CONTROL PROCESSES IN THE HUMAN THERMOREGULATORY SYSTEM: ANALYSIS BY SIMULATION

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INTRODUCTION

The most crucial part of problems involved in the analysis of human temperature regulation is the assessment of the structure and function of the controller, i.e. that subsystem which controls heat production, transfer and loss. As up to now, even the gross concept of the controlled variable and its processing is questionable, simulation analyses will help to give first approaches for the processing of central and peripheral temperature signals and for the numerical values of the controlling parameters.

METHODS

The models used in my laboratory are further developments of the well-known Stolwijk-Hardy model (1), i.e. they are based on the traditional approach using differential equations for the layers of the cylindrical elements of the human body. The mathematical description and the computer realization allow for representations of different levels of complexity of the human body and the heat transfer processes. 30 equations and more are used to approximate another class of models which use partial differential equations, e.g. those developed by Wissler (2) and Buse and Werner (3).
The essential physiological variables under study, besides temperatures are metabolic heat production, blood flow, and sweating rate. The characteristics of the body implemented in the models are weight, surface area, height, and the physical parameters to be used for the heat balance. The equations of the passive system are complemented by a series of equations for the actively controlling elements.
Computations were done for transient and steady-state regulation, changing environmental temperature between 13 °C and 50 °C. By comparison with experimental results, the controller equations and parameters were adjusted. In a first approach, the weight of the central and peripheral temperature signals to control blood flow in the "thermoneutral" zone, metabolic heat production in the cold, and sweat production in the heat were studied. The process of parameter adjustment in order to have optimal compatibility between experimental and computational results is described in detail elsewhere (4).

RESULTS

Blood flow control in the "thermoneutral" zone is provided both by central and peripheral temperatures, but central feedback is significantly dominant. The analysis of the dynamics shows that there are slow oscillations with a period of 30 - 40 min, which decrease with increase of the controller gain. According to our computation the most effective regulation, which means the least deviation from initial values of core temperatures (brain, blood, internal organs), takes place when the controller gain for the blood flow in relation to the central signal is about 5 l/min/°C. Combined researches using modelling and experimental facts analyzed in recordings on man, allowed to suggest that the threshold of vascular skin response in thermoneutral environment is about ± 0.05 °C.

In cold environments, the only feedback of the controller may be maintained by the peripheral signals. In fact, increase of metabolic heat production in response to changes of any thermal skin parameter, e.g. mean skin temperature, its rate of change or surface heat flow provides for effective regulation. The leading role of the peripheral signal in cold environments was proved both experimentally and by modelling (5). As to our results, the controller will be also effective if the peripheral loop will be fed by changes of heat flow only. This parameter has turned out to be informative enough under cold disturbance. This is important in relation to the fact revealing a two-layer localization of skin receptors (6).

In high ambient temperatures, control processes were studied by many specialists. The common opinion is that the main effector response of the system, skin sweat rate, followed by evaporation, takes place according both to central and to skin temperatures changes. Our aim was to determine the weight of the two signals. A significant influence of the parameters of the controller, threshold of effector response and gain for the central signal, on the control process, is obvious. In fact, regulation of brain or blood temperature is sufficiently effective; if the controller gain is rather high - in the vicinity of 500 ccal/hour/°C. But in this case transient processes are unstable. Peripheral feedback (skin temperature) according to our modelling provides for an aperiodic character of the transient processes. The ratio of central to peripheral gains controller is about 10.

CONCLUSIONS

The three basic physiological effectors providing thermal homeostasis, skin blood flow change, sweat production/evaporation and heat production, were studied in transient and steady state processes under a wide range of environmental temperature. Our results and the comparison with experimental data, allow to conclude, that the controller has no fixed structure acting in different environments, but that the controller parameters, particularly the impact of the central and the peripheral signals, change considerably, depending on the environmental conditions.

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