A MODIFIED DISCOMFORT INDEX (MDI) AS AN ALTERNATIVE TO THE WET BULB GLOBE TEMPERATURE (WBGT)

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INTRODUCTION

In 1957, Yaglou and Minard (1) developed the WBGT as a thermal index calculated as follows: $WBGT=0.7T_w+0.2T_g+0.1T_a$ where T_w = wet bulb temperature, T_g = black globe temperature and T_a = ambient temperature. This index has been in extensive use for evaluating environmental heat stress in the U.S. Army, sport activities and as safety guidance for workers in different occupations (2-4). However, WBGT was found to be limited in evaluating heat stress mainly due to the inconvenience of measuring T_g, the corrections needed for different clothing (e.g., protective clothing) and for various metabolic rates (5). The purpose of this study was to determine whether the newly developed modified discomfort index (MDI) calculated as (6) $MDI = 0.30T_a+0.75T_w$ can be used as an alternative for WBGT.

MATERIALS AND METHODS

The data for this study were obtained at 3 separate locations: USA, Egypt, and Israel. Measurements of the meteorological parameters to calculate WBGT and MDI were done using the same thermometers. T_a was measured using a mercury-in-glass thermometer, T_w was measured using a naturally aspirated wet bulb and T_g was measured using the Vernon black globe thermometer. In addition, wind speed at 1.2 m above ground level and total hemispheric radiation levels were measured in Egypt and in Israel. Evaluations and comparisons of WBGT and MDI were done using the procedures and calculations described above in the introduction (1,6). The material and methods can be found in greater detail elsewhere (7-9).

USA Measurements. Hourly weather measurements were collected daily between 7:00 AM to 8:00 PM from April until October in 1990 at a vegetative environment in South Carolina.

Egypt Measurements. Hourly weather measurements were collected daily between 5:00 AM to 4:00 PM for a week in August 1985 in an arid environment west of Cairo.

Israel Measurements. Daily weather measurements were collected simultaneously in the shade and under open sky every 15 min between 11:00 AM to 3:00 PM in July through August during 2 years (1987-1988) at a tropical location.

Table 1. The environmental climatic conditions and correlation coefficients between MDI and WBGT.

Study	Climate	T_a (℃)	T_w (℃)	T_g (℃)	r^2	*P*	n
USA	Semi-tropical	27.8 ± 3.9	24.7 ± 3.2	36.3 ± 7.5	0.94	0.001	3197
Israel*	Tropic	30.2 ± 1.1	24.9 ± 1.5	48.4 ± 1.4	0.95	0.001	721
Egypt	Desert	32.7 ± 3.5	22.2 ± 1.4	41.4 ± 5.0	0.83	0.001	86

* For exposures in the sun a factor of 2 was added to MDI.

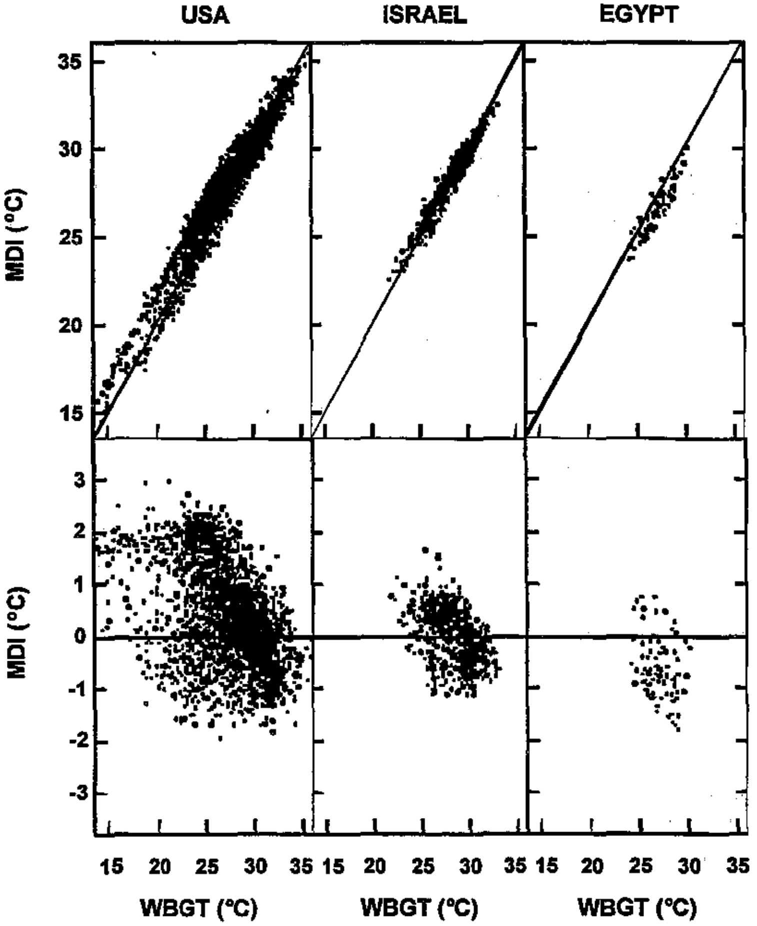

Figure 1. Validation of the MDI showing correlation with the WBGT at 3 sites: USA, Israel and Egypt (top) and the residual scattergrams (bottom).

RESULTS

The comparisons between MDI and WBGT are depicted in Table 1 and Figure 1. Generally, highly significant correlations were found between the indices.

DISCUSSION

The MDI was calculated from database sets obtained from three separate studies conducted in America, Africa and Eurasia and was favorably compared to the WBGT. These results strengthen the argument for use of MDI, which uses only T_a and T_w for evaluating heat stress.

The integrated T_g in the WBGT is an important parameter to evaluate thermal load by representing mainly the solar load (SL). Furthermore, T_g also considers the impact of the reflected radiation from any surface and object, including short- and long-wave radiation and is also affected by the wind velocity. However, measuring T_g by a black globe thermometer is cumbersome and inconvenient.

Analyzing the results from the three locations, using MDI without any correction factor, revealed a symmetrical distribution around the zero line only for the USA database. In the Egyptian and Israeli databases, the observations were mainly under the zero line, representing underestimation of WBGT by MDI. As a consequence, when a correction factor of 2 was added to the calculated MDI for the Israeli database depicting a high SL, a very high correlation was found between MDI and WBGT.

The effect of SL on the environment depends on four factors: time of year and latitude; time of day; the environmental surface; and the atmosphere (10). Seasonal variation in the incoming solar radiation at the upper layers of the atmosphere is a function of the earth-sun orbital geometry, which changes the distance between the earth and the sun. Latitude and the hourly changes in solar elevation influence path length through the atmosphere and the attenuation of solar radiation arriving at the earth's surface. As the source of the solar beam moves from directly overhead (~12:00 noon) to the horizon (sunset), the cross sectional area of almost any object to the solar rays goes from minimum to maximum. Thus, around 12:00 noon when the sun is overhead, the ray path through the atmosphere will be the shortest, resulting in the highest SL. The amount of absorbed solar radiation, apart from depending on the zenith angle calculated from the time of the day, is affected by the site characteristics. In a vegetative surface, there is no reflection of radiation, whereas in the desert about 20% of the overhead radiation would be reflected. In addition, the other radiative components including diffuse solar, reflected solar, ground thermal, and sky thermal radiation must be taken into account when we quantify the solar load (e.g., clouds and haze markedly decrease SL).

CONCLUSION

The MDI, obtained only from T_a and T_w, can be used as a simple tool for measuring thermal load. However, in order to use it as a substitute for WBGT a regional correction might be needed according to the latitude studied.

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