MECHANISM AND PREDICTION OF HEART RATE CHANGES UNDER HEAT LOAD AND EXERCISE

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INTRODUCTION

Heart rate (HR) response to different metabolic rates and heat loads has been a subject for intensive studies. These studies focused mainly on the basic physiological mechanisms of heat exchange and thermoregulation. As part of these studies HR response to heat load and exercise was also described in mathematical terms. These models were developed under controlled indoor environmental conditions and were based on biodynamic principles related to body heat exchange (1). Applying the model for HR under outdoor conditions revealed some discrepancies with actual measurements. Pandolf et al. and Shapiro et al. attributed these discrepancies to the indoor conditions under which the model was developed, which could not fully simulate the outdoor environment (2-4). Furthermore, a distinct difference between temperature and heart rate dynamics limits the direct usage of heat exchange equations in predicting HR response (1,5). We aimed to suggest a simple empirical model for HR response to various combinations of metabolic rates, climatic conditions and clothing ensembles.

METHODS

Forty male volunteers (18-25 years) were exposed to 3 indoor climatic conditions: 21°C; 62%RH, 44°C; 40%RH, and 35°C; 70%RH; 20 subjects were also exposed to outdoor conditions of 31°C; 50%RH and solar load of 900 $W \cdot m^{-2}$. They were tested while wearing 3 different types of clothing ensembles: shorts (clo=0.35; i_m/clo=0.94), cotton fatigues (clo=0.99; i_m/clo=0.75), and a nylon protective suit (clo=0.70; i_m/0.08). Exercise consisted of walking for 60 min on a treadmill at 3 intensities: 300W, 450W, and 600W. HR and skin temperature were monitored every 5 min and VO_2 was measured towards the end of the exercise session.

RESULTS

A linear model was fitted to describe heart rate (HR) response as follows: **HR=a+(b·logt)**. The intercept (a) is the relative weight of initial HR (HRi), assuming a linear effect of HRi on HR. The slope (b) represents the effect of the various metabolic and heat balance parameters on HR, where time>0 (t). Four basic physiological and environmental parameters were found to be significant in determining HR changes under heat load and exercise: initial heart rate (HRi), metabolic rate (M), maximal evaporative capacity (Emax), and the required evaporation for thermal equilibrium (Ereq) which was transformed according to Shapiro et al. to include solar radiation and long wave emission (3,4). Accordingly, the following model was suggested:

$$\mathbf{HR=57.1+0.6HR_i+\log t(0.07M-0.011(E_{max}-E_{req})-19.06);}\ \text{bpm}$$

The correlation between predicted and observed values was high ($r^2=0.78$; $p<0.0001$) with residuals distributed symmetrically around the zero line. To test the validity of the model, a separate database of more than 200 measurements was used; the correlation coefficient between measured and predicted values for this set of data was $r^2=0.69$ ($p<0.001$). These measurements represent data collected from another outdoor study (solar radiation –900 $W \cdot m^{-2}$; Ta = 29±2°C ; RH=50±10%) which involved 24 subjects exercising at a moderate work load (350 or 500 watt).

DISCUSSION

The present model for predicting heart rate response under exercise - heat stress differs from other models which have been suggested in the past. Though it is based on metabolic and biodynamic parameters, it is not directly linked to body heat balance. The model overcomes the limitations inherent in other models since:

a) it does not depend on body core temperature response;

b) it does not assume a linear relation between body core temperature and heart rate, as the relation is limited only to heart rates lower than 150 bpm (1);

c) it accounts for the effect of solar radiation absorption and long wave radiation emission on body heat balance.

The strength of a model is the ability to apply it in various conditions. This model was tested in 36 different sets of exposures which revealed high correlations with measured values.

In summary, a predictive model for heart rate which overcomes some of the difficulties observed in other models was presented. This is mainly attributed to the successful integration of the effect of radiation in calculating the heat balance equation and analyzing HR response independently from body temperature response.

REFERENCES

1. Givoni B. and Goldman R.F. 1973, Predicting heart rate response to work, environment and clothing, *J. Appl. Physiol.* 34, 201-204.

2. Pandolf K.B., Shapiro Y., Breckenridge J.R. and Goldman R.F. 1979, Effects of solar heat load on physiological performance at rest and work in the heat, *Fed. Proc.* 38, 4360.

3. Shapiro Y., Epstein Y., Moran D. and Mayer R. 1988, Predicting sweat loss response to exercise, climate, solar load, and clothing. *Proc. ICE-O-SHE,* Beijing.

4. Shapiro Y., Moran D., Epstein Y., Burstein R. and Altar J. 1988, Predicting rectal temperature response under different combination of environmental climate, solar load, work intensity and clothing, *Proc. 3rd Int. Conf. Environ. Ergonomics*, Helsinki.

5. Givoni B. and Goldman R.F. 1972, Predicting rectal temperature response to work environment and clothing, *J. Appl. Physiol.* 32, 812-822.