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Shivering thermogenesis: prediction based on the theory of reciprocal inhibition of thermal afferent information

Igor B. Mekjavic

Address for reprints:

School of Kinesiology
Simon Fraser University
Burnaby, British Columbia
Canada, V5A 1S6

Current models of human temperature regulation predict the magnitude of the metabolic response to cold exposure as an algebraic product of the linear displacement of both core (Tc) and skin (Tsk) from threshold values. Though predictions of heat production (HP) may have proven adequate, these modeling approaches do not simulate the manner in which thermoafferent information emanating from skin and core temperature sensors is integrated centrally, to effect the thermogenic response. An alternate approach to predicting HP has been developed, incorporating the theory of reciprocal inhibition of neural coded temperature information from cold and warm sensors. According to this principle, stimulation of cold sensors will enhance heat production and inhibit heat loss; similarly, stimulation of warm sensors will simultaneously enhance heat loss and inhibit heat production. The region of overlapping activity of these two sensor groups corresponds to the thermoneutral zone, a temperature region devoid of effector activity.

The model converts the skin and core temperatures into static neural activity (impulses.sec.$^{-1}$) of the cold and warm sensors, which is known to describe two bell shaped curves, with a region of overlap in their activity in the thermoneutral zone. The bell-shaped static firing characteristics of the two sensor groups are adjusted so that the pre-immersion values for Tsk and Tc correspond to the region where the activity of both sensors is identical. The neural activity of the peripheral and core sensors is then summated, to yield an excitatory drive for heat production from the cold sensors and an excitatory drive for heat loss from the warm sensors. The principle of reciprocal inhibition is satisfied by subtracting the warm sensor drive from the net cold sensor drive. This neural model may be represented by the following equation :

$$HP = HP_0 + g\,((PC + CC) - (PW + CW))$$

where, HP_0 = the resting pre-immersion level of heat production; PC and CC = the static neural activities of the peripheral and core cold sensors, respectively; PW and CW = the static neural activities of the peripheral and core warm sensors, respectively; g = the gain of the shivering repsonse for a given peripheral and core cold stimulus.

The model was evaluated with data obtained from a series of cold water immersions. Five subjects participated in immersions in 15" and 20°C water wearing only shorts. Their observed shivering responses were compared to predictions obtained either with the neural model, introduced above, or with the standard form of the linear models, predicting HP as a product of the linear displacement of Tsk and Tc from set-point values. Benefits of each model were determined on the basis of an analysis of the residuals generated. Results indicate that the neural model offers substantial improvements in the prediction of HP, as evidenced by the decrease in the magnitude of the sum of the squared residuals and the better conformity of the residuals to a normal distribution.

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