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Comment on Havenga et al. (2022): Standard heat stress indices may not be appropriate for assessing marathons

Significance:

An article in the July/August 2022 issue (Havenga et al., S Afr J Sci. 2022;118(7/8), Art. #13118) argued that changing the date of the Comrades Marathon from May to August would result in increased heat stress for participants. Heat stress was estimated using the Universal Thermal Climate Index (UTCI), which is designed to represent a person walking, not running. In this Commentary, I argue that using the UTCI may lead to an underestimation of heat stress for the Comrades Marathon, and that the conclusion that August has worse heat stress than May depends on the assumptions in the estimation of heat stress.

Introduction

While Havenga et al.[1] are right to examine the thermal environment of the Comrades Marathon, the Universal Thermal Climate Index (UTCI) might not be an appropriate metric. When the thermal environment is simplified into a single index, choices about the relative importance of temperature, humidity, wind, and radiative temperature are codified. Choice of thermal index can reverse the conclusion of a study in some contexts[2], thus it is important to identify cases where choice of thermal index is a critical assumption.

The UTCI has some advantages in that it has a strong thermo-physiological basis, and that it accounts for radiation. However, the derivation of the UTCI contains assumptions about activity and preferred clothing that are not true for a distance running event, which may distort the results.[3] In this Commentary, I aim to identify the effect of these assumptions.

Havenga et al.[1] justified their use of UTCI with reference to other studies, but these other studies do not provide a strong justification for using UTCI. One reference related to the thermal comfort of spectators, rather than competitors.[4] Brocherie and Millet[5] were cited for the statement "the Universal Thermal Comfort Index (UTCI) is regarded to be a better measure to model sports heat stress," but this reference does not actually test this and only proposes that newer indices might improve on the deficiencies of wet bulb globe temperature (WBGT). Honjo et al.[6] used the UTCI alongside WBGT, and noted the limitation that UTCI does not allow variations in metabolism or clothing. Gasparetto and Nesseler[7] used UTCI alongside WBGT but did not note these limitations. None of these studies demonstrates that UTCI is uniquely appropriate for thermal evaluation of distance running, and other research has highlighted these limitations for the sports context.[3] The limitations of UTCI are acknowledged by its developers[8] but Havenga et al.[1] do not discuss how these limitations affect their results.

The UTCI operational procedure is based on a person walking, with a metabolic rate of 2.3 MET.[8] Running involves higher metabolic rates than this: studies of Comrades Marathon participants found metabolic rates ranging from 6.6 to 10.6 MET (23–37 mL O_2/kg/min).[9] The bodies of distance runners need to dissipate much more internal heat than assumed in the derivation of the UTCI. Therefore, UTCI may underestimate heat stress or may not correctly identify the conditions with the highest heat stress.

The UTCI clothing model is based on the assumption that clothing preference is determined by air temperature[10], with clothing insulation reaching a minimum around 35 °C. Air temperatures on historical and proposed race days range from 5 °C to 32 °C with a mean of 19 °C. Applying Equation 3 from Havenith et al.[10] (with an assumed minimum of 0.25 clo), clothing values for the distribution of race temperatures have a mean of 0.75 clo and a maximum of 1.32 clo. The clo unit is defined as the estimated amount of clothing for a person at rest indoors at 21 °C to maintain thermal equilibrium: trousers, long-sleeved shirt, long-sleeved sweater and a t-shirt are 1.0 clo, sweat pants and a sweat shirt would correspond to 0.74 clo, while walking shorts and a short-sleeved shirt would correspond to 0.36 clo.[11] The UTCI clothing model is based on surveys of people going about ordinary daily activities[10], but it is simply wrong to assume that this is also the amount of clothing that runners wear. While runners do vary their level of clothing, metabolic production of heat needs to be included in any prediction of clothing level. The expected effect of this is that clothing levels are lower than assumed by the UTCI clothing model, generally distorting the pattern of heat stress predicted by the UTCI, as higher temperatures will be partly compensated by lower clothing insulation.

In the following sections, I demonstrate how the metabolic heat assumption affects the heat stress calculation and estimate the effect on this study.

Method

To estimate the combined effect of these assumptions, some calculations were performed. The full computer code for the underlying thermo-physiological model of the UTCI is not public, so it is not possible to directly test the effect of these assumptions. Physiological equivalent temperature (PET) operates in a similar way to UTCI but contains less physiological detail; PET code is publicly available and allows activity and clothing assumptions to be changed directly.[12] PET and UTCI do not have the same reference conditions, and are intended to represent slightly different things (heat stress vs heat strain). This is intended only to be an example, and I am not arguing that PET is necessarily the best index to assess thermal conditions for marathons in general.

PET was calculated with two sets of assumptions: (1) metabolic rate of 2.3 MET (based on the UTCI assumptions[8]) and clothing of 0.4 clo, and (2) metabolic rate of 8.6 MET and clothing of 0.4 clo. The chosen metabolic rate of 8.6 MET is the middle of the range observed in Comrades Marathon runners by Byrne et al.[9]

PET was calculated using the 'pythermalcomfort package' (https://pythermalcomfort.readthedocs.io accessed 2023-07-07)[13], which uses the Walther and Qoestchel 2018 specification[12]. When calculating PET, wind speed at 10 m height was transformed to wind speed at a height of 1.1 m using the same logarithmic scaling specified for the UTCI, and wind speed at 10 m height was limited to a minimum of 0.5 m/s for both UTCI and PET.[8] Limits specified in Brode et al.[8] were applied to the UTCI calculation – a step which appears to not have been applied in the ERA-HEAT supplied UTCI, which appears to overestimate heat stress at low wind speeds.

Temperature and humidity were taken from ERA5[14], with radiant temperature from ERA5-HEAT[15]. Hourly PET was calculated at locations for the start, halfway point, and end of the race. Following Havenga et al., the calculation was performed for the last 10 days of May and August. Only data between 03:00 and16:00 UTC were included, to match the time of the race.

The distribution (across years) of maximum PET and UTCI, and total hours of heat stress categories according to PET and UTCI, were compared during the last 10 days of May and August 1980–2019 to determine if heat stress would typically be higher on August dates or May dates. This calculation was repeated with different metabolic heat assumptions to demonstrate its importance.

Results and discussion

Firstly, I note that the UTCI and PET produce very similar results when calculated with similar assumptions. Figure 1 shows UTCI plotted against PET calculated with the low metabolism assumption. The coefficient of determination between these two quantities is 0.96, i.e. 96% of the variance in the UTCI is explained by the PET. The main difference between UTCI and PET seems to be in sensitivity to wind speed. I argue, therefore, that making the analogy of UTCI and PET is justified for the purposes of this calculation. However, there are individual times when there is a large amount of disagreement about the level of heat stress, as shown by Table 1.

Secondly, I note that, by definition, the PET always increases with the metabolic rate. Figure 2 shows the extent to which PET is decreased by the low metabolism assumption. Changes in magnitude ranged from −13.8 °C to −3.8 °C, with a mean of −7.6 °C, with the largest changes occurring at high values of PET.

Table 2 shows the number of heat stress hours according to UTCI, PET(1) and PET(2). Using UTCI, there are more days in August than in May on which the maximum UTCI indicates 'strong' or 'very strong' heat stress. There are no days when the UTCI indicates 'extreme' heat stress. Using PET(1), there are more days in August than in May on which PET indicates 'strong' heat stress, and no days when the PET indicates 'extreme' heat stress. Using PET(2), there are more days in May than in August on which the PET indicates 'strong' or 'extreme' heat stress. Therefore, UTCI and PET(1) indicate that May has lower heat stress, but PET(2) indicates that August has lower heat stress.

Repeating the calculation with wind speed fixed at 2 m/s, August has higher heat stress using UTCI and PET(2), as shown by Table 3. The heat stress predicted by UTCI and PET is highly sensitive to wind speed, especially at low wind speed, and the two models have different sensitivity to wind speed. ERA5 indicates that wind speed is higher in August, as shown by Figure 3: the lower heat stress in August compared to May indicated by PET(2) is largely the result of wind speed being higher in August. This is problematic as near-surface wind speeds in the actual race environment are likely to differ considerably from the wind speed at a height of 10 m and horizontal resolution of 31 km in ERA5 in ways not well represented by logarithmic scaling. Furthermore, at low wind speed, the effect of the runners' body movements will become a substantial source of air movement, which is not properly taken into account in either the UTCI or PET calculations.

Conclusion

In this Commentary, I have demonstrated how the assumptions of low metabolic heat production used in the UTCI distorts thermal assessment for athletic events. PET calculations indicate that the assumption of low metabolic heat production leads to underestimation of heat stress. Furthermore, PET calculations using a higher metabolic heat assumption can indicate the opposite conclusion to PET with a lower metabolic heat assumption, i.e. August dates for the Comrades Marathon have lower heat stress. However, there is a strong dependence on low wind speeds

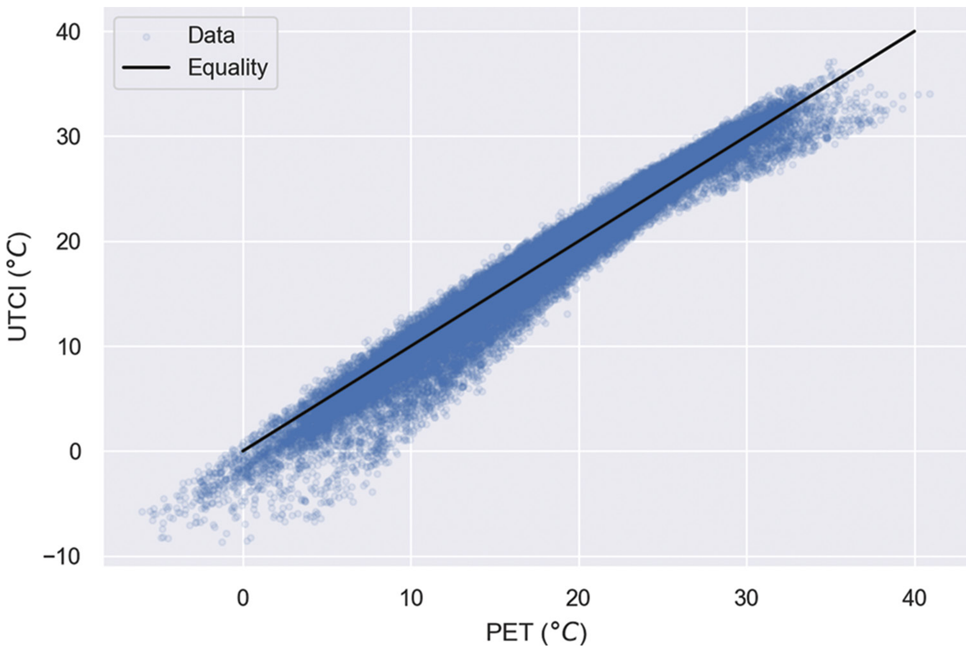

Figure 1: Universal Climate Thermal Index (UTCI) versus physiological equivalent temperature (PET). PET is calculated here with a metabolic rate matching the UTCI.

Table 1: Cross-tabulation of physiological equivalent temperature (PET) and Universal Thermal Climate Index (UTCI) categories calculated from hourly ERA5 data for the Comrades Marathon. Counts are hours for each pairing of categories.

	UTCI heat stress categories				
	No	**Moderate**	**Strong**	**Very strong**	**Extreme**
PET heat stress categories					
No	11 238	0	0	0	0
Slight	8516	0	0	0	0
Moderate	5137	2415	0	0	0
Strong	399	2889	300	0	0
Extreme	35	603	148	0	0
PET heat stress categories (low metabolism)					
No	21 837	0	0	0	0
Slight	3476	4015	0	0	0
Moderate	12	1844	385	0	0
Strong	0	48	63	0	0
Extreme	0	0	0	0	0

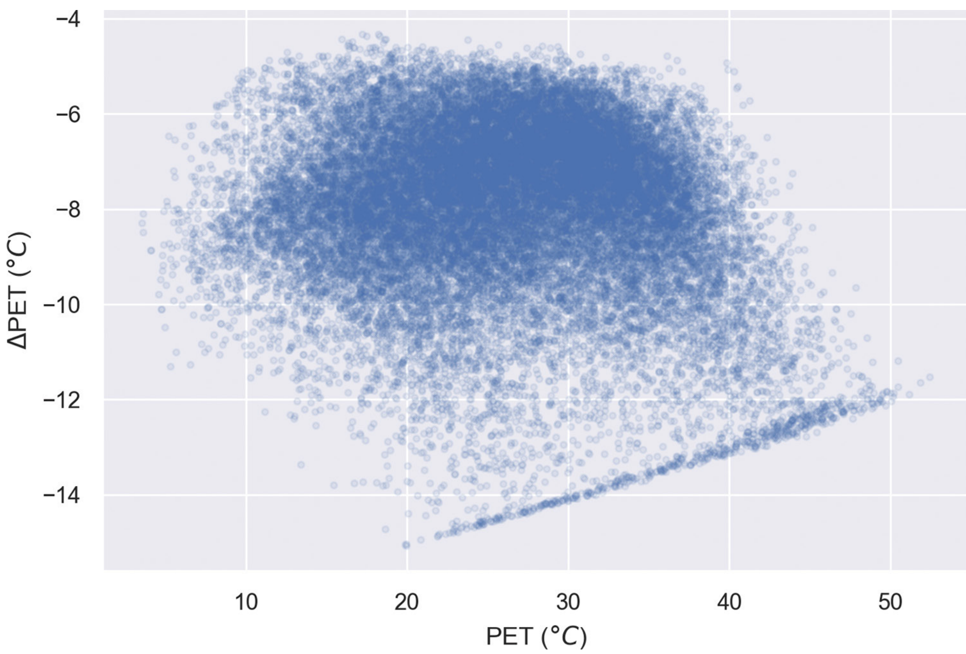

Figure 2: Difference in physiological equivalent temperature (PET) calculated with different metabolic assumptions. The *x*-axis shows the PET calculated with high metabolic rate (8.6 MET), whereas the *y*-axis shows the difference in the PET when calculated with a lower metabolic rate (2.3 MET).

in both PET and UTCI, and ERA5 wind speed at 10 m might not well represent the real race environment.

Grundstein and Vanos[3] argued that none of WBGT, UTCI, or PET are ideal for monitoring heat strain in athletes (although they refer to a PET implementation that did not allow for changes to metabolic rate or clothing). There may be demand for an equivalent of the UTCI with modified clothing and metabolism in the future, which would be useful for sport and occupational contexts. The ability to modify clothing and metabolic rate assumptions is vital in this context, and would point towards using an implementation of PET which allows these modifications, or another model of heat balance.

Table 2: Counts of hours in different heat stress categories defined by Universal Thermal Climate Index (UTCI) and physiological equivalent temperature (PET)

	May (hours)	August (hours)	Difference (hours)
UTCI			
No	12 456	12 869	–413
Moderate	3280	2627	653
Strong	104	344	–240
Very strong	0	0	0
Extreme	0	0	0
PET(1) (low metabolic heat)			
No	10651	11186	–535
Slight	3977	3514	463
Moderate	1160	1081	79
Strong	52	59	–7
Extreme	0	0	0
PET(2) (high metabolic heat)			
No	5501	5737	–236
Slight	3974	4542	–568
Moderate	3872	3680	192
Strong	1979	1609	370
Extreme	514	272	242

Table 3: Counts of hours in difference heat stress categories defined by Universal Thermal Climate Index (UTCI) and physiological equivalent temperature (PET), with windspeed fixed at 2 m/s

	May (hours)	August (hours)	Difference (hours)
UTCI with fixed wind speed			
No	11 777	11 393	384
Moderate	3937	3946	–9
Strong	126	501	–375
Very strong	0	0	0
Extreme	0	0	0
PET(2) with fixed wind speed			
No	4738	4442	296
Moderate	4719	4459	260
Slight	3949	3966	–17
Strong	2417	2808	–391
Extreme	17	165	–148

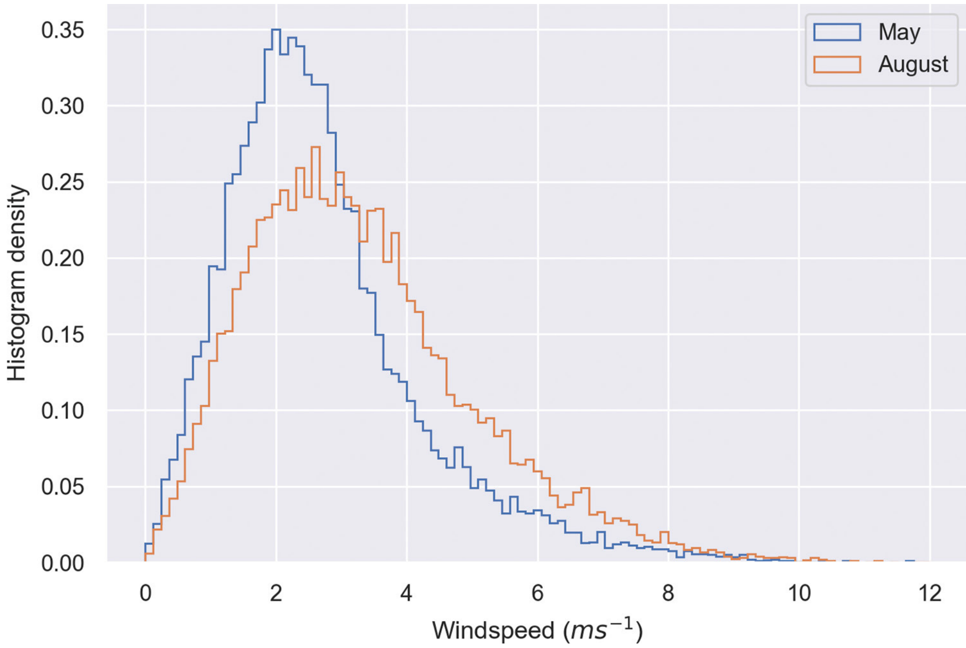

Figure 3: Histogram of wind speed in August and May at race locations. Windspeed is typically higher in August than in May.

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Competing interests

I have no competing interests to declare.

Data availability

All code and data supporting the results of this study are archived and freely available for download from https://doi.org/10.5281/zenodo.8348335. ERA5 is freely available from the Copernicus Climate Service https://cds.climate.copernicus.eu/.

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