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Investigation of the compatibility of wet bulb globe temperature (WBGT) and predicted heat strain (PHS) in assessing the environmental conditions and heat load imposed on individuals: a case study in bakery workers

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Abstract

Introduction: This study was designed with the main purpose of examining the compatibility of the two indicators of wet bulb globe temperature (WBGT) and predicted thermal strain (PHS) in assessing the environmental conditions and the heat load imposed on the subjects.

Method: In this cross-sectional study, 163 bakers were included in the study. Thermal stress was determined using the WBGT and PHS. At the same time, physiological responses of subjects were recorded, including tympanic temperature, heart rate and mean skin temperature. Finally, the predicted heat strain was evaluated and compared with actual values.

Results: Based on the results, the WBGT index is accompanied with an underestimation and PHS with an overestimation, compared to the tympanic temperature. In addition, the WBGT index with the core temperature and the predicted rectal temperature component of the PHS index are the most consistent (kappa value of 0.614 and 0.66, respectively). While the Kappa value is between the amount of water lost and the WBGT index, it indicates a mismatch (Kappa = 0.339).

Conclusion: The prediction of heat strains only based on the PHS index cannot reflect the actual heat load on individuals in thermal environments such as bakeries and it is associated with an overestimation. On the other words, this indicator is more suitable for indoor thermal environments, with minimal variation in individual and environmental factors affecting thermal stress.

Key words: Sweating, ear temperature, heat stress, WBGT, PHS

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1. Introduction

Many thermal indices have been introduced and used for many years to evaluate the thermal conditions of work environments and the stresses inflicted on individuals. In spite of the basis of these indices, which can be analytical or empirical, they all seek to combine environmental and individual factors influencing thermal stress to provide values that represent environmental conditions and loads properly. Among the available heat indexes, the International Standard Organization (1) certifies the predicted heat strain (PHS) index, like the wet bulb globe temperature (WBGT) index. This indicator is able to predict the rectal temperature and the amount of sweating and body water lost and determine the allowable time for exposure to heat. However, unlike the WBGT index, the computation is very complex and is not possible without the computer and related software.

Given the necessity of using standard and validated indices to more accurately assess environmental thermal conditions and the limitations and benefits of each of the standard indices, this study aimed to investigate the compatibility of the two heat stress and strain indices, WBGT and PHS. In addition, considering the importance of physiological responses and comparing the values predicted by the PHS index, the actual physiological responses of individuals were also measured directly to compare the actual and predicted heat stress levels.

2. Methods

In this cross-sectional study, 163 bakery workers were selected, taking into account the inclusion and exclusion criteria. The WBGT index was measured in accordance with ISO7243 (2), on hot days of July and August from 10 am to 15 pm. Physiological responses including tympanic temperature, heart rate and mean skin temperature were recorded simultaneously with WBGT measurement. For the purpose of the study, the predicted heat strain index (PHS) was calculated using Malchaire's computational software (3). Inputs of this software include dry temperature, radiant temperature, relative humidity, air velocity, metabolism rate and thermal insulation resistance of clothing which were all entered based on measured data in the work and rest times of the subjects. All predicted values and their interpretation were in accordance with ISO 7933, 2004 (1).

Finally, the predicted heat strains were evaluated based on two important outputs of PHS model including total water loss and rectal temperature. Also, along the comparing the PHS index with the WBGT, the actual and predicted core temperature values were also compared. Descriptive and analytical statistical analyzes were performed by SPSS software version 24 and all analyzes were performed at the significant level of 0.05.

3. Results and discussion

The measured environmental parameters as well as the mean and standard deviation of the WBGT index are shown in Table 1. The correlation between the actual and predicted measured physiological parameters and their relation to the WBGT index is shown in Table 2. As shown in this table, all parameters were significantly correlated with WBGT index, but only the predicted rectal temperature and measured tympanic temperature had acceptable correlation coefficient with this index. In addition, except the two parameters of mean skin temperature and heart rate, other parameters including tympanic temperature, predicted rectal temperature, and amount of water lost had a good correlation coefficient ($r = 0.646$ to $r = 0.947$, $P<0.001$). Therefore, further studies were performed only on these physiological parameters.

Also, according to the WBGT limits, which is itself determined based on the average metabolism, clothing resistance, work and rest schedule and assumed by the workers, and as well as the extent of the permissible strain parameters, the compatibility

Table 1. Measured values of environmental parameters and WBGT index in the workplace (n =163)

	Measured values		
Parameter	**Min**	**Max**	**M± *SD***
Dry temperature (°C)	29.40	47.10	35.91± 3.31
Natural wet temperature (°C)	22.30	35.40	27.22± 2.59
C)°Globe temperature (	30.10	54.70	38.81±5.51
Relative humidity (%)	39.00	58.00	4.33± 52.20
Air velocity (m.S^{-1})	0	0.5	0.1± 0.1
WBGT (°C)	24.27	36.28	29.35± 2.10

Table 2. Relationship between the actual measured physiological parameters with the predicted components of the PHS index and the WBGT index

Physiological Parameter		**WBGT**		**Predicted components of the PHS index**			
		Rectal temperature		**Total water loss**			
		r	**P value**	**r**	**P value**	**r**	**P value**
Measured	Tympanic temperature	0.781	<0.001	0.718	<0.001	0.801	<0.001
	Mean skin temperature	0.418	0.025	0.535	<0.001	0.650	0.004
	Heart rate	0.667	<0.001	0.530	<0.001	0.650	<0.001
Predicted	Rectal temperature	0.845	<0.001	1		0.947	<0.001
	Total water loss	0.646	<0.001	0.947	<0.001	1	

of the indexes was compared and Kappa values were determined separately to show the extent of this compatibility for both studied parameters. These results are presented in Table 3. Accordingly, the WBGT index has most correlation with the tympanic temperature as well as the predicted rectal temperature component of the PHS index (Kappa values of 0.614 and 0.640, respectively). Whereas Kappa value between the amount of water lost and WBGT index indicates inappropriate match (Kappa = 0.339).

In order to better understand the performance of each index, the stress and strain responses to the defined limits for each physiological parameter are shown in Fig. 1

The results show that among the measured physiological parameters, the best correlation coefficient was related to the tympanic temperature (r = 0.781) and WBGT index (Table 3). Other parameters including heart rate and mean skin temperature did not show an acceptable correlation. Many other studies have also shown a greater association of tympanic temperature with heat stress indices, especially with the WBGT index (4-5).

In the present study, it was found that the

Table 3. Examination of WBGT index compliance with predicted components by PHS index and tympanic temperature

Index/ Physiological response		**Predicted components of the PHS index**				**Tympanic temperature**	
		Rectal temperature		**Total water loss**			
		Permissible	**Impermissible**	**Permissible**	**Impermissible**	**Permissible**	**Impermissible**
WBGT	**Permissible**	57	20	28	3	53	24
		86.4%	20.6%	36.3%	3.5%	88.3%	23.3%
	Impermissible	9	77	49	83	7	79
		13.6%	79.4%	63.7%	96.5%	11.7%	76.7%
	p- Value	<0.001		<0.001		<0.001	
	Kappa	0.640		0.339		0.614	

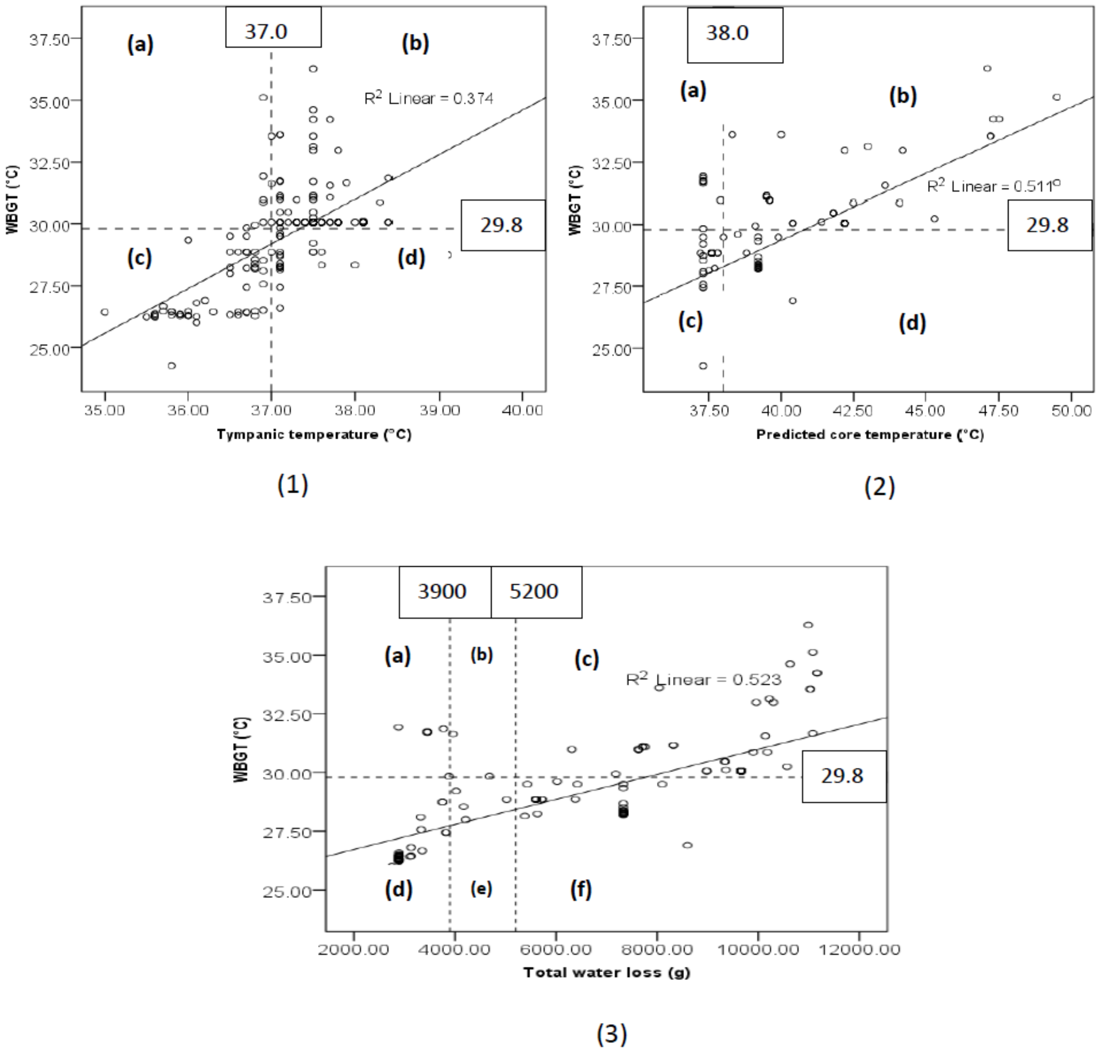

Figure 1. Compliance strain and stress response diagrams based on WBGT index in permissible and impermissible areas

(Diagram 1: Compliance of measured tympanic temperature and WBGT index; a) WBGT is impermissible but tympanic temperature is permissible; b) both of WBGT and tympanic temperature are impermissible; c) both of WBGT and tympanic temperature are permissible; d) WBGT is permissible but tympanic temperature is impermissible ;
Diagram 2: Compliance of predicted core temperature and WBGT index; a) WBGT is impermissible but predicted core temperature is permissible; b) both of WBGT and predicted core temperature are impermissible; c) both of WBGT and predicted core temperature are permissible; d) WBGT is permissible but predicted core temperature is impermissible;
Diagram 3: Compliance of the total water loss and WBGT index: a) WBGT is impermissible but the total water loss is permissible; b) WBGT is impermissible but the total water loss is in caution region; c) both of WBGT and the total water loss are impermissible; d) both of WBGT and the total water loss are in permissible regions; e) WBGT is permissible but the total water loss is in caution region; f) WBGT is permissible but the total water loss is impermissible).

predicted rectal temperature component of PHS showed the best agreement with WBGT index (Kappa = 0.640, p <0.001) and agreement of WBGT with measured tympanic temperature was acceptable (kappa = 0/614, p <0.001). Similar results can be found in Monazzam et al. (7). However, the lowest coefficient of agreement was observed between water lost component of PHS index and WBGT (Kappa = 0.339, p <0.001). Therefore, it can be expressed that the rectal temperature compared to the water lost, can be better predictor for tympanic temperature. In other words, it can represent the actual thermal strain inflicted on the individual better than water lost (8).

In addition, when the WBGT index was higher than the permissible limit, 77 individuals (79.4%) had a core temperature higher than normal temperature. This value was 83 (96.5%) for the lost water and 79 (76.7%) for the measured tympanic temperature.

4. Conclusion

In general, the results of this study show that although at first glance the WBGT index is more sensitive than the PHS index, but by examining the components of the PHS index it is determined that based on the predicted core temperature, the results of PHS index compared to the WBGT index are accompanied with an underestimation. However, based on another PHS component, total water lost, the results are reverse. Therefore, in order to better judge the thermal conditions of work environments, it is advisable to measure the tympanic temperature along with heat stress measurements using WBGT and PHS due to the stronger relationship between the tympanic temperature and the thermal indices than the water lost.

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