DYNAMICS OF REGULATION OF PULMONARY VENTILATION DURING TRANSITION FROM REST TO EXERTION

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The dynamics of regulation of the pulmonary ventilation during the transition from rest to exertion of different power (from 200 to 1000 kg·m/min) was analyzed by means of a mathematical model in experiments on healthy subjects who varied in their standard of training. The half-period of the transition process for ventilation was found to increase initially with an increase in the power of exertion. Later, when the "critical" power was reached, it began to fall. In healthy untrained subjects the critical point was at the level of approximately 500 kg·m/min, whereas in trained athletes the point was shifted to the region of more strenuous exertion.

KEY WORDS: pulmonary ventilation; transition process; physical exertion.

The study of the regulation of external respiration during the transition from rest to physical exertion is an important problem in sport medicine and also in occupational selection. However, the question of regulation of respiration in transition states of physical exertion has not yet been completely answered either in the experimental literature or in investigations involving mathematical simulation of the control system for external respiration.

The aim of regulation of external respiration is the maintenance of homeostasis and the increase in pulmonary ventilation to correspond to increased metabolism during work, irrespective of the actual mechanism of regulation. Accordingly, a mathematical model based on this principle can be constructed.

Despite a fair number of experimental studies of the response of external respiration to physical exertion [7-10], the facts obtained on the dynamics of transition processes are somewhat contradictory. Some workers found an increase in the duration of the transition process in response to an increase in the power of physical exertion, whereas others found a decrease. Meanwhile the duration of the transition process reflects the special character of regulation of the system and, in particular, the system of external respiration.

Accordingly the object of the present investigation was to study the dynamics of changes in the duration of the transition period during physical exertion in healthy subjects with different degrees of training.

EXPERIMENTAL METHODS

The subjects (all healthy persons) were divided into two groups. Group 1 included four persons without special training, group 2 contained three athletes (grade 2 volleyball players). To rule out any effect of adaptation, the exercises were assigned in arbitrary order. Each subject carried out 3 or 4 exercise tests. Each test was followed by a long period of rest, not less than 30 min. The tests assigned were not maximal for the subjects, and the final values of ventilation at each level of exertion were virtually a linear function of their power (Fig. 1). In the course of the experiments the ventilation (by the Jaeger "Ergotest") and the CO_2 concentration in the alveolar air (by the GUM-3 apparatus, from the "Medfizpribor" Special Design and Technical Bureau) were measured continuously during exertion ranging from 200 to 1000 kg·m/min in power on a bicycle ergometer under steady-state conditions for 5 min. In all cases this time was long enough for ventilation to reach a constant level.

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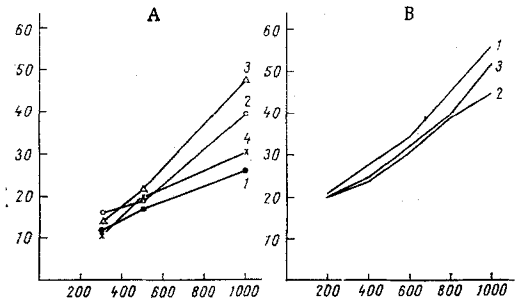

Fig. 1. Change in pulmonary ventilation $\dot{V}_E$ (in liters/min) as a function of power of physical exertion W (in kg • m/min). A) Untrained healthy person: subjects K. (1), L. (2), S. (3), and V. (4); B) athletes: subjects M. (1), L-n (2), and V-v (3).

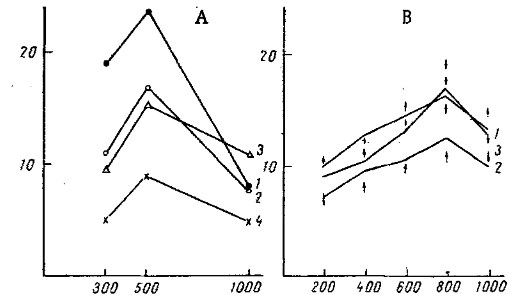

Fig. 2. Half-ventilation time for transition process ($t_{1/2}$) as a function of power of exertion W (in kg • m/min). Legend as in Fig. 1.

EXPERIMENTAL RESULTS AND DISCUSSION

Ventilation was a linear function of the power of exertion in both groups of subjects (Fig. 1). No significant differences were observed in the ventilation responses. The half-ventilation time for the transition process ($t_{1/2}$) was chosen to characterize the regulation of respiration in response to exertion because this index is accurate and easy to obtain and also because it can conveniently be compared with data in the literature. It will be clear from Fig. 2 that this time changes depending on the power of exertion: It increased between 200 and 500 kg • m/min in untrained subjects and to 800 kg • m/min in athletes. After reaching the "critical" power, $t_{1/2}$ decreased with an increase in the load. This distinctive pattern of behavior was observed in all subjects. The contradictory nature of the experimental results obtained by different workers can thus be explained by the fact that they chose different ranges of physical exertion and subjects with different levels of training.

The question of how to explain the differences in the velocity of the ventilation response to different loads arises. To study this problem a mathematical model of the respiratory system with feedback, constructed by the writers previously [1], which describes the adaptive mechanism of maintenance of homeostasis under different conditions, was used. Regulation takes place in accordance with signals received by the subject indicating changes in the internal milieu. The mechanism of regulation itself is described in the model by a feedback equation and it incorporates certain parameters relating to the given subject. These parameters were combined into an amplification factor of the feedback circuit, which in general form , represents the sensitivity of the respiratory center to CO_2.

The basic principle of the investigation was that the respiration control system can work satisfactorily within a certain range of possible amplification factors, and for a given subject this is not a constant parameter but is established as a certain optimal level in accordance with the momentary conditions of activity of the subject. Consequently, an optimality criterion, based on the following suppositions, was introduced into the model: 1) When starting exertion, the subject chooses a transitional regime in which the rate of change of ventilation is the minimal possible, in order to avoid overregulation in the system; 2) the duration of the transition process must be the shortest possible to ensure that, when exertion begins, the system can switch sufficiently rapidly to adequate respiration; 3) if the CO_2 concentration in the tissues reaches a certain critical threshold, the regime of the transition process established in the subject is such that the CO_2 concentration in the tissues will not exceed this level.

This principle of adaptation of the feedback circuit of the respiratory system explains the experimentally determined pattern of dynamics of $t_{1/2}$. The increase in $t_{1/2}$, it can tentatively be suggested, takes place during exertion of such intensities that the CO_2 concentration in the tissues has not yet reached the critical threshold and, for that reason, the optimal regime of regulation of ventilation is that in which the increase in $\dot{V}_E$ takes place sufficiently smoothly. With a further increase in the power of exertion the CO_2 concentration in the tissues goes beyond the critical threshold and, accordingly, an adequate increase in $\dot{V}_E$ in this regime must enable the excess of CO_2 to be eliminated very quickly; in this regime $t_{1/2}$ decreases with an increase in the load. The relationship observed (Fig. 2) can be used to obtain the critical power after which there is a switch from one regime of regulation to another. As Fig. 2 shows, this critical point in the group of athletes was shifted into the region of higher loads.

This investigation can thus be used to analyze the dynamics of regulation of the human respiratory system with respect not only to the time of the transition process of ventilation, but also to the power of critical exertion.

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