

## Is the Wet-Bulb Globe Temperature (WBGT) Index Relevant for Exercise in the Heat?

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We have read with great interest the comprehensive review of our colleagues [1] on the ‘hot’ topic of training and competing in the heat. We agree with the authors that environmental indices should be defined with guidelines rather than universal (fixed) cut-off values across different sporting disciplines. However, we are surprised that they did not highlight one of the main current limitations: the recommendations for various sporting governing bodies (i.e., event organizers and international federations) are still based on the wet-bulb globe temperature (WBGT) index. We believe that this point is paramount for improving heat-related exercising safety guidelines.

The WBGT, originally developed by the US Navy [2], is used world-wide as a screening tool for the assessment of environmental heat stress during industrial, military, occupational, and sport applications, and has been recommended by the International Organization for Standardization (ISO) certification (ISO 7243, ISO/DIS 7933 [3]), American Conference of Governmental Industrial Hygienists (ACGIH, [4]), American College of Sports Medicine (ACSM, [5, 6]), International Olympic Committee [7], and numerous leading sports federations (e.g., Fédération Internationale de Football Association [FIFA], International Association of Athletics Federations [IAAF], International Tennis Federation [ITF] [8, 9]). This empirical index is computed from the reading of the dry-bulb temperature and two derived measures: the natural wet-bulb temperature and the black-globe

temperature. Notwithstanding the primary recommendations by ISO and ACGIH—that is, to use WBGT as a preliminary tool, while the predicted heat strain (PHS) approach (ISO 15265 [10]) must be used to investigate more severe heat conditions—many users still utilize only the WBGT index regardless of the severity of the thermal environment. Because “its origin, and its limitations are apparently being forgotten” [11], the WBGT is seen as a user-friendly and reliable measure of heat stress. Nearly 60 years after its first formulation, d’Ambrosio Alfano et al. [12] recently critically reviewed the WBGT and clearly demonstrated that it is becoming obsolete. Briefly, the main issue is that the WBGT does not appropriately reflect the severity of the weather/climate. This is mainly due to the following:

1. The use of nonstandard instrumentations or unreliable calibration procedures.
2. The debate on the assessment of the natural wet-bulb temperature, which is not a thermodynamic parameter but a measured quantity that depends on both radiative and convective heat flows. This is especially true in the presence of solar radiation which may be affected by the cloud cover [13].
3. The omission of measurement of the air velocity, in absolute or relative (on sports locomotion) values.
4. The inaccurate correction clothing adjustment factor—shown to vary as a function of the weather.

All these points (for details, see d’Ambrosio Alfano et al. [12]) question the validity, accuracy, and applicability of the WBGT. Additionally, it seems more relevant to calculate the WBGT from the basic weather elements (i.e., air temperature, mean radiant temperature, absolute humidity, and air velocity). This may partly explain the preference for the WBGT approximation formula [14],

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**Table 1** Selected heat-stress indices' temperature limits (°C) in reference to thermal sensations, alert descriptions, and recommended sporting activity

Thermal sensation	Alert description <sup>a</sup>	Recommended sporting activity <sup>a</sup>	Index		
			WBGT	PMV	UTCI
Neutral	Generally safe	Unlimited/normal activity	<18	−0.5 to 0.5	9–26
Warm	Caution	Increase exercise-to-rest ratio; decrease intensity and total duration of activity	18–24 <sup>d</sup>	0.5–2.5	26–32
Hot	Extreme caution	Activity of unfit, unacclimatized, high-risk <sup>b,c</sup> subjects should be curtailed	24–28	2.5–3.5	32–38
Very hot	Danger	Activity for all except well acclimatized should be stopped	28–30 (28.6)	>3.5 (13.5)	38–46
Sweltering	Extreme danger	Cancel or stop all practice and competition	>30 <sup>e</sup>		>46 (49.6)

Figures in bracket have been computed from meteorological input variables (<http://www.wunderground.com/history/>; accessed 25 July 2015) corresponding to the hottest day during the 2014 Australian Open Tennis Championships, Melbourne, Australia

PMV predicted mean vote, UTCI universal thermal climate index, WBGT wet-bulb globe temperature

<sup>a</sup> Alert description/recommended sporting activity for WBGT

<sup>b</sup> While wearing shorts, t-shirt, ankle socks, and sneakers

<sup>c</sup> Internal heat production exceeds heat loss and core body temperature rises continuously, without a plateau

<sup>d</sup> Threshold (WBGT = 21 °C) recommended by marathon organizations in northern latitudes

<sup>e</sup> Threshold (WBGT > 30 °C) recommended by most sporting governing bodies (e.g., American College of Sports Medicine [ACSM], International Tennis Federation [ITF], Women's Tennis Association [WTA], and Fédération Internationale de Football Association [FIFA])

based on meteorological measurements or databases [15], where the four basic weather elements are available, rather than WBGT.

Despite caution by Racinais et al. [1] that “environmental indices should be viewed as recommendations to implement preventive countermeasures to offset the potential risk of heat illness”, it seems that event organizers and international federations face a ‘vicious cycle’ as they should implement the recommended countermeasures—including rules and regulations adaptation—based on WBGT-resembling cut-off values (see Table 2 in Racinais et al. [1]). In line with the conclusion of d'Ambrosio Alfano et al. [12], the FIVB (Fédération Internationale de Volleyball) heat stress surveillance system indicates that available guidelines (e.g., ACSM [6]) are too conservative to guide informed decisions regarding whether or not it is safe to let a professional beach volleyball tournament continue in the face of elevated heat stress [16]. Accumulating evidence in sporting contexts demonstrates that dry-bulb temperature is a more appropriate and robust predictor of heat stress than WBGT [17, 18], thereby highlighting its irrelevance to approximate safety thresholds.

On the whole, and taking into account the worldwide effects of global warming, it seems appropriate to urgently move on metrics other than WBGT for a more adequate screening of heat stress for exercise [12, 13, 19]. In addition to the four basic weather elements, including the short- and long-wave radiation fluxes [20], several factors already

mentioned by Racinais et al. [1]—i.e., physiological strain, thermoregulatory system, and clothing (insulation and moisture permeability characteristics)—need to be considered when defining an alternative thermo-physiological model. It should include the heat budget models (i.e., heat exchange between the human body and the thermal environment [20] comprising the aforementioned PHS [10] or the predicted mean vote [PMV] [21]) or the recently developed universal thermal climate index (UTCI), based on an advanced multi-node model of human heat transfer and thermo-regulation [22, 23]. For example, during the 2014 Australian Open Tennis Championships matches played at ~44 °C, both PMV and UTCI values (13.5 and 49.6 °C, respectively) exceeded the critical reference values of their respective assessment scales (Table 1), while the WBGT value of 28.6 °C did not and clearly underestimated the heat stress. Conversely, the operational UTCI procedure appears useful and promising to assess athletes' physiological responses to humidity and radiative loads in hot environments. Nonetheless, we have to admit that available human comfort models generally do not consider inter-individual variability and that future investigation is needed in reference to different metabolic rates, clothing characteristics, and exposure times before considering UTCI to replace WBGT.

To conclude, there is a considerable challenge ahead of ‘us’ in creating universal safety standards and guidelines in order to account for all environmental scenarios and sports. However, we believe that incorporating newly available

bioclimatic indices such as UTCI instead of WBGT would considerably improve sport-specific heat stress modeling and current guidelines. A multidisciplinary approach integrating human bio-meteorologists, thermal physiologists, and exercise physiologists is an essential driver to speed up this change.

#### Compliance with Ethical Standards

Franck Brocherie and Grégoire Millet have no conflicts of interest that are directly relevant to the content of this letter.

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