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THE INFLUENCE OF LOW CONCENTRATIONS OF INSPIRED CARBON DIOXIDE ON SOME PHYSIOLOGICAL PARAMETERS AT MODERATE PHYSICAL WORK

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ABSTRACT

Six young coal miners were exposed to laboratory conditions, roughly identical with those existing in a coal-mine. The climate was maintained at an ET of 20 °C, while the subjects performed intermittent moderate work on a bicycle. They inhaled different mixtures of air and CO_2 by a close circuit method, where the CO_2 concentrations varied from 0.03 to 3.0 vol%. A constant climate, two different dynamic loads (300 and 450 kpm min^{-1}) and six different concentrations of CO_2 in the inspired air gave rise to 12 possible combinations, each of which was repeated twice in a series at random.

During the experiment many physiological parameters were measured such as heart frequency, tidal volume, breathing minute volume, oxygen uptake, carbon dioxide expired, alkali reserve, rectal temperature, skin temperature and subjective rating of fatigue.

First, $\dot{V}$ increased with increasing CO_2 insp. At a lower physical load (300 kpm min^{-1}) there was a greater increase of $\dot{V}$ due to V_T, whereas an augmented physical load (of 450 kpm min^{-1}) led to a greater increase of $\dot{V}$ due to f_v. This may partly be due to a decreased concentration of O_2 insp, but the main cause remains the increase in the CO_2 insp concentration. The oxygen uptake increased with increasing CO_2 insp. This can be explained as a consequence of a greater activity in the respiratory muscles. A portion of CO_2 insp is retained in the body, whereas the alkali reserve in the venous blood remains within physiological limits. Other physiological parameters (f_H, t_{re}, t_s, SRF) did not show any significant correlation with increased concentrations of CO_2 insp.

Summarizing the effects of low concentrations of CO_2 in the inspired air at moderate physical work, concentrations of CO_2 insp not exceeding 1.5 vol% in the inspired air were found to be tolerable.

In modern coal-mining using coal-cutting machines considerable amounts of carbon dioxide and methane tend to escape. The CO_2 concentration sometimes exceed 3 vol%, the MAC in Yugoslavia being 0.5 vol%. The vital question arises, whether work in such environmental conditions, at the usual effort and in the usual shifts, is still tolerable.

SUBJECTS AND METHODS

A previous study[5] dealing with the miner's work place was used to work out a programme for the laboratory experiment. Climatic conditions roughly identical with those met in mines were provided by a climatic chamber and maintained at an external temperature of 20 °C (Fig. 1). The subjects, i.e. six young miners, were volunteers, motivated partly by their own problem and

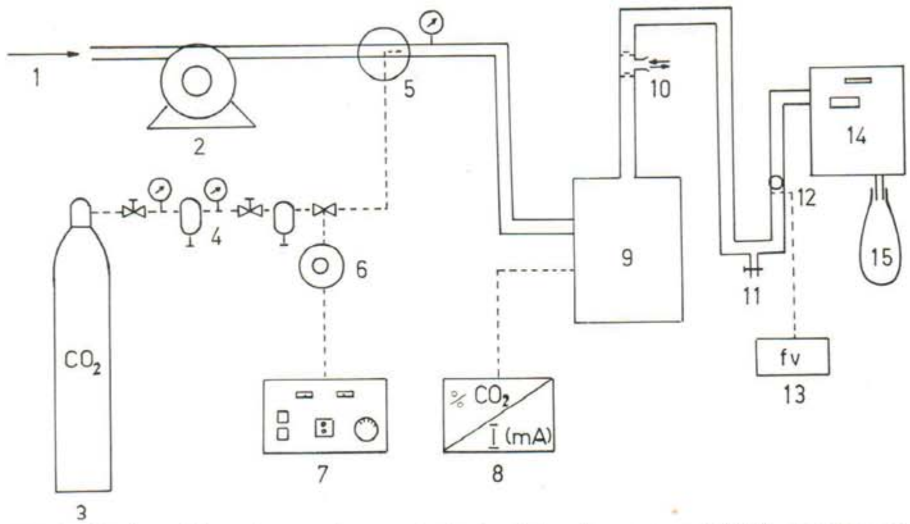

FIG. 1 – Design of the equipment: 1. room air, 2. electric fan, 3. container with CO_2, 4. valves and pressure gauges, 5. gas mixing chamber, 6. servo motor for opening, and closing of the valve, 7. regulator of the CO_2 concentration, 8. automatic analysis of CO_2 concentration, 9. container for the gas mixture, 10. ventilation (breathing) valve, 11. drop off of condensed water vapour, 12. and 13. ventilation rate counter, 14. gasometer, 15. a sample of the expired air.

TABLE 1
Data on volunteers taken in the experiment.

	Age	Height (cm)	Weight (kg)	Mean circumference: Thorax (cm)	Mean circumference: Abdomen (cm)	Maximal aerobic capacity (l min^{-1})	Vital capacity (cm^3)	FEVS (cm^3)
	35	175.5	71.3	99.0	83.0	3.20	5500	3960
	22	175.0	77.5	101.0	85.0	3.40	5620	4120
	22	176.5	72.5	90.5	87.0	2.60	5140	4700
	27	174.0	66.0	90.0	84.0	2.30	5500	3700
	22	176.5	73.0	94.5	78.0	4.10	4900	4180
	26	180.0	67.5	90.0	79.0	2.95	5150	4250
$\bar{X}$	25.7	176.3	71.3	94.2	82.7	3.1	5301.7	4151.7
S.D.	5.09	2.07	4.13	4.87	3.50	0.63	279.46	332.53

partly by the payment offered for the participation. Table 1 lists some personal data of these miners. In that study we found a mean oxygen uptake of about 0.8–1.1 l min^{-1} at a ventilation of 23–31 l min^{-1} during the intermittent work. On this basis the experimental load was planned consisting of cycling on the ergometer in twelve cycles of 12 minute work and 3-minute rests. The daily alternated load was 300, or 450 kpm min^{-1}. The subjects inhaled a mixture of air and CO_2 in a close circuit in the following concentrations (vol%): 0.03, 0.5, 1.0, 1.5, 2.0 and 3.0. The increased amount of CO_2 in the mixture caused diminishment of O_2 concentration similar to the atmosphere in a coal mine. Assuming a constant climate at two alternating dynamic loads and six different $CO_{2\ insp}$ concentrations, 12 possible combinations presented themselves each of which was repeated twice in a series at random.

The parameters heart frequency (f_H), tidal volume (V_T) and breathing minute volume ($\dot{V}$) were recorded every three minutes and expressed as a mean of the cycle (12-minute work plus 3-minute rest). After each cycle the end values of the rectal temperature (t_{re}), skin temperature (t_s) on the manubrium sterni and subjective rating of fatigue (SRF) were measured on a scale ranging from 0–100[4]. Gas samples of the expired air were taken after the first, fifth, seventh and eleventh cycle. Concentrations of CO_2 and O_2 were analysed according the Schollander's method and corrected to STPD conditions. Samples of the venous blood were taken after cycles 5 and 11. The alkali reserve was analysed according to the method of van Slyke.

RESULTS AND DISCUSSION

With increasing $CO_{2\ insp}$ concentration in the inspired air, the concentrations of $O_{2\ insp}$ decreased according to the following equation:

$$O_2\ vol\% = -0.22\ CO_2\ vol\% + 20.61$$

Thus the subjects inhaled a lower concentration of O_2 at a higher concentration of $CO_{2\ insp}$.

Cycles 5 and 11 appeared to be the most representative for a further analysis. First, the $\dot{V}$ increased according to the increased $CO_{2\ insp}$ in the form of a linear regression:

$$\dot{V}\ l\ min^{-1} = 4.86\ CO_{2\ insp}\ vol\% + 19.17 \quad E\ I/5/300$$
$$\dot{V}\ l\ min^{-1} = 4.97\ CO_{2\ insp}\ vol\% + 18.06 \quad E\ II/5/300$$
$$\dot{V}\ l\ min^{-1} = 4.66\ CO_{2\ insp}\ vol\% + 23.51 \quad E\ I/5/450$$
$$\dot{V}\ l\ min^{-1} = 4.25\ CO_{2\ insp}\ vol\% + 23.42 \quad E\ II/5/450,$$

where I/II means the first or the repeated series, 5 the fifth cycle, and 300 and 450, respectively the load in kpm min^{-1}.

No significant difference was established either between the first and the second series, or between the fifth and eleventh cycle, which confirms a stable physiological response (Fig. 2).

$\dot{V}$ l min^{-1} represents a product of the breathing frequency (f_v) and V_T. At 300 kpm min^{-1}, V_T was observed to cause a greater increase in $\dot{V}$, whereas at 450

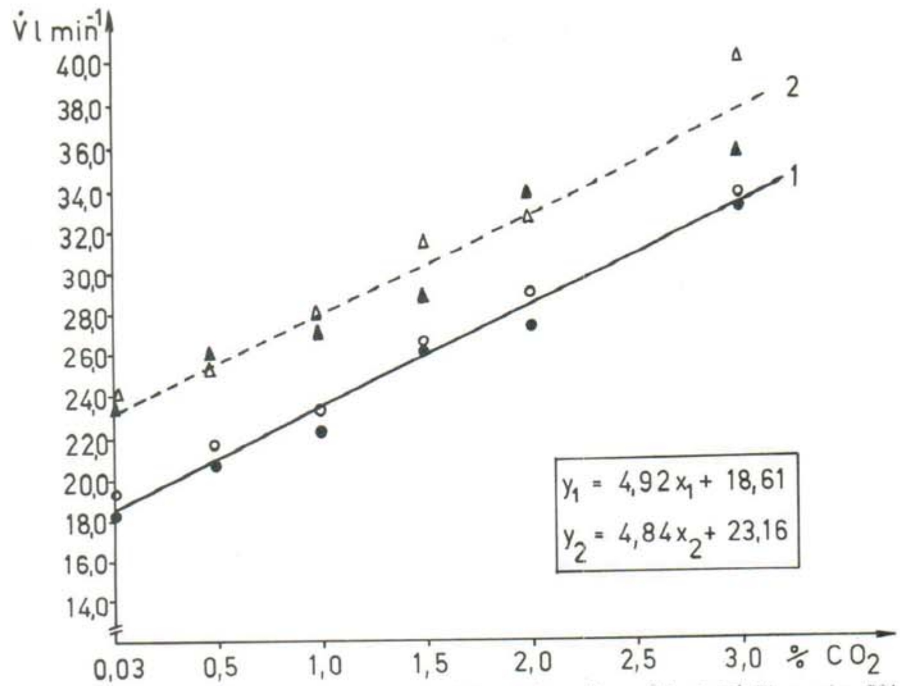

FIG. 2 – On the abscissa vol% CO_2 in the inspired air, on the ordinate $\dot{V}$ l min^{-1}. First series, fifth cycle 300 kpm min^{-1} ○; second series, fifth cycle 300 kpm min^{-1} ●; first series, fifth cycle 450 kpm min^{-1} △; second series, fifth cycle 450 kpm min^{-1} ▲. Regression equation y_1 for 300 kpm min^{-1}, y_2 for 450 kpm min^{-1}.

kpm min^{-1} $\dot{V}$ increased to a greater extent due to f_v (Figures 3 and 4). When augmenting the dynamic load, we observed an increased dependency of the $\dot{V}$ increase on f_v.

Menn and co-workers[3] report however, that at submaximum work and an increased concentration of $CO_{2\,\text{insp}}$ $\dot{V}$ depends more upon V_T. Bannister and co-workers[1] attribute the increase of $\dot{V}$ in dynamic work and in conditions of a higher concentration of $CO_{2\,\text{insp}}$ not only to an increased pCO_2, but also to a lowered concentration of pO_2 and a lowered threshold of the respiratory center to CO_2 respectively, resulting from acidosis and changes of body temperature.

As stated above, in our experiment the concentration of $O_{2\,\text{insp}}$ decreased with increasing concentration of $CO_{2\,\text{insp}}$ which partly explains the effects reported. On the other hand, there is no correlation between t_{re} and increased $\dot{V}$.

The O_2 uptake increased with increasing of $CO_{2\,\text{insp}}$ in a linear way. The following regression equations were found:

O_2 1 min^{-1} = 0.017 vol% $CO_{2\,\text{insp}}$ + 0.92 E I/5/300
O_2 1 min^{-1} = 0.041 vol% $CO_{2\,\text{insp}}$ + 0.84 E II/5/300
O_2 1 min^{-1} = 0.039 vol% $CO_{2\,\text{insp}}$ + 1.09 E I/5/450
O_2 1 min^{-1} = 0.025 vol% $CO_{2\,\text{insp}}$ + 1.10 E II/5/450,

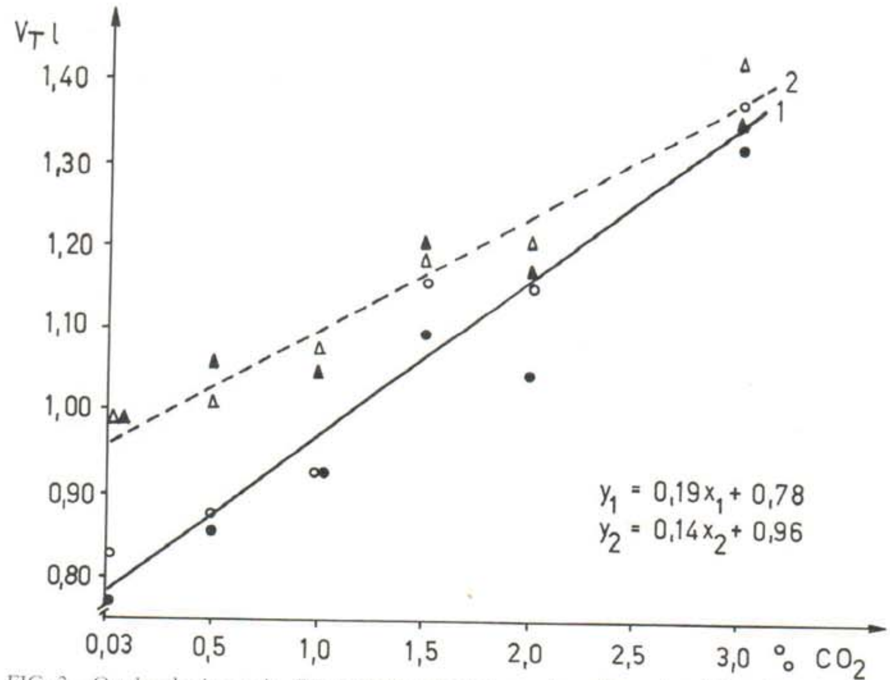

FIG. 3 – On the abscissa vol% CO_2 in the inspired air, on the ordinate the tidal volume V_T l. For description see Figure 1.

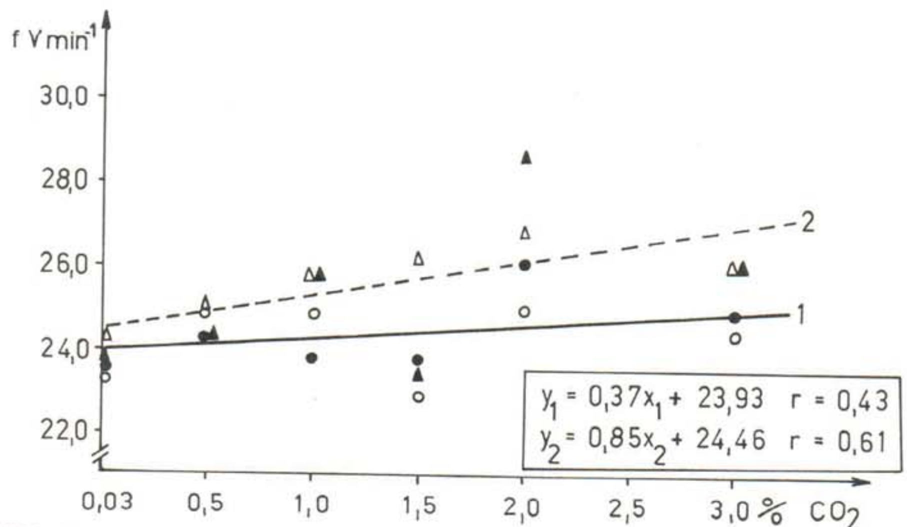

FIG. 4 – On the abscissa vol% CO_2 in the inspired air, on the ordinate the ventilation (breathing) frequency per minute. For description see Figure 1.

where I/II means the first or the repeated series, 5 the fifth cycle, 300 and 450 respectively the load in kpm min^{-1}.

Menn and co-workers[3] dispute such an increase of O_2 uptake which, however, is supported by Craig[2]. The increase might be due to an increased activity of the respiratory muscles with increasing $\dot{V}$.

A portion of CO_2 insp is retained in the body, following the equations:

$$y_{300} = 0.329\ x - 0.03$$
$$y_{450} = 0.336\ x + 0.07$$

where y is the gMol CO_2 retained per hour, and x the vol% CO_2 insp, while 300, and 450, respectively are the dynamic loads expressed in kpm min^{-1} (Fig. 5).

The question arose as to what happens with the CO_2 retained. As is well known, CO_2 is mainly transported by the blood as bicarbonate, in a smaller proportion only as carbonic acid or solved gas, and as carboxy haemoglobin. It can, of course, also enter the synthesis of organic molecules. The increased retention of CO_2 was anticipated to change the alkali reserve, but it remained within the physiological limits throughout the experiment (Table 2). As regards the other measured parameters (f_H, t_{re}, t_s, SRF) these did not show any significant correlation with increased concentration of CO_2 insp. Summarizing the effects of low concentrations of CO_2 insp at moderate physical work, concentrations of CO_2 insp up to 1.5 vol% in the inspired air may be considered risk-free.

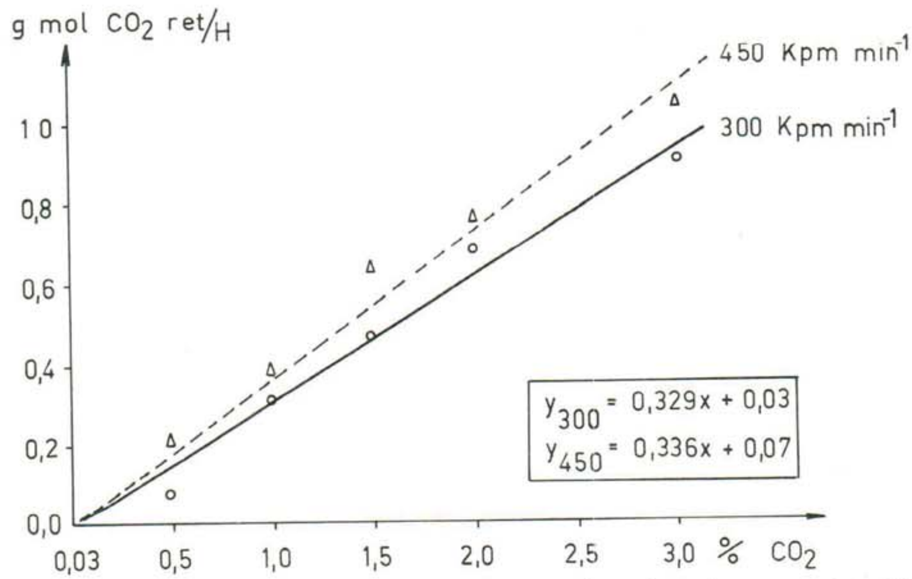

FIG. 5 – On the abscissa vol% CO_2 in the inspired air, on the ordinate the amount of the CO_2 retained in g mol per hour. The upper regression line refers to the exercise 450 kpm min^{-1}, the regression line beneath refers to the exercise 300 kpm min^{-1}.

TABLE 2

Mean alkali reserve in the venous blood at different concentrations of CO_2 in the inspired air and at two different dynamic loads.

vol% $CO_{2\ insp}$	300 kpm min^{-1}	450 kpm min^{-1}
0.03	49.28	48.80
0.5	52.65	53.76
1.0	58.24	56.00
1.5	71.23	58.70
2.0	47.04	56.82
3.0	53.76	56.00

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