EVALUATION OF HEAT STRESS BY THE PHYSIOLOGICAL STRAIN INDEX (PSI)

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INTRODUCTION

During this century, more than 20 heat strain indexes were developed (1,2). However, none are accepted as a universal physiological strain index. The best known index to use is the Heat Strain Index (HSI) suggested by Belding and Hatch (3). This index, which related total evaporation required to the evaporative capacity **of** the environment is widely accepted, probably because it combines environmental variables and body activity. However, according to Belding (2) there were situations in which heat strain was seriously underpredicted or over-predicted by this index, and corrections were necessary for improving the prediction of the index for various exposures (4,5).

In 1996, Frank et al. (6) suggested a different approach for evaluation of heat stress by introducing the Cumulative Heat Strain Index (CHSI) based on rectal temperature (T_{re}) and heart beats (HB). However, HB is not commonly measured and therefore causes difficulties in using this index. The purpose **of** this study was to evaluate **a** simple physiological strain index (PSI) for hot environments (9).

MATERIALS AND METHODS

The data for this study were obtained from 2 separate studies by Montain et al. (7,8). In the first study, **7** men wearing full (clo = 1.5) and partial (clo = 1.3) protecting clothing performed exercise ($\dot{V}O_2$ –1 L·min⁻¹) for **180** min in hot/dry and hot/wet environmental conditions (**43°C, 20%RH; 35°C, 50%RH,** respectively). Evaluation of the index was performed with a 2nd study representing a database **of 9** men who completed a matrix of 9 trials of 50 min each at 3 metabolic rates (25, 45 and 65% $\dot{V}O_{2max}$) while euhydrated and hypohydrated at 3% and 5% of body weight (BWL).

The HSI was calculated as suggested by Belding and Hatch (3), with algorithm modifications published by Pandolf et al. (10). The CHSI was calculated as suggested by Frank et al. (6). The material and methods are presented in greater detail elsewhere (7,8).

RESULTS

To evaluate heat stress on a universal scale of 0 to 10 and to overcome the CHSI's limitation of continually getting higher values during rest or recovery periods, we constructed an index that enabled us to calculate the strain online.

The index is based on the maximal limits for T_{re} and heart rate (HR) of 39.5°C and 180 bpm, respectively. The same weight functions for T_{re} and HR are assumed normalized for the initial value of each, resulting in the following Physiological Strain Index (PSI) (9):

$$PSI = 5(T_{re_t}-T_{re0}) \cdot (39.5-T_{re0})^{-1}+5(HR_t-HR_0) \cdot (180-HR_0)^{-1}$$

where T_{re_t} and HR_t are simultaneous measurements taken at any time.
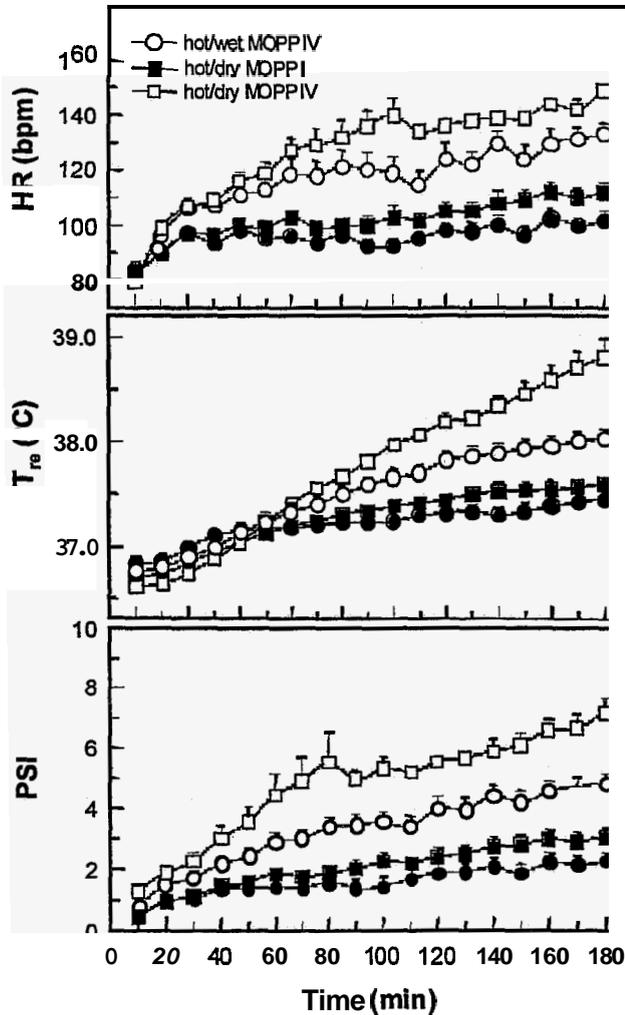

Figure 1. Comparison between HR (top), T_{re} (middle) and PSI (bottom) in hot-dry and hot-wet climates wearing partial (MOPP I) and full (MOPP IV) protective clothing. Data obtained from Montain et al. (7).

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PSI differentiated significantly *(P< 0.05)*between the strain at the hot/dry and the hotlwet climates, and between the full (MOPP IV) and the partial (MOPP I) protective clothing configurations (Figure 1. The CHSI and PSI rated the exposures in the hot/dry climate condition at higher physiological strain, whereas the HSI used in Montain et al. study **(7)**rated the exposures in the hot/wet climate condition with higher strain (Table 1.

Table 1. Comparison between PSI, HSI and CHSI applied to Montain et al. **(7)** database at 180 min.

	PSI		HSI		CHSI	
	MOPP I	*MOPP IV*	*MOPP I*	*MOPP IV*	*MOPP I*	*MOPP IV*
Hot/dry	3.1 ±0.9	7.2 ± 1.3	77 ± 4	152 ± 11	362 ± 212	1516 ± 400
Hot/wet	2.3 ± 0.9	4.9-10.7	85 ± 5	161 ± 14	228 ± 171	843 ± 289

The 2nd database to validate PSI was compiled from results obtained during 50 min exposure under 9 combinations of exercise intensity and hypo- hydration level. The PSI correctly discriminated between the exposures (Table 1) and categorized the heat strain in a rank order. Significant values of PSI were observed with increasing hypohydration level and exercise intensity $(P < 0.01)$.

Table 2. PSI (mean± SE) applied to Montain et al. **(8) database at** 50 min.

Hypohydration (%BWL)	$25\% \, Vo_{2max}$	$45\% \, Vo_{2max}$	$65\% \, Vo_{2max}$
0	1.6 ± 0.2	4.3 ± 0.2	7.4 ± 0.3
3	2.2 ± 0.3	5.5 ± 0.4	9.1 ± 0.9
5	3.1 ± 0.3	6.4 ± 0.4	10.0 ± 0.9

DISCUSSION

The PSI described well the physiological strain on a universal scale of 0 to 10 and categorized every exposure in proper order. This index, which is based only on two physiological parameters (HR and T_{re}), adequately depicts the combined strain reflected by the cardiovascular and the thermoregulatory systems.

PSI differs from other indexes that are based on HR and T_{re}. The CHSI, which is also based on T_{re} and HR, is valid only for subjects exposed for the same duration, without rest or recovery periods. From following the T_{re}, HR and PSI dynamics in Figure 1, it can be concluded that the HSI failed to rate the exposures in a hot-dry climate with higher strain, probably because subjects were dressed in protective clothing.

Most of the heat strain indexes are limited in their evaluation since they were valid only under certain specific conditions. The suggested PSI is a valid index either online or when data analysis is applied. It is **a** simpler index to interpret and to use than other indexes available and includes the ability to be applied in

rest or recovery periods. This index has the potential to be widely accepted and used universally.

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