TEMPORAL AND SPATIAL PARAMETERS OF VOLUNTARY (ASSIGNED) HUMAN RESPIRATORY MOVEMENTS DURING VARIOUS TYPES OF CHEMORECEPTOR STIMULATION

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UDC 612.21-06

The dynamics of temporal and spatial parameters of assigned respiratory movements (compared with movement of the upper limb) was investigated in ten men aged 19-30 years under conditions of progressive hypoxia, hypercapnia, and a combination of hypoxia and hypercapnia. Hypercapnia (especially if combined with hypoxia) was shown to be a specific factor preventing voluntary control of respiratory movements. The factors indicated above had their greatest effect on the precision (exceeding the assigned respiratory volume) of the respiratory movements and ability to correct them. These facts are regarded as the result of chemoreceptor stimulation of the respiratory center (imperative stimulus).

KEY WORDS: regulation of respiration; voluntary movements; chemoreceptors; hypoxia; hypercapnia.

Voluntary control of respiration in man is known to be limited by the range of intensity of chemoreceptor stimulation of the respiratory center. Disturbances of the gas composition and acid–base balance of the internal medium of the body lead to the formation of an imperative stimulus [1], and as a result the respiratory movements fall completely under the control of the bulbar reflex-humoral mechanisms. However, the qualitative aspect of this influence of chemoreceptor stimulation on the voluntary control of respiratory movements has so far received little investigation. To assess specific features of this effect, it is necessary to know how the voluntary control of movements not concerned with the act of respiration is modified under the same conditions.

The object of this investigation was to study the characteristics of the temporal and spatial parameters of voluntary respiratory movements (by comparison with upper limb movements) during exposure to progressive hypoxia, hypercapnia, and a combination of hypoxia and hypercapnia.

EXPERIMENTAL METHOD

Experiments were carried out on ten clinically healthy men aged 19-30 years. The method of recording temporal and spatial parameters of assigned respiratory movements developed by the writer was used: motion-picture spirography with the Meta 1-25 spirograph. The parameters of the respiratory movements were assigned by a program recorded beforehand on the squared paper tape of the spirograph, which moved during the experiment "away from the subject" at a speed of 60 mm/sec. The subject had to reproduce this program under pursuit tracking conditions [3] by forced inspirations and expirations (Fig. 1). The experiments with upper limb movements (at the wrist joint) were performed in a similar way.

The characteristics of the program were as follows: number of assigned respiratory cycles 7; tidal volume 800 ml; time between assigned movements from 1.8 to 2.7 sec; length of program 32 sec; assigned

Department of Physiology of Man and Animals, Kalinin State University. Laboratory of Physiology of Respiration, I. P. Pavlov Institute of Physiology, Academy of Sciences of the USSR, Leningrad. (Presented by Academician V. N. Chernigovskii.) Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 83, No. 1, pp. 3-5, January, 1977. Original article submitted June 29, 1976.

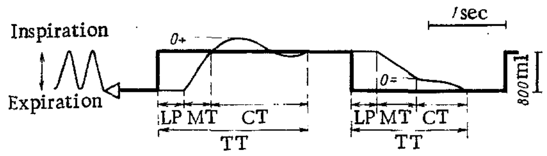

Fig. 1. Record of temporal and spatial parameters of assigned respiratory movements (motion-picture spirogram). Thick line represents assigned program; thin line is spirogram. Triangle marks time of activation of program. Remainder of explanation in text.

TABLE 1. Temporal and Spatial Parameters of Voluntary (assigned) Respiratory Movements and Upper Limb Movements in Initial State (1) and in Last Minute of Breathing in Closed System of Spirograph (2) (M ± m)

Parameters			Hypoxia and hypercapnia			Hypoxia			Hypercapnia		
			respiration	upper limb	*P*	respiration	upper limb	*P*	respiration	upper limb	*P*
TT	msec	1	1285±32	829±32	<0,001	1286±32	843±26	<0,001	1287±32	839±29	<0,001
		2	2103±58	1059±43	<0,001	1613±72	1266±79	<0,01	1871±58	1034±35	<0,001
		P	<0,001	<0,01		<0,01	<0,001		<0,001	<0,01	
LP		1	407±16	325±13	<0,01	405±16	321±14	<0,01	408±16	318±12	<0,01
		2	557±29	354±23	<0,001	499±17	412±30	<0,05	470±12	342±10	<0,001
		P	<0,01	>0,05		<0,01	<0,05		<0,05	>0,05	
MT		1	396±17	145±6	<0,001	397±17	131±4	<0,001	39[illegible]±16	135±6	<0,001
		2	450±27	148±6	<0,001	426±17	182±9	<0,001	441±18	136±6	<0,001
		P	>0,05	>0,05		>0,05	<0,001		>0,05	>0,05	
CT		1	482±20	359±23	<0,01	484±21	391±24	<0,05	483±20	386±27	<0,05
		2	1096±57	557±28	<0,001	687±85	672±49	>0,05	960±70	556±35	<0,001
		P	<0,001	<0,001		<0,05	<0,001		<0,001	<0,01	
0+	mm	1	1,9±0,2	2,2±0,2	>0,05	2,0±0,2	2,6±0,4	>0,05	1,9±0,2	2,6±0,5	>0,05
		2	8,6±0,8	2,1±0,3	<0,001	2,5±0,3	2,1±0,2	>0,05	4,8±0,6	1,8±0,3	<0,01
		P	<0,001	>0,05		>0,05	>0,05		<0,01	>0,05	
0−		1	1,0±0,2	1,4±0,1	>0,05	1,0±0,2	1,3±0,3	>0,05	1,0±0,2	1,3±0,2	>0,05
		2	0,1±0,03	2,4±0,2	<0,001	0,8±0,3	1,9±0,3	<0,05	0,7±0,2	1,7±0,4	>0,05
		P	<0,01	<0,01		>0,05	>0,05		>0,05	>0,05	

volume of ventilation 10.5 liters/min. Under these circumstances the total task performance time (TT), latent period (LP), movement time (MT), correction time (CT), precision of movement (PM), and the error with excess (0+) or with deficiency (0−) of the assigned volume (Fig. 1) were recorded.

Changes in chemoreceptor stimulation were obtained by breathing in the closed system of the spirograph "to the limit": 1) without absorption of CO_2 (exposure to hypoxia and hypercapnia); 2) with absorption of CO_2 (hypoxia); 3) without absorption of CO_2 but with automatic supply of O_2 into the spirograph system in an amount equal to that utilized (hypercapnia).

The experiments under the various conditions (hypoxia, hypercapnia, a combination of both) were alternated in random order. Each experiment with control of respiratory movements was preceded by an experiment with control of upper limb movements under the same conditions. All the subjects participated in a series of trial experiments and reproduced the assigned program sufficiently clearly.

Under ordinary conditions and during exposure to the factors specified above the following parameters of the assigned movements were recorded (four times, for 32 sec each time): S_{aO_2} (oxyhemometer), F_{ACO_2} (GUM-2 capnigraph), ventilation of the lungs.

EXPERIMENTAL RESULTS

In the initial state the mean values of the temporal parameters of the respiratory movements were considerably higher than the indices during upper limb movements (Table 1). Differences between the indices of accuracy of movements were not significant.

The combined action of progressive hypoxia and hypercapnia (a decrease in S_{aO_2} to 70.0 ± 5.1% and an increase in F_{ACO_2} to 9.17 ± 0.13%) was accompanied by an increase in MVR at the 6th minute of the function test to 75.4 ± 5.1 liters/min (by 606.3%). Voluntary control of respiratory movements [with an assigned minute volume of respiration (MVR) of 10.5 liters/min] against the background of this deficiency of pulmonary ventilation gave rise to maximal difficulty. A further decrease in S_{aO_2} and an increase in F_{ACO_2} as a rule led to abandonment of the respiratory program. A considerable increase in the motor task performance time and a decrease in accuracy of the respiratory movements were observed (Table 1). The greatest changes affected the values of CT and O+. Changes in the parameters of the assigned upper limb movements under the same conditions were less marked (Table 1).

Exposure to progressive hypoxia (a decrease in S_{aO_2} to 57.8 ± 3.6%) with an increase in MVR to 18.2 ± 1.3 liters/min caused much smaller changes in the parameters of the assigned respiratory movements (Table 1). Abandonment of the respiratory program was virtually never observed under these circumstances. Characteristically, hypoxia has a greater effect on voluntary control of upper limb movements than of respiratory movements.

The isolated action of progressive hypercapnia (an increase in F_{ACO_2} to 9.29 ± 0.14%) was accompanied by an increase in MVR to 52.4 ± 1.6 liters/min (by 460.1%). Voluntary control of respiratory movements under these conditions was considerably more difficult: A further increase in F_{ACO_2} as a rule led to abandonment of the motor program. The character of the effect of hypercapnia on parameters of the assigned respiratory movements was similar to that of combined hypoxia and hypercapnia (Table 1). In this case also there was a considerable increase in CT + O+. The effect of hypercapnia on voluntary control of upper limb movements was not significant (Table 1).

Hypoxia, hypercapnia, and a combination of both thus caused a decrease in the quality of voluntary control of the muscles not participating in the act of respiration. This was expressed as changes in the temporal and spatial parameters of the assigned movements in the same direction. Characteristically, the latent period and voluntary speed were changed to a lesser degree by the factors indicated above than ability to correct the movement. The main reason for the observed fact was evidently a disturbance of the optimal conditions of activity of the motor cortex (oxygen deficiency, acidosis).

The effect of progressive hypoxia and hypercapnia on the voluntary control of respiratory movements was manifested differently. An essential condition for voluntary control of respiration is cortical (volitional) inhibition of the rhythmic activity of the respiratory center by contrast to the excitatory chemoreceptor stimulation [1, 2, 4]. The increase in F_{ACO_2} and decrease in S_{aO_2} lead to considerable potentiation of chemoreceptor stimulation and to the formation of an imperative stimulus [1], the role of which can be reduced to an effort to bring the respiratory movements out of cortical control and to subject them to autonomous bulbar neurohumoral mechanisms, which must ultimately lead to correction of the deficiency of pulmonary ventilation. This is expressed as a disturbance of the voluntary control of respiratory movements in the form of exceeding the assigned respiratory volume, and a considerable increase in the difficulty of correcting the respiratory movements at the level of inspiration or expiration "inadequate" for the given condition.

The basic role in the formation of the imperative stimulus, preventing voluntary control of respiration, is played by hypercapnia [1, 5, 7], and this was manifested as a stronger (compared with hypoxia) effect of hypercapnia on the quality of performance of the respiratory program by the subject. Exposure to the action of hypoxia alone can hardly be considered to be a specific factor in the disturbance of voluntary control of respiratory movements. Ill-defined changes in the parameters of the assigned respiratory movements during hypoxia are evidently the result of oxygen insufficiency in the cortical motor centers and the respiratory center [6].

On the basis of indices obtained by the motion-picture spirography method, a definite idea can thus be obtained of the functional state of the apparatus for controlling respiration under different conditions.

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