skin temperature and sweat rate. Comparisons between observed and predicted data were carried out. The applicability of the PHS model was addressed.

Methods

Subjects

Eight unacclimated male volunteers with no history of heat illness participated in this study. The mean ± SD age was 27 ± 3 (range 24–34), height was 1.76 ± 0.06 m (range 1.65–1.89), weight was 77.0 ± 10.2 kg (range 60–92), body surface area was 1.94 ± 0.15 m^2 (range 1.66–2.15) and the body mass index (BMI) was 24.6 ± 2.2 $kg \cdot m^{-2}$(range 22.0–26.1). They were informed not to smoke and consume alcohol, coffee or tea two hours before each trial. They should not do high intensive activities at least one hour before the trail either. Subjects were not allowed to eat or drink during exposure sessions. They performed trials at the same period of a day. Each trial was separated by at least 48 h to dissociate physiological responses that may carry over between trials. Subjects were informed of the purpose, test procedure and potential risks of these trials. They provided written consents prior to participation. The study protocol followed the Helsinki Declaration.

Clothing ensembles

In this study, five most widely used Swedish vocational ensembles were used. Clothing physical parameters such as thermal insulation (I_T) and evaporative resistance (R_{et}) were determined by a thermal manikin. The manikin surface temperature was controlled at 34.0°C. All manikin tests followed two standards: ISO 15831[13] and ASTM F2370[14]. For wet experiments to determine evaporative resistance, a pre-wetted fabric 'skin' was dressed on top of the nude manikin to mimic human sweating. Wet-tests were conducted at an air temperature of 34.0°C, and relative humidity (RH) was 38%. The partial vapour pressure inside the chamber was 2 kPa accordingly. Dry tests were performed at 20.0°C, RH = 45%. The air velocity was 0.33 ± 0.05 $m \cdot s^{-1}$. The characteristics of these five ensembles are described in Table 1. It should be noted that the insulation values of MIL and CLM are slightly out of the validation range of the PHS model (0.1–1.0 clo). The FIRE has a thermal insulation of 2.01 clo, which is far beyond the model's validation range. Thus, another aim of this study was to explore the possibility of extending the application range of the PHS model to include thick and low permeable protective clothing.

Test procedures

The clothing, equipment (i.e., face mask and pulse watch), and subjects were weighed on a weighing scale (Mettler-Toledo Inc., Switzerland, precision: ± 2 g) during preparation. After the preparation, subjects came into a chamber and walked on a treadmill (Exercise™ X Track Elite, Norway) at a speed of 4.5 $km \cdot h^{-1}$ (i.e., 1.25 $m \cdot s^{-1}$). In order to get a steady-state sweat production rate, the subjects were weighed again after 30 min of walking. The heart rate, rectal (T_{re}) and skin (T_{sk}) temperatures were recorded throughout the exposure. Test sessions were terminated when one of the following three criteria was reached: (i) subjects felt the conditions were intolerable

Table 1. Details of clothing ensembles

Code	Garment components	I_T clo	I_{cl} clo	R_{et} Pa m^2/W	i_m nd
L	short sleeve tee-shirt, briefs, short pants, socks, sports shoes	1.05	0.48	19.8	0.49
HV	short sleeve tee-shirt, briefs, long trousers with reflective materials, socks, shoes	1.20	0.63	25.7	0.43
MIL	jacket, long trousers, short sleeve net tee-shirt, briefs, socks, sports shoes	1.65	1.08	42.1	0.36
CLM	polyamide overall laminated with Gore-tex membrane, short sleeve tee-shirt, briefs, socks, sports shoes	1.68	1.11	74.5	0.21
FIRE	RB90 firefighting clothes, underwear, short sleeve tee-shirt, briefs, socks, sports shoes	2.58	2.01	122.4	0.20

L: light clothing; HV: high vision clothing; MIL: military clothing; CLM: climber overall; FIRE: firefighting clothing. I_{cl}, clothing intrinsic thermal insulation, clo; i_m, clothing permeability index; nd, non-dimensional.

and were unable to continue, (ii) the rectal temperature T_{re} reached 38.5°C or (iii) subjects walked 70 min on the treadmill.

The subject was weighed again immediately after each exposure. Afterwards, they took off equipment and clothing. Each garment was quickly weighed separately after the subject removed it. Right after subjects were undressed and measuring equipment was removed, they were weighed again just wearing briefs and rectal sensor.

Measurements and calculations

The rectal sensor (YSI-401, Measurement Specialties Inc., USA, accuracy ± 0.1°C) was inserted by the subject at a depth of approximately 10 cm beyond the anal sphincter. Four thermocouples (NTC-resistant thermistors ACC-001, Rhopoint Components Ltd, UK, accuracy ± 0.2°C, time constant 10 s) were taped (surgical waterproof tape, 3M, USA) on the left body side, i.e., chest, upper arm, thigh and calf. The mean skin temperature was calculated using the Ramanathan 4-point weighting system[15] of 0.3 chest, 0.3 upper arm, 0.2 thigh and 0.2 calf. Rectal and skin temperatures were recorded via a LabVIEW program (National Instruments Corp., USA) with an interval of 15 s when subjects started walking on the treadmill. The oxygen uptake was determined by a MetaMax I instrument (Cortex Biophysik GmbH, Germany) for 5 min after 10 min of walking. A heart rate monitor (Sport Tester, Polar Electro Oy, Finland) was worn throughout the exposure.

Subjective ratings

Subjective ratings of perceived physical exertion, based on Borg RPE scale[16], 9-point whole-body thermal sensation[17] (−4: very cold, −3: cold, −2: cool, −1: slight cool, 0: neutral, 1: slight warm, 2: warm, 3: hot, 4: very hot) and 4-point skin humidity sensation (0: neutral, 1: slightly wet, 2: wet, 3: very wet) were requested every 10 min throughout each trial.

Test conditions

Two thermal environmental conditions were chosen: moderate warm environment with high humidity (MWH, 20.0°C, RH=86%) and warm environment with moderate humidity (WMH, 30.0°C, RH=47%). In MWH condition, the subjects performed three trials in clothing ensembles HV, MIL, and CLM. In WMH condition, they had five trials with all five clothing ensembles. The air velocity inside the climatic chamber was kept at 0.33 ± 0.05 m·s^{-1}.

Statistical analyses

Means and SD (standard deviation) were reported for dependent variables. Using SPSS 16.0 (SPSS Inc., Chicago, IL, USA), the repeated measures ANOVA (analysis of variance) was used to determine whether there were significant differences on metabolic rate, heart rate, subjective sensations, sweat rate and evaporative rate in all test scenarios. The level of significance was set at $p<0.05$. Besides, the root mean square deviation (RMSD) was used to quantify the average difference between predicted and observed data endpoints. The RMSD was computed as follows:

$$RMSD = \sqrt{\frac{\sum_{i=1}^{n}(T_{meas} - T_{pred})^2}{n}}$$

where, T_{meas} and T_{pred} are the observed experimental data and the predicted data by a model; n is the number of compared points.

Results

All subjects successfully completed each trial. Physiological parameters and subjective perceptions are presented in the following four sections.

Metabolic rate and heart rate

The mean metabolic rate and mean heart rate are listed

in Table 2. The mean heart rate was about 100 bpm (beats per minute) for all eight-test conditions and no significant difference was observed among those five ensembles ($p>0.1$). Two thermal environments had no significant influence on mean heart rate either ($p>0.1$). Metabolic rates during walking in clothing L, HV, MIL and CLM were around 165 $W \cdot m^{-2}$. In contrast, the metabolic rate in clothing FIRE was significantly higher than other four ensembles ($p<0.001$). The testing temperature has no significant effect on the metabolic rate ($p>0.1$).

Subjective sensations

Subjects had very similar pre-exercise subjective perceptions. The post-exercise subjective sensations are presented in Table 3. Clothing ensembles had significant effects on these subjective sensations ($p<0.05$). Similarly, the testing temperature also had significant effects on the thermal and skin humidity sensations, but not on the RPE. Significant differences were detected between clothing FIRE and other four ensembles on the thermal sensation ($p<0.05$). The skin humidity sensation in clothing FIRE was significant different with clothing L, HV and MIL ($p<0.001$). The RPE values in clothing FIRE were significant different with clothing L and HV ($p<0.05$). However, no significant difference was registered between clothing FIRE and MIL on both skin humidity sensation and RPE value ($p>0.1$).

Table 2. Metabolic rate and heart rate for all test scenarios (mean ± SD)

Clothing ensemble	Environmental conditions	Metabolic rate W/m^2	Heart rate bpm
HV	MWH	169 ± 13	95 ± 14
MIL	MWH	163 ± 7	92 ± 15
CLM	MWH	167 ± 11	99 ± 15
L	WMH	163 ± 7	96 ± 14
HV	WMH	164 ± 12	98 ± 13
MIL	WMH	165 ± 11	94 ± 11
CLM	WMH	175 ± 14	108 ± 19
FIRE	WMH	190 ± 6*	107 ± 17

* $p<0.001$.

Predicted and observed skin and rectal temperatures

The time course of the observed rectal and skin temperatures is illustrated in Fig. 1a–h. In MWH, mean skin temperatures in clothing MIL and CLM were rather stable during the last 40-min exposure. They were raised by 0.56 and 1.29°C respectively, compared with pre-exercise data. The mean skin temperature in HV was slightly decreased by 0.1°C. The post-exercise rectal temperature in clothing L, HV, and MIL was increased by 0.26, 0.33 and 0.46°C, respectively.

For clothing L, HV and MIL in WMH, the observed skin temperature was stable during the last 40-min exposure. In contrast, mean skin temperatures in clothing CLM and FIRE continuously increased with the time course. The post-exercise mean skin temperature in clothing L, HV, MIL, CLM, and FIRE was increased by 1.7, 2.1, 2.1, 2.8 and 3.3°C, respectively. The post-exercise mean rectal temperature in clothing L, HV, MIL, CLM and FIRE was increased by 0.32, 0.33, 0.39, 0.48 and 0.82°C, respectively (Table 4).

A PHS model program[12] was used to generate physiological predictions for each testing scenario. Generally, the average core temperature of human being is above 36.8°C for most of the time. In this study, rather than using default values (i.e., *Tre*= 36.8°C and *Tsk*=34.1°C), the starting rectal and skin temperatures in the model was set the same as our observed data for each test scenario. The predicted temperature curves and post-exercise mean skin

Table 3. Post-exercise subjective thermal sensation (mean ± SD)

Clothing ensemble	Condition	Thermal sensation	Skin humidity sensation	RPE
HV	MWH	0.94 ± 0.86	1.25 ± 0.46	11.6 ± 2.1
MIL	MWH	1.13 ± 0.64	1.13 ± 0.35	11.5 ± 1.6
CLM	MWH	2.06 ± 0.56	2.06 ± 0.18	12.2 ± 1.7
L	WMH	2.32 ± 0.96	1.81 ± 0.53	11.4 ± 2.2
HV	WMH	2.13 ± 0.69	1.75 ± 0.46	12.1 ± 2.4
MIL	WMH	2.38 ± 0.79	2.13 ± 0.52	12.3 ± 2.2
CLM	WMH	3.00 ± 0.60	2.50 ± 0.27	13.1 ± 1.4
MIL	WMH	3.63 ± 0.79	2.69 ± 0.46	14.1 ± 2.1

*$p<0.05$; **$p<0.001$.

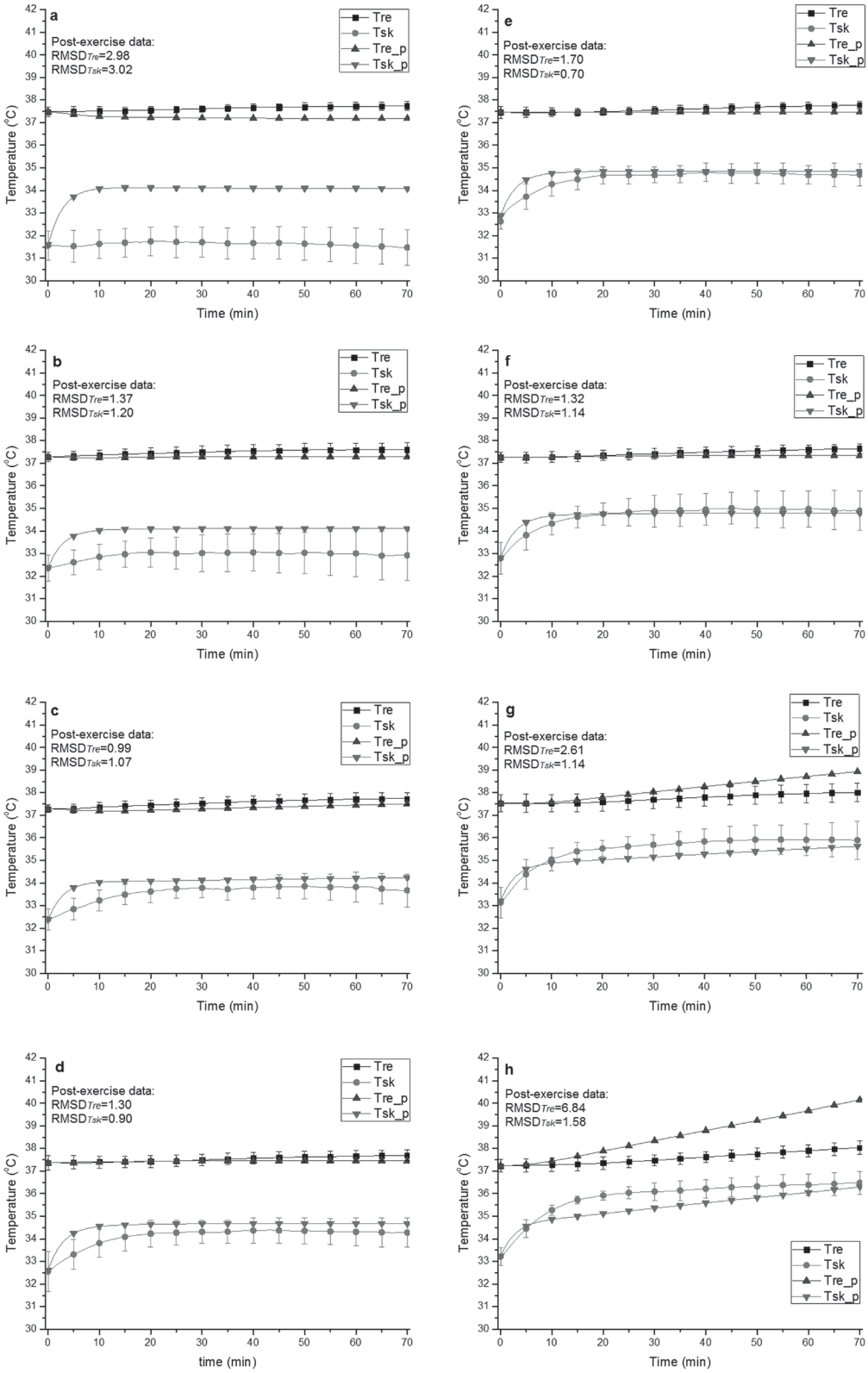

Fig. 1. Predicted and experimental curves of mean skin temperature and rectal temperature.
a) clothing HV in MWH; b) clothing MIL in MWH; c) clothing CLM in MWH; d) clothing L in WMH; e) clothing HV in WMH; f) clothing MIL in WMH; g) clothing CLM in WMH; h) clothing FIRE in WMH; *Tre*, rectal temperature; *Tsk*, mean skin temperature; *Tre_p*, predicted rectal temperature; *Tsk_p*, predicted mean skin temperature. Note: all predictions are one simulation based on the averaged subject data rather than an average of simulations based on individual data.

Table 4. Pre-, post-exercise and predicted post-exercise mean rectal temperature and mean skin temperature (mean ± SD)

Condition	*Tre_pre*	*Tsk_pre*	*Tre_post*	*Tsk_post*	*Trep_post*	*Tskp_post*
HV, MWH	37.48 ± 0.22	31.55 ± 0.64	37.74 ± 0.19	31.47 ± 0.79	37.22 ± 0.17	33.74 ± 0.15
MIL, MWH	37.28 ± 0.30	32.36 ± 0.57	37.61 ± 0.30	32.92 ± 1.12	37.32 ± 0.11	33.76 ± 0.08
CLM, MWH	37.28 ± 0.18	32.38 ± 0.46	37.74 ± 0.28	33.67 ± 0.73	37.68 ± 0.18	33.94 ± 0.13
L, WMH	37.37 ± 0.32	32.55 ± 0.88	37.69 ± 0.24	34.28 ± 0.65	37.46 ± 0.17	34.41 ± 0.10
HV, WMH	37.45 ± 0.27	32.62 ± 0.33	37.78 ± 0.17	34.69 ± 0.50	37.45 ± 0.07	34.47 ± 0.08
MIL, WMH	37.26 ± 0.23	32.79 ± 0.70	37.65 ± 0.21	34.89 ± 0.87	37.44 ± 0.25	34.47 ± 0.18
CLM, WMH	37.53 ± 0.38	33.13 ± 0.67	38.01 ± 0.41	35.89 ± 0.84	39.03 ± 0.46	35.29 ± 0.30
FIRE, WMH	37.23 ± 0.28	33.22 ± 0.38	38.04 ± 0.29	36.48 ± 0.51	39.98 ± 0.46	35.81 ± 0.26

Tre_pre, pre-exercise rectal temperature, °C; *Tsk_pre*, pre-exercise mean skin temperature, °C; *Tre_post*, post-exercise rectal temperature, °C; *Tsk_post*, post-exercise mean skin temperature, °C; *Trep_post*, predicted post-exercise rectal temperature, °C; *Tskp_post*, predicted post-exercise mean skin temperature, °C; Data were presented in mean ± SD.

and rectal temperature points are presented in Fig. 1a–h and Table 4, respectively.

If the predicted data are more than two times higher than the mean standard deviation of the experimental data, which indicates that the prediction fall outside of the 95% of the an average population. It can be seen from Fig. 1a–h that the PHS model demonstrated good performance on predicted skin temperatures in clothing MIL and CLM at both two thermal environments (RMSD<1.2SD). However, there was a large discrepancy between predicted and observed skin temperatures in such light clothing as HV at a high humidity thermal environment (RMSD>3SD), i.e., the MWH condition. The predicted curve on skin temperature showed an initial rise rate that was much greater than the experimental curve at the first 10 min, and then adopted a relatively constant temperature plateau. The predicted post-exercise skin temperature was 2.27°C higher than the experimental value. In MWH, the predicted curves on rectal temperature in clothing MIL and CLM closely followed the observed curves. However, the post-exercise rectal temperature in HV was 0.52°C lower than the observed temperature (RMSD=2.98SD). In WMH, predicted curves on rectal temperature in clothing L, HV and MIL were relatively good (RMSD<2SD). However, the predicted curve in clothing CLM rose above the experimental line after about 45-min exposure. Similarly, the predicted curve on rectal temperature in FIRE stayed above the still rising experimental line after 15 min. Finally, predicted rectal temperatures in clothing CLM and FIRE were 0.92 and 2.12°C higher than observed data (Table 4).

Sweat and evaporation rates

The sweat production rate (g/h) was determined from nude body weight differences between pre- and post-exercise. The evaporation rate was calculated from the weight difference of the human-clothing system before and after each trial. The sweat and evaporation rates in MWH and WMH are presented in Fig. 2a and 2b. The evaporation rate based on the last 40-min data was also presented. The clothing ensemble and testing temperature had significant influence on the sweat rate (p_1<0.01, p_2<0.01). Similarly, the testing temperature also had a significant effect on evaporation rate (p<0.01). However, the clothing ensemble had no significant effect on the evaporation rate (p_1>0.5, p_2>0.5). Predicted sweat rates in clothing MIL, CLM and FIRE at these two environments were significantly greater than observed values (p<0.05). Predicted evaporation rates were significantly underestimated for all test scenarios except clothing L and HV in MWH (p<0.05). Predicted sweat rates in clothing L and HV at two ambient temperatures were in close agreement with our experimental data.

Discussion

Clothing thermal properties and environmental conditions such as insulation, evaporative resistance, and air temperature play an important role in determining human body heat balance. Most vocational ensembles are made to protect the human body against various heat and chemical hazards, they may generate serious ergonomic problems however[18, 19]. The main problem is the added load on the body in terms of weight. A reduction in mobility might also be a problem due to garment's bulkiness, stiffness and fit[4]. In our study, the clothing FIRE (total weight: 6.45 kg) was almost 4 times heavier than clothing L, and twice heavier than clothing CLM. The observed metabolic rate and RPE value in clothing FIRE in WMH increased about 10% (metabolic rate: 15 W·m^{-2}; RPE: 1.6), which made it

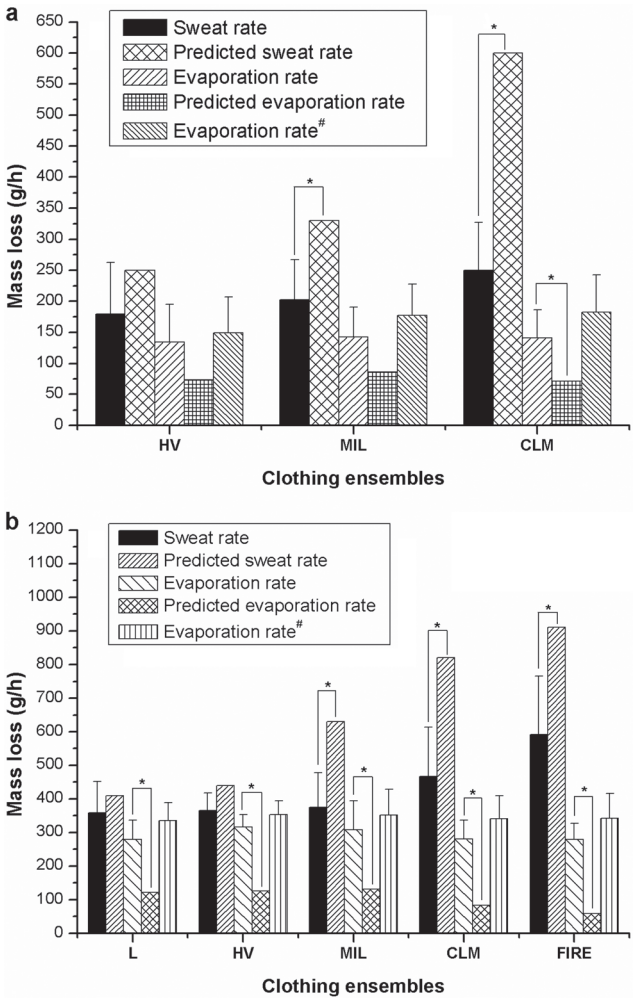

Fig. 2. The observed and predicted sweat rate and evaporation rate. a) MWH; b) WMH; # based on the last 40-min experimental data; *$p<0.05$.

significantly different with other 4 ensembles. This finding reconfirmed the conclusions presented in previous studies by Holmér and Dorman[20, 21].

Yamauchi and Morooka[22] studied the effect clothing humidity on humidity sensation of human subjects. They found that clothing humidity was related more to the comfort feeling than thermal sensation. There was a higher positive correlation between humidity sensation and clothing humidity. In addition, there were significant correlations between humid sensation and some physiological parameters such as heart rate, oral temperature, and mean skin temperature. Fan and Tsang[23] investigated the effect of clothing thermal properties on thermal comfort sensation during active sports. They observed that thermal comfort sensations during active sports were strongly related to the evaporative resistance and moisture accumulation within clothing. In our study, the permeability index of all five ensembles ranged from 0.20 to 0.49. The evaporative resistance of all clothing ensembles ranged from 19.8 to 122.4 $Pa \cdot m^2 \cdot W^{-1}$. Clothing ensembles CLM and FIRE can be classified as low permeable clothing accordingly (the permeability index of typical outdoor 1–2 layer clothing was around 0.38[4]). Therefore, such low permeable clothing could significantly influence human humidity sensation, comfort sensation and thermal sensation.

The post-exercise sweat accumulation inside clothing HV, MIL, and CLM in MWH was 53, 70 and 127 g, respectively (expressed as the percentage of produced sweat: 25.1, 29.6, and 43.6%). Similarly, for all ensembles in WMH, the sweat accumulation was 92, 56, 78, 216 and 364 g (expressed as the percentage of produced sweat: 22.1, 13.5, 17.9, 39.8, and 52.7%), respectively. No difference in sweat accumulation was registered among clothing L, HV and MIL at both two levels of thermal conditions. However, there was a much higher percentage of sweat accumulation inside clothing CLM and FIRE. The high sweat accumulation was directly corresponded to the subjects' skin humidity and comfort sensations.

At a moderate warm condition such as the MWH condition, mean skin temperatures in clothing HV, MIL and CLM were relatively stable during the last 40-min exercise, fluctuating within 0.1°C. With only a short sleeve t-shirt covered the upper body in clothing HV, the thermocouple attached on the left upper arm located close to sleeve opening, which caused the observed skin temperature was much lower than other clothing under the same thermal condition. The rectal temperature increased slightly throughout the exposure in all three ensembles, the increase became slow at the end of each trial, however. For low permeable ensembles CLM and FIRE in WMH, mean skin and rectal temperatures increased continuously with the time course. Therefore, uncompensated body heat strain was widely registered under these scenarios.

Sakoi *et al.*[24] reported the characteristics of the Required Sweat Rate index and pointed out that the multiple regression equation used for skin temperature prediction cannot reflect all heat transfer characteristics. Although some important modifications based on this index have been made in the latest PHS model, our previous study and this study have clearly demonstrated that the model is inapplicable for heavy protective clothing. For high insulation protective clothing and low permeable clothing, the PHS model generated relatively conservative predictions on both evaporation rate and duration limited exposure (DLE) time[25]. Consequently, the worker's productivity

would be highly reduced. In order to maximize the workers' productivity but keep them safe, it is necessary to revise this model and extend its applicability. Although the test scenario HV in MWH is well within the application range of the PHS model, the predictions on mean skin temperature are not reasonable. It seems that the model has a problem in generating mean skin temperature data for people with HV in the MWH condition. The data on CLM in MWH has shown that the PHS model is capable of predicting good results in such moderate warm conditions. However, it is not suggested to run the PHS model for such impermeable clothing. More human validation trials with various protective clothing are greatly needed to extend the application range of the PHS model to include high insulating protective clothing.

Finally, this study has some limitations. First, the initial thermal conditions of the subjects are slightly high. The observed rectal temperatures were well above 36.8°C, while the mean skin temperatures were below 34.1°C. This may influence the evolution of the physiological data during a short exposure time (i.e., 70 min). Second, occupational workers, in real cases, may start their work with various thermal states, which are different from the one assumed in the PHS model. The possibility of changing the initial thermal state of the PHS model needs to be further studied.

Conclusions

We assessed five ensembles on eight unacclimated subjects at two environments: MWH and WMH. Comparisons were made between experimental data and predicted values by the PHS model. It was found that the high insulating protective clothing such as FIRE added both physical and thermal load to the wearers, and thus the reported metabolic rate and subjective sensations were significantly different with other types clothing such as L, HV and MIL. The PHS model presented good performance on mean skin temperatures in MIL and CLM at two tested conditions. However, in the condition MWH, there was a large discrepancy between predicted and observed skin temperatures in light clothing HV. For high insulating clothing such as CLM and FIRE, the predictions put workers on the safe side. It is concluded that the PHS model should be used with caution when running simulations for high insulating or impermeable protective clothing.

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