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A Body Characteristic Index to Evaluate the Level of Risk of Heat Strain for a Group of Workers With a Test

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*The purpose of this study was to develop a body characteristic index (*BCI*) based on the distribution of maximal oxygen uptake per body mass (V_{O2max}/mass), body surface area per body mass (BSA/mass), and percentage of body fat (Fat%) to evaluate the relative level of individual physiological responses to heat strain in a group of workers.* BCI *was based upon the data obtained from 10 males and 10 females exercising for 60 min on a treadmill at 2 relative exercise intensities of 25% and 45%* V_{O2max} *in mild, warm wet, and hot dry climate condition, separately.* BCI *was developed into 2 formulas, which were proved to be better predictors for heat strain responses than each individual characteristic, and more sensitive than body type to describe the distributions of individual characteristics and distinguish the differences in physiological responses to heat.*

heat environment physical fitness anthropometric characteristic index heat strain

1. INTRODUCTION

The heat environment at present is very common in industrial, military, and other occupational fields [1, 2]; it leads to a variety of heat-related disorders for workers, e.g., heat cramps, heat syncope, heat stroke, and heat exhaustion [3]. Much effort has been invested in attempts at evaluating heat strain imposed on bodies. So far, dozens of indexes for evaluating heat strain have been developed. They can be divided into three categories: direct, rational, and empirical indexes [4]. First, direct indexes, whose calculation is the simplest of the three, are based on environmental variables, e.g., ambient temperature, wet bulb temperature, black-globe temperature, and wet bulb globe temperature (*WBGT*) [5]. Direct indexes are usually used to evaluate the risk level of heat strain in a given set of environmental conditions. The original application of direct indexes is traced to Haldane (1905) (as cited in Moran, Pandolf, Shapiro, et al. [6]), who suggested an index based on the wet bulb thermometer for heat load. Later, in 1916, Hill, Griffith, and Flack developed the kata-thermometer [7] and, in 1923, Houghten and Yaglou developed the effective temperature (*ET*) index [8]. On the basis of the *ET* index, in 1957, Yaglou and Minard (as cited in Moran, Shitzer, Epstein, et al. [9]) developed the *WBGT* index based on psychrometric wet bulb temperature. The convenience of the *WBGT* was later enhanced and gained popularity. The *WBGT* is obtained mainly from three parameters: black globe temperature (T_g), wet bulb temperature (T_w), and dry bulb temperature (T_a). Calculating the *WBGT* involves measuring T_g and T_w, whose inconvenience of measurement still limits the evaluation of heat stress. In 1959, Thom from the *U.S.* Weather Bureau (as cited in Epstein and Moran [4]) developed the discomfort index (*DI*) based only on dry and wet bulb temperatures. In 2001, Moran et al. used more advanced statistical analysis to develop a modified version of *DI* and a modified discomfort index (*MDI*) [6]. In 2001, Moran et al. introduced a new environmental stress index (*ESI*) developed

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from measurements of T_a, relative humidity (*RH*), and solar radiaton (*SR*) [6]. The *ESI* was validated with large databases and found to be highly correlated with the *WBGT* index. In 2005, Wallace, Kriebel, Pennett, et al. suggested the wet-bulb dry temperature (*WBDT*) index and the relative humidity (*RHDT*) index on the basis of cumulative daily average *WBGT* index to predict exertional heat illness (*EHI*) risk [10].

The second most comprehensive indexes, rational indexes, are based on a heat balance equation; they integrate all environmental and behavioral parameters, i.e., heat storage rate, external work rate, metabolic rate, convective heat exchange, radiant heat exchange, convective heat exchange, respiratory heat exchange, and evaporative heat loss [11]. There exist some models of rational indexes, such as predicted 4-h sweat rate developed by McArdle et al. in 1947 (as cited in Moran, Shitzer, and Pandolf [5]), the heat stress index (*HSI*) suggested by Belding and Hatch in 1955 [12], predicted sweat rate also developed by Belding and Hatch in 1955 [12], and the physiological heat strain prediction model by McPherson in 1992 (as cited by Gallagher, Robertson, Goss, et al. [11]). It is assumed that lack of technology prohibits the assessment of the integration of all the environmental and behavioral variables [11]. Moreover, the calculation of the rational indexes is more complex than the other two categories.

Finally, empirical indexes are based on objective and subjective strain. Considering that the physiological strain is time-dependent and nonlinear in nature, and that end-point values or the changes from baseline cannot measure the dynamic changes, Frank, Moran, Epstein, et al. suggested a cumulative heat strain index (*CHSI*) in 1996 [13]. The *CHSI* is based on core temperature (T_c) and heart rate (f_c), but the former is a combination of thermoregulatory strain described by the area under the curve of temperature changes during exposure, and the latter is the cardiovascular cost characterized by heart beat count. In terms of the physiological cost of external stress, the *CHSI* can access total physiological strain. The best known of empirical indexes is the physiological strain index (*PSI*) introduced by Moran et al. in 1998 [5], which is easier to interpret and to use than the *CHSI*. The *PSI* is based on the summation in equal weights of individual strains for core temperature (T_c) and heart rate (f_c); it has been widely used in recent years. In 2011, Gallagher, et al. developed a perceptual hyperthermia index (*PHI*) to evaluate heat strain during treadmill exercise; it can easily and quickly assess the level of risk for exertional heat stress [11]. However, all these indexes were developed based on environmental parameters and physiological parameters without involving human individual characteristics.

According to many researchers, human heat strain responses are influenced by ambient environment, workloads, and clothing ensembles as well as individual characteristics, e.g., physical fitness, somatotype, and gender [14, 15, 16, 17]. Most individual characteristics make significant contributions to the variance of physiological responses to heat exposure. Previous studies have confirmed that physical fitness described by maximal oxygen uptake (V_{O2max}) or maximal oxygen uptake per body mass (V_{O2max}/mass) produces evident effects on physiological responses. Havenith, Coenen, Kistemaker, et al. conducted a series of human experiments, which proved a positive relation between V_{O2max} and core temperature (T_{co}), skin temperature (T_{sk}), and heat storage [18]. They found that V_{O2max} made a major contribution to heart rate (*HR*) compared to other characteristics. In addition, aerobic capacity can be changed by a heat acclimation program. Gagnon, Jay, Lemire, et al. found that if aerobic trained subjects had a higher workload than untrained ones when exercising at the same relative intensity ($\%V_{O2max}$), they generated more metabolic heat [19]. Mora-Rodriguez, Coso, Hamouti, et al. found that aerobic trained subjects had greater increases in rectal temperature than untrained ones during exercise in the heat environment at similar relative intensities [20]. Besides improving V_{O2max}, aerobic training also increases heat dissipation by increased skin vasodilation and sweating [21].

Anthropometric characteristics have also been confirmed to make additional contributions [18, 22, 23, 24]. Coso, Hamouti, Ortega, et al. concluded that T_{co} negatively related to body mass and body surface area (*BSA*), and that a large body size was beneficial to reducing body temperature [24].

Havenith et al. conducted experiments in multiple conditions and found positive relations between T_{co} and *BSA*/mass in warm humid, mild, and hot dry climates, which implies that humans with larger *BSA*/mass in the heat will be imposed with greater relative heat load from the ambient environment [18]. In addition, *Fat%* also makes positive contributions to the variance of T_{co} [23] and T_{sk} [25]. As confirmed by Dougherty, Chow and Kenney, obese subjects indicate significantly higher baseline T_{co} and a slower rate of reduction in T_{co} and *HR* than lean ones during 6 days of acclimation training [26].

Most of the studies discussed in this section were conducted to find out the most effective individual characteristic. However, they analyzed the effects of anthropometric variability separately, and failed to integrate them. Yokota, Berglund, and Bathalon [17] and Yokota, Bathalon, and Berglund [27] identified five major somatotypes through anthropometric distribution for height, weight, and *Fat%* in both males and females, and concluded the different tolerance levels to heat strain among somatotypes: fat individuals tended to have higher T_{co} than medium ones, and lean ones maintained lower T_{co} than medium ones. Nevertheless, physical fitness was not considered and the classification of somatotypes was only based on body size (height, weight, and *Fat%*) without involving the different effects of body characteristics.

The purpose of this study is to develop an integrative index, the body characteristic index (*BCI*), based on the distribution of related individual characteristics among a group of people. This index is capable of evaluating the relative level of individual physiological heat strain in this group. *BCI* is expected to be more sensitive to distinguishing the differences of human physiological responses than a single individual characteristic or the body type clustered based on both physical fitness and anthropometric distribution.

2. METHODS

2.1. Subjects

Ten male and 10 female university students with the heterogeneous somatotype and different aerobic fitness volunteered to participate in the heat exposure experiment. No subjects were trained for heat acclimation before the beginning of the experiment. After signing a consent form, each subject underwent a physical test for cardiovascular function with a progressive treadmill exercise. The subjects were informed of all details associated with possible risk and discomfort during the experiment. During the experiment, the subjects were required to wear cotton vests, short trousers, sport socks, and shoes. The total clothing thermal resistance was 0.2 clo.

2.2 Experimental Design

This experiment was conducted in a climate chamber of 5 m × 4 m × 3 m (length × width × height). The chamber can modulate indoor temperature from –20 °C to 85 °C, and relative humidity (*RH*) from 20% to 98%. All subjects were asked to exercise at a relative exercise intensity of 25% and 45% V_{O2max} in a mild (26 °C, 50% *RH*), warm wet (32 °C, 80% *RH*), and hot dry (40 °C, 30% *RH*) environment, separately. The metabolisms of these two exercises intensities were equal to the medium and high metabolic rate classified by American Conference of Governmental Industrial Hygienists [28]. To avoid heat acclimation, all six conditions were performed in random order.

Seven days prior to the experiment, the subjects were required to live with a normal schedule and keep in a good medical condition. Alcohol and drugs were forbidden in the 24 h before the experiment. After a 30-min rest in a buffer room at 26 °C and 50% *RH*, the subjects stepped into the chamber and adapted to the experimental climate environment for 5 min. Then, the 60-min exercise on a treadmill started (Figure 1). The subjects were not allowed to break off before the scheduled 60 min unless their T_{co} reached 38.5 °C, *HR* exceeded 180 beats/min for 3 consecutive minutes, or they felt exhausted.

2.3. Measurements

2.3.1. Anthropometric Characteristics

Before the exposure, the subjects' height, weight, and four skinfold thicknesses at biceps, triceps, subscapular, and supra-iliac were measured three

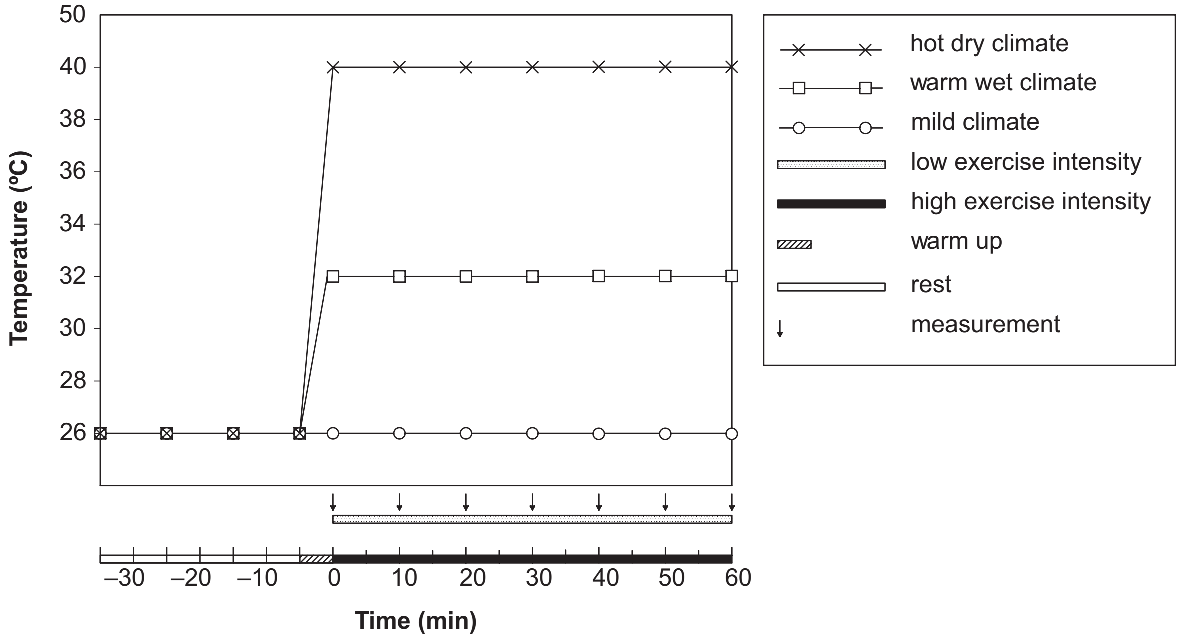


Figure 1. The experiment protocols.

times at the same time on three consecutive days. The average measurement to calculate *BSA* was developed with Du Bois and Du Bois's method [29], and *Fat%* with Durnin and Womersly's method [30].

2.3.2. V_{O2max}

Three days prior to the exposure, the individual V_{O2max} of all subjects was measured with a continuously increasing load test on a treadmill in the mild climate. Before the test, the subjects were requested to warm up for 5 min; then there was a short recovery. The initial slope and speed of the treadmill was set to 0% and 9.6 km/h, respectively. When the test began, the slope was increased by 2% every 2 min. The test duration was narrowed to 15 min. When the subjects engaged in exercise in the chamber, their expiratory gas was collected continuously into a breathing mixing chamber with a respiratory mask. The chamber was connected to a PowerLab gas analyzer (ADInstruments, Australia), which analyzed the gas collected and recorded oxygen uptake (V_{O2}), respiratory quotient, and respiratory rate every 15 s. As the exercise proceeded, physiological traits gradually appeared: the respiratory quotient exceeded 1.1; the difference of respiratory rate fell below 150 ml/min; V_{O2} reached the highest level for several seconds and then declined. When two of those conditions were met, the test was terminated and the highest recorded V_{O2} was defined as V_{O2max}.

2.3.3. Physiological responses

During the exposure, T_{co} and *HR* were recorded at an interval of 10 min. The oral temperature was selected as the indicator of T_{co} and measured with PowerLab data acquisition systems (ADInstruments, Australia) according to Standard No. ISO 9886:2004 [31] by placing a thermistor probe under the tongue, at the side close to the base of the tongue. To avoid the influence of ambient air, the mouth remained closed before and throughout the duration of measurement for 3–5 min. The subjects were also required to keep the mouth closed as much as possible when exercising. *HR* was measured with an automatic sphygmomanometer (HEM-7112; Omron, Japan) on the upper right hand.

2.4 Statistical Analysis

The test data were calculated as *M* (*SD*). Then the multiple regression analysis was applied and standardized regression coefficients [18] were used to express the effects of independent parameters

(*BSA*/mass, *Fat%*, etc.) on dependent variables (ΔT_{co}, sum of increased T_{co} recorded over the whole exercise at 25% and 45% V_{O2max}; ΔHR, sum of increased *HR* recorded over the whole exercise at 25% and 45% V_{O2max}), and to determine the parameters' coefficients of *BCI*. All statistical significance was set at the level of $p \leq .05$, and the statistical contrasts were regarded as a trend at the level of $.05 < p < .1$. All analyses were performed with SPSS 19.0 for Windows.

3. RESULTS

3.1. Body Type Analysis

Table 1 summarizes the aerobic capacity and anthropometric characteristics obtained of all subjects.

TABLE 1. The Individual Characteristics of All Subjects

Parameters	*M* (*SD*)
Age (years)	23.53 (0.84)
Height (cm)	167.08 (7.94)
Mass (kg)	61.75 (14.04)
BSA (m^2)	1.69 (0.21)
Fat% (%)	23 (6)
V_{O2max} ($L \cdot min^{-1}$)	3.88 (1.23)

Notes. *BSA* = body surface area; *Fat%* = percentage of body fat; V_{O2max} = maximal oxygen uptake.

3.2. Determination of *BCI*

3.2.1. Correlation analysis

To obtain a general understanding about the inner correlations of individual characteristics, as well as the relative effects on ΔT_{co} and ΔHR, a correlation analysis was carried out. Table 2 shows that

TABLE 2. Correlations Between Individual Characteristics and Physiological Responses and Inner Correlations Among Individual Characteristics

Climate	Responses	Mass	V_{O2max}	V_{O2max}/mass	*BSA*	*BSA*/mass	*Fat%*
Mild	ΔT_{co}	−.276	−.003	.445*	−.257	.446	−.087
		(.239)	(.990)	(.050)	(.274)	(.076)	(.723)
	ΔHR	−.592**	−.373	.198	−.622**	.626**	.319
		(.006)	(.106)	(.403)	(.003)	(.003)	(.184)
Warm wet	ΔT_{co}	−.408	.018	.559**	−.432	.497*	−.445
		(.074)	(.940)	(.010)	(.051)	(.036)	(.064)
	ΔHR	−.194	.239	.669**	−.286	.478*	.425
		(.412)	(.309)	(.001)	(.222)	(.045)	(.079)
Hot dry	ΔT_{co}	−.317	.013	.468*	−.363	.470*	.144
		(.173)	(.955)	(.037)	(.116)	(.049)	(.558)
	ΔHR	−.054	.144	.292	−.086	.213	.173
		(.822)	(.543)	(.212)	(.718)	(.381)	(.480)
	mass		.790**	.019	.982**	−.979**	−.039
			(.000)	(.937)	(.000)	(.000)	(.871)
	V_{O2max}			.622**	.777**	−.804**	−.290
				(.003)	(.000)	(.000)	(.215)
	V_{O2max}/mass				.010	−.063	−.440*
					(.965)	(.793)	(.050)
	BSA					−.943**	−.093
						(.000)	(.697)
	BSA/mass						.015
							(.950)

Notes. * significantly correlated at $.01 < p \leq .05$; ** significantly correlated at $p \leq .01$; V_{O2max} = maximal oxygen uptake; V_{O2max}/mass = maximal oxygen uptake per body mass; *BSA* = body surface area; *BSA*/mass = body surface area per body mass; *Fat%* = percentage of body fat; ΔT_{co} = sum of increased core temperature recorded over the whole exercise at 25% and 45% V_{O2max}; ΔHR = sum of increased heart rate recorded over the whole exercise at 25% and 45% V_{O2max}; data in parenthesis represent significant correlation.

V_{O2max} had no significant correlations with ΔT_{co} and ΔHR in all climate conditions, while V_{O2max}/mass correlated well with all except with ΔHR in the mild and hot dry climates. Mass and *BSA* had similar effects on ΔT_{co} and ΔHR in the same conditions. *BSA*/mass produced a more significant effect on ΔT_{co} and ΔHR in the warm wet environment, and ΔT_{co} in the hot dry environment. *Fat%* tended to correlate negatively with ΔT_{co} but positively with ΔHR in the warm wet climate.

3.2.2. Multiple regressions

Table 3 presents multiple regression coefficients of climate and individual characteristics to predict physiological responses. Climate was introduced into the regression equations first, as it had been confirmed to produce significant effects [23]. In consideration of the inner correlations and relative relations to ΔT_{co} and ΔHR, V_{O2max}/mass, *BSA*/mass, and *Fat%* among individual characteristics were introduced into the regression equations. The inner correlation between V_{O2max}/mass and *Fat%* was neglected when *Fat%* represented body adiposity. All three characteristics made positive contributions in both ΔT_{co} and ΔHR. The explained variance of ΔT_{co} added up to 83.3%, slightly more than ΔHR (R^2_{adj} = .819).

As a new body characteristic index, *BCI* integrates the various individual characteristics in combination with their relative effects on heat responses of ΔT_{co} and ΔHR. In this design, V_{O2max}/mass, *BSA*/mass, and *Fat%*, which depicted physical fitness and anthropometric characteristics, were assigned different weight determined by the standardized regression coefficients. Table 4 lists the standardized regression coefficients of V_{O2max}/mass, *BSA*/mass, and *Fat%*, which reflect the relative effects on ΔT_{co} and ΔHR. It is assumed that the total variance of ΔT_{co} explained by V_{O2max}/mass, *BSA*/mass, and *Fat%* is 10. When *BCI* is applied to evaluate ΔT_{co}, V_{O2max}/mass explains half of the total, *BSA*/mass explains 30%, and *Fat%* explains 20%. The assigned weights of V_{O2max}/mass, *BSA*/mass, and *Fat%* are 5, 3, 2, respectively. In the same vein, when *BCI* is applied to evaluate ΔHR, the assigned weights are 4, 3, 3, respectively. To set the average to be the reference point, and eliminate different dimension among the related characteristics, each related characteristic is adjusted by *M* and *SD* (Equations 1–2).

For evaluating ΔT_{co}, BCI_{Tco} is calculated as follows:

TABLE 4. Weighting Coefficients of V_{O2max}/mass, BSA/mass, and Fat% in Body Characteristic Index (*BCI*) Determined by Standardized Regression Coefficients of ΔT_{co} and ΔHR

Parameter	Standardized Regression Coefficients	Weighting Coefficients
ΔT_{co}		
V_{O2max}/mass	.295	5
BSA/mass	.178	3
Fat%	.116	2
ΔHR		
V_{O2max}/mass	.319	4
BSA/mass	.219	3
Fat%	.210	3

Notes. ΔT_{co} = sum of increased core temperature recorded over the whole exercise at 25% and 45% V_{O2max}; V_{O2max} = maximal oxygen uptake; V_{O2max}/mass = maximal oxygen uptake per body mass; *BSA*/mass = body surface area per body mass; *Fat%* = percentage of body fat; ΔHR = sum of increased heart rate recorded over the whole exercise at 25% and 45% V_{O2max}.

TABLE 3. Multiple Regression Coefficients of Climate and Certain Individual Parameters

Parameter	Constant	Climate	V_{O2max}/mass	*BSA*/mass	*Fat%*	R^2_{adj}
ΔT_{co}	–8.364	0.165	27.737	70.577	2.300	.833
ΔHR	–193.605	3.638	809.402	2837.676	119.772	.819

Notes. ΔT_{co} = sum of increased core temperature recorded over the whole exercise at 25% and 45% V_{O2max}; ΔHR = sum of increased heart rate recorded over the whole exercise at 25% and 45% V_{O2max}; V_{O2max} = maximal oxygen uptake; V_{O2max}/mass = maximal oxygen uptake per body mass; *BSA*/mass = body surface area per body mass; *Fat%* = percentage of body fat; R^2_{adj} = R^2 adjusted for the number of cases and the number of parameters.

$$BCI = 5\,\frac{V_{O2max}/mass - M\,(V_{O2max}/mass)}{SD\,(V_{O2max}/mass)} + 3\,\frac{BSA/mass - M\,(BSA/mass)}{SD\,(BSA/mass)} + 2\,\frac{Fat\% - M\,(Fat\%)}{SD\,(Fat\%)}, \quad (1)$$

where BCI = body characteristic index, V_{O2max} = maximal oxygen uptake, V_{O2max}/mass = maximal oxygen uptake per body mass, BSA = body surface area, BSA/mass = body surface area per body mass, $Fat\%$ = percentage of body fat.

For evaluating ΔHR, BCI_{HR} is calculated as follows:

$$BCI = 4\,\frac{V_{O2max}/mass - M\,(V_{O2max}/mass)}{SD\,(V_{O2max}/mass)} + 3\,\frac{BSA/mass - M\,(BSA/mass)}{SD\,(BSA/mass)} + 3\,\frac{Fat\% - M\,(Fat\%)}{SD\,(Fat\%)}, \quad (2)$$

where BCI = body characteristic index, V_{O2max} = maximal oxygen uptake, V_{O2max}/mass = maximal oxygen uptake per body mass, BSA = body surface area, BSA/mass = body surface area per body mass, $Fat\%$ = percentage of body fat.

Figure 2 shows the unary linear regression modules of BCI and heat responses in the different climate conditions. For ΔT_{co}, BCI_{Tco} explains over 60% of the variance, especially in the hot dry climate condition (R^2 = .705). For ΔHR, BCI_{HR} explains a similar percentage of the variance. The maximum value of the two equations exists in the mild climate condition (R^2 = .712).

4. DISCUSSION

4.1. Physiological Responses

In this study, increased T_{co} or HR in the exercise intensity at 25% V_{O2max} and 45% V_{O2max} in each climate condition were added up, and selected to be the dependent variables instead of increased T_{co} or HR. In this approach, the influence of

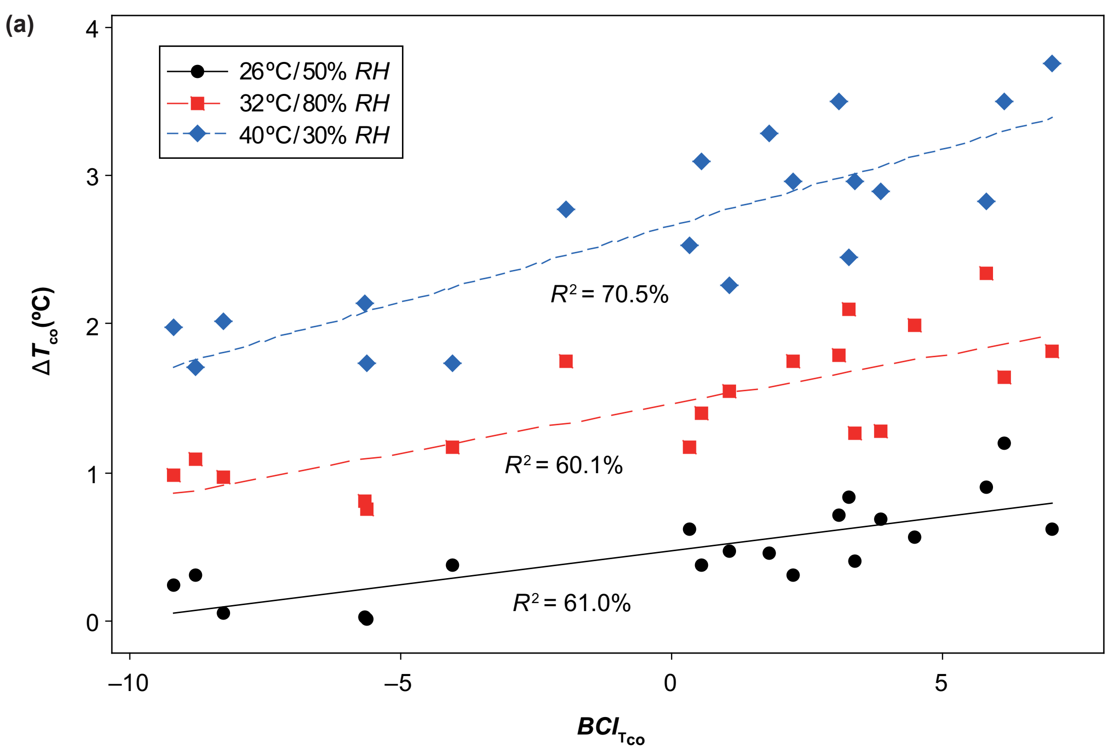


Figure 2. The regression line of (a) BCI_{Tco} and ΔT_{co} in each climate condition; (b) BCI_{HR} and ΔHR in each climate condition. *Notes.* BCI = body characteristic index; ΔT_{co} = sum of increased core temperature recorded over the whole exercise at 25% and 45% V_{O2max}; ΔHR = sum of increased heart rate (HR) recorded over the whole exercise at 25% and 45% V_{O2max}; V_{O2max} = maximal oxygen uptake; RH = relative humidity (RH). BCI_{Tco} = BCI applied to evaluate ΔT_{co}, BCI_{HR} = BCI applied to evaluate ΔHR.

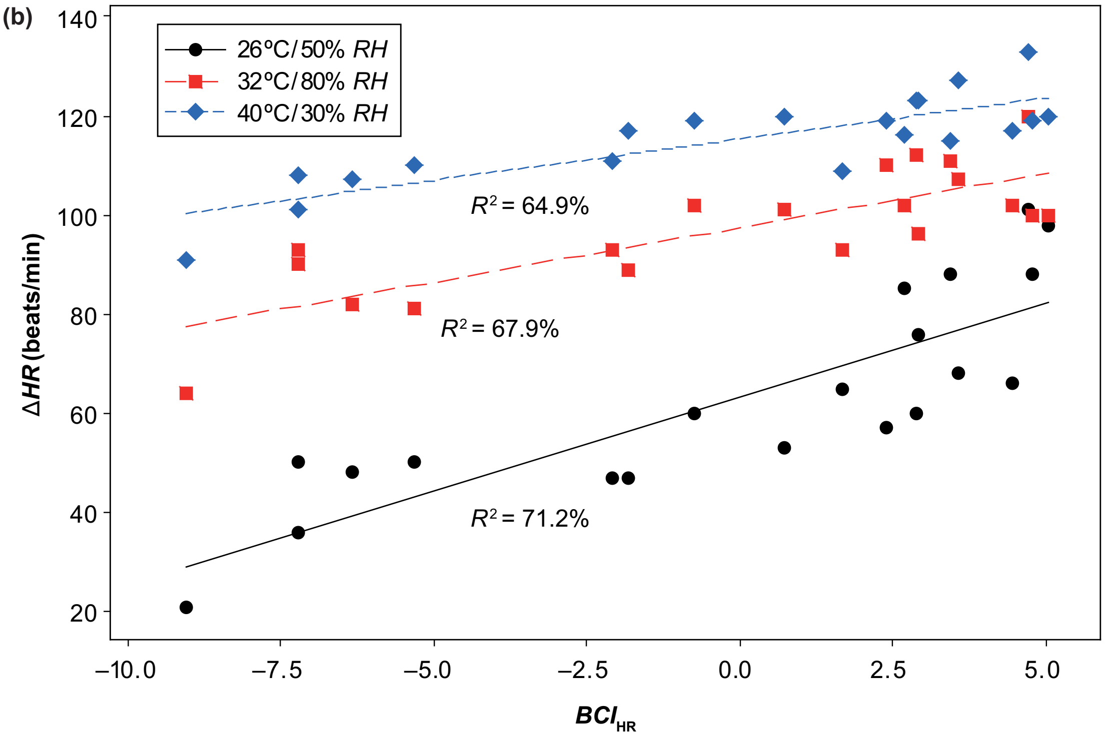


Figure 2. (*continued*)

exercise intensity was eliminated and the influential parameters were reduced.

4.2. *BCI*

BCI is a new index for evaluating individual heat response according to the change in T_{co} and *HR* with the distributions of individual characteristics among a group. This index is different from other approaches that have been developed in the past. This can be justified by the following: first, the calculation of direct indexes based on environmental variables usually involves measuring environmental parameters, e.g., black globe temperature (T_g), wet bulb temperature (T_w), and dry bulb temperature (T_a). For example, the *WBGT* adopted by many organizations (e.g., World Health Organization, U.S. National Institute for Occupational Safety and Health, and International Organization for Standardization) is based on only three environmental parameters. However, the *WGBT* is limited to assessing heat strain because measuring black globe temperature (T_g) and wet bulb temperature (T_w) is inconvenient and simply not practical under many conditions. Recently, it has been suggested that, with the present knowledge, the discomfort index (*DI*), whose correlation to sweat rate both at rest and under exercise reflects its physiological significance, is a more universal heat stress index [4]. The *DI* is expressed in discomfort units (*DU*) and its application may be limited in some conditions. Compared to direct indexes, this index is environment independent; its calculation is based on V_{O2max}/mass, *BSA*/mass, and *Fat%*, and measuring those parameters is easy and convenient.

Second, compared with rational indexes, the calculation of the index is easier to obtain with fewer variables. As a model of rational indexes, the *HSI* [12] has been proved to be meaningful but of limited application. The *HSI* is based on multiple components and calculations, and involves over 15 variables, which involve complex calculations and possible numerous errors. Moreover, the *HSI* is limited to evaluating heat strain in hot dry climate conditions, when subjects wear protective clothing. On the other hand, the new index *BCI* can be used in any conditions and its calculation involves fewer variables. Thus, the number of sources of error can be decreased.

Last, the physiological strain index (*PSI*) introduced by Moran et al. in 1998 [5] is the best known of empirical indexes, which are based on objective and subjective strain [6]. The *PSI* originated from online calculations at different time intervals, calculated when subjects were exposed to stress. The limitation is that when exposed to heat stress, the subjects may suffer great physical and mental damage. So, *PSI* is of limited value, when used to assess the risk level of heat strain. Furthermore, the participating subjects in the study of the *PSI* were young men, and some researchers had shown that the general population of middle-aged men and women showed less tolerance to heat stress than younger men, and the application of the *PSI* may be limited to women and different age groups. In 2011, the perceptual hyperthermia index (*PHI*) was introduced [11]; it can assess heat stress easily and quickly, but the application of the *PHI* is limited to firefighters. Unlike the *PSI*, which is used to assess the risk level of heat strain, this novel index is computed from the body characteristic parameters of each subject and it is not necessary to worry about the damage suffered from heat stress. Thus, this index can be applied to common people.

This index is based on V_{O2max}/mass, *BSA*/mass, *Fat%*, and somatotypes, which depict the individual aerobic fitness and body size. The weighting functions of all parameters in the *BCI* are determined by their contributions to the variance of ΔT_{co} and ΔHR during heat exposure. The effects of individual characteristics on ΔT_{co} are different from those on ΔHR, which entail two forms. *BCI* includes two forms. In this approach, V_{O2max}/mass, *BSA*/mass and *Fat%* were assigned weighting coefficients of 5, 3, 2 for BCI_{Tco} and 4, 3, 3 for BCI_{HR}, respectively. This index sets the average V_{O2max}/mass, *BSA*/mass, and *Fat%* among all subjects as the reference point with 0 as the value. If *BCI* is over 0, *BCI* has positive contributions to the variance of ΔT_{co} and ΔHR, whereas contributions are negative if *BCI* is under 0. Subjects with higher *BCI* are predicted to indicate higher ΔT_{co} or ΔHR. Figure 2 illustrates the unary linear regression modules of *BCI* and heat responses in each climate condition. *BCI* explains over 60% of the total variance in ΔT_{co} and ΔHR in each climate condition. The contributions of *BCI* in this study reach the total explained variance of T_{co} and *HR* attributed to the various individual characteristics in Havenith, Luttikholt, and Vrijkotte's study [25], where the individual characteristics explain 34%–65% of the total variance in ΔT_{co} and ΔHR [25]. Hence, the capability of the *BCI* predicts ΔT_{co} and ΔHR during heat exposure relatively reliably.

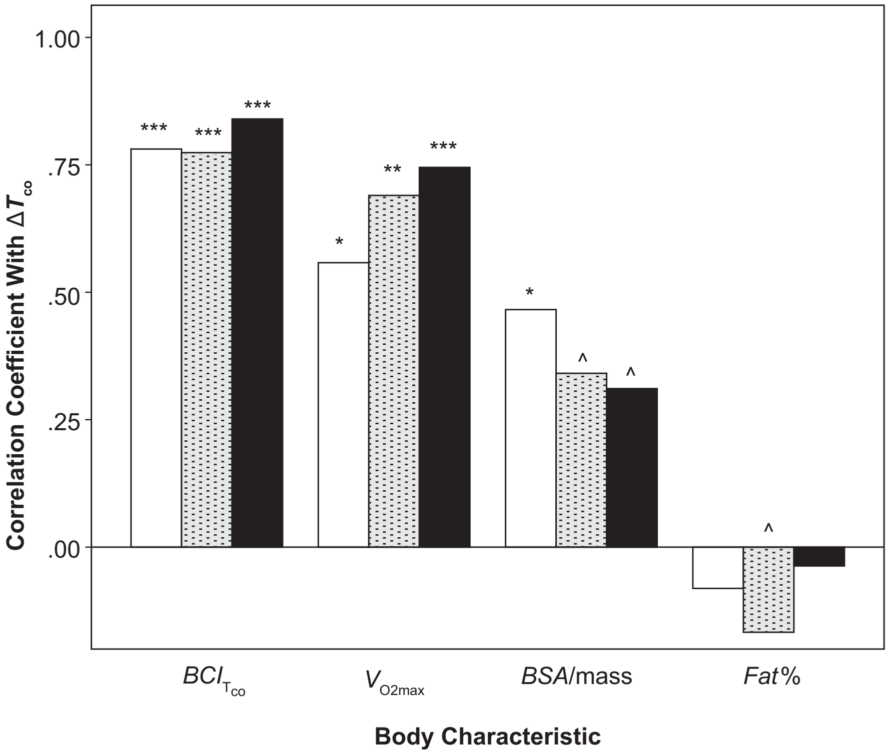
4.3. *BCI* and Individual Characteristics

The relative effects of individual characteristics on heat responses, e.g., T_{co}, *HR*, heat storage, have been confirmed and widely accepted [18, 23, 24, 25]. Thermoregulation and cardioregulation of human beings are influenced by several individual characteristics. *BCI* is designed to integrate three related representative characteristics, which produce effects on thermoregulation and cardioregulation.

In this study, the Pearson correlation analysis was applied to compare relative effects of *BCI*, V_{O2max}/mass, *BSA*/mass, and *Fat%* on ΔT_{co} and ΔHR in different climate conditions (Figure 3). Among the individual characteristics, V_{O2max}/mass explains the most variance of ΔT_{co} and ΔHR, in all climate conditions except mild climate, and *BSA*/mass contributes the most variance of ΔHR. As discussed in previous studies [23, 24, 25], during heat exposure, subjects with a high V_{O2max}/mass generate a large heat production at the same relative intensity, and individuals with a larger *BSA*/mass are at an advantage as heat transits to the ambient environment mainly through evaporation and convection. The significant correlations between ΔT_{co} and ΔHR for *Fat%* disappeared in this study, which is different from the findings of Haymes, McCormick, and Buskirk [32]. This may be due to the interaction between *Fat%* and V_{O2max}/mass (Table 2). For example, subjects with high V_{O2max}/mass but low *Fat%* tend to have similar ΔT_{co} to those with low V_{O2max}/mass but high *Fat%*.

Figure 3 shows that BCI_{Tco} and BCI_{HR} are correlated with ΔT_{co} and ΔHR at the significant level of $p < .001$ in all climate conditions. The significance of the correlations between physiological responses and individual characteristics tended to eliminate, especially in the correlations between

(a)



(b)

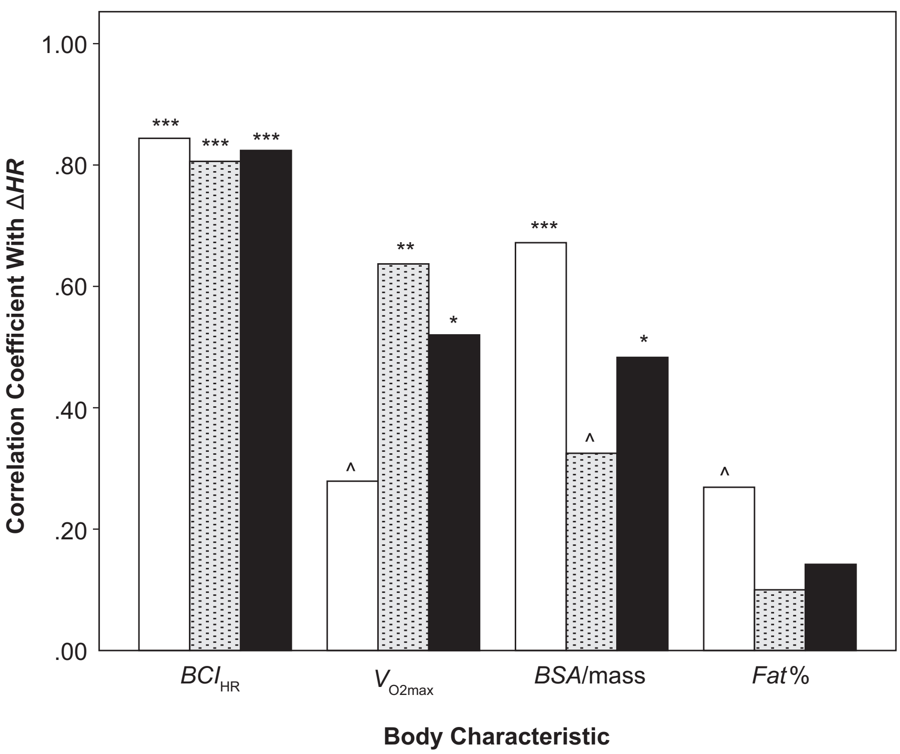


Figure 3. Comparisons of the contributions of body characteristic index (*BCI*) with those of individual characteristics, including V_{O2max}/mass, *BSA*/mass, and *Fat*%, in mild climate (open bars), warm wet climate (dotted bars), hot dry climate (full bars); (a) ΔT_{co} , (b) ΔHR. *Notes*. * significantly correlated at $.01 < p \leq .05$; ** significantly correlated at $.001 < p \leq .01$; *** significantly correlated at $p \leq .001$; ^ = tend to correlate at $.05 < p \leq .1$; ΔT_{co} = sum of increased core temperature recorded over the whole exercise at 25% and 45% V_{O2max}; ΔHR = sum of increased heart rate (*HR*) recorded over the whole exercise at 25% and 45% V_{O2max}; V_{O2max}/mass = maximal oxygen uptake per body mass; *BSA*/mass = body surface area per body mass; *Fat*% = percentage of body fat; V_{O2max} = maximal oxygen uptake.

Fat% and physiological responses. Moreover, correlation coefficients of ΔT_{co} and ΔHR deemed to evaluate the reliability and validity of predictive variable, were found higher in *BCI* than in V_{O2max}/mass, *BSA*/mass, and *Fat%*. Therefore, *BCI* is a better predictor for ΔT_{co} and ΔHR than any single individual characteristic.

5. CONCLUSIONS

In summary, this paper presents a novel approach to evaluating the level of risk of heat strain for a group of workers exposed to a heat occupational environment. This index is based on individual constitution, namely, V_{O2max}/mass, and shape described by *BSA*/mass and *Fat%*. The weighting functions were determined by the relative effects on physiological responses. *BCI* includes two forms: BCI_{Tco} for evaluating individual ΔT_{co}, and BCI_{HR} for evaluating individual ΔHR. *BCI* explains over 60% of the total variance of both ΔT_{co} and ΔHR in all climate conditions. However, V_{O2max}/mass, *BSA*/mass, and *Fat%* have lower or null significant effects (Pearson coefficient is lower or $p > .05$). As this index is based on only three variables, whose measurements are easy and convenient to conduct, the computation of the index is simple and may avoid some small errors. Moreover, *BCI* is easy to implement and does not require heat exposure, which is an advantage compared to former indexes. *BCI* proved to be a better predictor for heat strain responses than each individual characteristic. It is more sensitive than body type to describe the distributions of individual characteristics and distinguish the difference of physiological responses to the heat. However, this index results from a preliminary test of 20 subjects, and the assessment of this index to heat strain is of relative value to all. Further studies of more subjects should be developed to research the value for the general use.

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