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Ventilatory control in the athlete

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BYRNE-QUINN, EDWARD, JOHN V. WEIL, INGVAR E. SODAL, GILES F. FILLEY, AND ROBERT F. GROVER. *Ventilatory control in the athlete.* J. Appl. Physiol. 30(1): 91–98. 1971.—Control of ventilation was studied by measuring resting hypoxic and hypercapnic ventilatory drives together with the ventilatory response to hypoxia on exercise in a group of 13 athletes who were compared with a control group of 10 nonathletes. All subjects were native to low altitude and were resident at 1,600 m altitude. Hypoxic ventilatory drive was measured as the shape of the isocapnic $V_E - P_{A_{O_2}}$ curves and in the athletes averaged 35% of the value for the controls ($P < 0.01$). Similarly hypercapnic ventilatory drive as measured by the slope of the isoxic $\dot{V}_E - P_{A_{CO_2}}$ lines was reduced in the athletes to 47% of the controls ($P < 0.01$). In contrast, the induction of hypoxia during exercise produced an increase in ventilation in the athletes that was not significantly different from the controls. Both hypoxic and hypercapnic ventilatory drives were inversely related to maximal oxygen uptake. There was a positive correlation between resting hypoxic and hypercapnic ventilatory drives. Thus normal low-altitude native athletes have been shown to have marked attenuation of hypoxic and hypercapnic ventilatory drives at rest suggesting diminished peripheral chemoreceptor function.

nonathletes; hypoxic and hypercapnic ventilatory drives at rest; hypoxic ventilatory drive on exercise; maximal oxygen uptake

IN 1913 DOUGLAS and his colleagues (20) commented: "with a rapidly falling alveolar oxygen pressure some persons simply become blue and lose consciousness without the respiratory center making any evident response." Although occasional normal lowland subjects with a decreased ventilatory response to hypoxia have been reported, (10, 20, 30, 39, 40) no well-defined group with this characteristic has been described. It has recently been shown that man born in a hypoxic environment due either to high altitude (12, 29, 33, 35, 41) or to cyanotic congenital heart disease (21, 46) has a markedly decreased hypoxic ventilatory drive compared with sea-level natives. Monge (36) has suggested that "athleticism must be the norm for the survival of man in the high altitudes" implying similarity between athletes and high-altitude dwellers. During studies of hypoxic ventilatory drive at rest in normal lowlanders we observed an abnormally low response in two subjects. The only feature distinguishing these individuals was that they had engaged in college athletics and participated in regular physical conditioning programs. These points raised the question whether physical conditioning influenced hypoxic ventilatory drive. This report is a study of hypoxic and hypercapnic ventilatory drives at rest, and the hypoxic ventilatory drive on exercise, in a group of fully conditioned athletes and in a control group of sedentary nonathletes. The results indicate that athletes have a marked decrease in both hypoxic and hypercapnic ventilatory drives at rest but that during exercise the increase in ventilation in response to hypoxia is similar to that in nonathletes.

METHODS

Thirteen male athletes were selected from college varsity or national track, swimming, or cross-country skiing teams. They attended the University of Colorado at Boulder (altitude, 1,600 m). They were all native to low altitude. Ten nonathletes, residents of Denver (altitude 1,600 m), served as control subjects and were also native to low altitude and consisted of staff and students of the University of Colorado Medical Center. None of these had ever engaged in formal physical conditioning and they were generally considered to be sedentary. A full explanation of the proposed studies were given to the subjects and informed consent obtained.

All studies were carried out in the Webb-Waring Institute for Medical Research and the Cardiovascular Pulmonary Research Laboratory at the University of Colorado Medical Center, Denver (altitude 1,600 m).

Hypoxic ventilatory drive at rest. A detailed description of this technique has been given by us elsewhere (50). Briefly, the seated subject breathes through a Rudolph respiratory valve (Collins) from which gases are continuously sampled by an infrared CO_2 analyzer (Beckman LB-1) and by a fuel-cell oxygen analyzer (42, 51). Output from both analyzers together with information from a pneumotachograph (Fleich) are fed into an on-line PDP-8 computer, the data emerging as continuous, real-time oscilloscopic plots of end-tidal oxygen tension, end-tidal carbon dioxide tension, and minute ventilation. The end-tidal oxygen plot is used to guide the manual addition of nitrogen to the inspired air so as to produce a gradual fall in end-tidal oxygen tension from 120 to 40 mm Hg over 15–20 min. Output from the carbon dioxide analyzer is also displayed on an oscilloscope and used to guide the manual addition of 100% CO_2 to the inspired gas in amounts sufficient to prevent hypocapnia.

The use of this nonsteady-state technique for measuring the ventilatory response to hypoxia with isocapnia is justified by the fact that the ventilatory adjustment to a change in alveolar P_{O_2} is virtually complete in 20 sec and the maximal effective $P_{A_{O_2}}$ phase error is 1.2 mm Hg higher

than actually observed at a given point in time. Also the accuracy of the maintenance of isocapnia and a stable pH has been confirmed by simultaneous arterial blood analyses (50).

The plots of ventilation in relation to $P_{A_{O_2}}$ are hyperbolic. To compare curves a simple empirical equation is used similar to one originally suggested by Lloyd et al. (34). This equation relates ventilation and alveolar P_{O_2} as follows: $\dot{V}_E = \dot{V}_{E_o} + A/(P_{A_{O_2}} - 32)$, where $\dot{V}_E$ and $P_{A_{O_2}}$ are minute ventilation in liters per minute STPD and alveolar P_{O_2} in millimeters of mercury, respectively. Parameter $\dot{V}_{E_o}$ is the asymptote for ventilation obtained by extrapolation and parameter A determines the shape of the curve such that the higher the value for A the greater the hypoxic ventilatory drive.[1] In practice the curve-fitting procedure and evaluation of parameters are accomplished by a time shared GE-400 computer programmed for a nonlinear least-squares curve fit by the method of Marquardt (11).

Hypercapnic ventilatory drive at rest. With the seated subject breathing air progressive hypercapnia is induced by gradual addition of 100% CO_2 to the inspired gas such as to increase the $P_{A_{CO_2}}$ by 10–15 mm Hg in a period of 10–15 min. End-tidal P_{O_2} is maintained constant at about 70 mm Hg (normal for Denver) by the addition of 100% nitrogen to the inspired gas in amounts sufficient to prevent it rising during the ensuing hyperventilation. The relationship between $P_{A_{CO_2}}$ and minute ventilation is linear and the data are analyzed by least-squares linear regression (43). The equation traditionally used to relate ventilation and $P_{A_{CO_2}}$ is as follows: $\dot{V}_E = S(P_{A_{CO_2}}-B)$ (15) where B is the extrapolated intercept on the abscissa ($P_{A_{CO_2}}$ axis) and S is the slope of the line expressed as change in ventilation (Δ $\dot{V}_E$ liters/min STPD) per unit change in $P_{A_{CO_2}}$ ($\Delta P_{A_{CO_2}}$ mm Hg).

Hypoxic ventilatory drive during exercise. During two or three levels of steady-state submaximal treadmill exercise ventilation was measured while breathing first 100% oxygen and second 14% oxygen in nitrogen. After 6 min of a given work load with the subject breathing 100% oxygen ($P_{I_{O_2}}$ = 630 mm Hg) the inspired air was switched, without the subject stopping, to 14% oxygen ($P_{I_{O_2}}$ = 88 mm Hg) and maintained for a further 6 min. Ventilation was measured during the last minute of each period by a Parkinson-Cowan ventilation meter. Samples of expired gas were obtained from a 5-liter mixing chamber interposed in the expiratory side of the system and gases were measured by the micro-Scholander technique. Oxygen uptake was not measured during the hyperoxic period of exercise as measurement of this when high oxygen concentrations are breathed is unreliable (6, 9, 27). As a measure of work load oxygen uptake was measured during the last minute of hypoxic exercise and this value assumed in analysis of data during the hyperoxic period. The two or three points relating $\dot{V}_E$ to $\dot{V}_{O_2}$ for each subject at a given inspired oxygen fraction were analyzed by linear regression. The mean slope for a group was obtained by averaging the regression coefficients and intercepts for each individual in the group.

[1] Value of parameter A as originally used by the Oxford group (34) can be obtained by dividing A in the above equation by $\dot{V}_{E_o}$ taking into account that ventilation is expressed here as STPD.

In analyzing the data it was assumed that during submaximal exercise, the change from hyperoxia to hypoxia produced no change in oxygen uptake. This assumption was based on a number of studies which showed that at high altitude a given submaximal work load required the same $\dot{V}_{O_2}$ as at low altitude (1, 4, 20, 24, 38). In acute studies at sea level, $\dot{V}_{O_2}$ has also been shown to be independent of $F_{I_{O_2}}$ (3, 27), although there are two studies that show a small decrease in $\dot{V}_{O_2}$ during hypoxic compared to normoxic exercise (17, 37).

Maximal oxygen uptake. This was measured in all subjects while breathing ambient air. A modified Balke test was used with a constant treadmill speed suitable to the individual and the grade was increased automatically 1.5% per minute. The test was planned so that exhaustion was reached between 6 and 8 min. During this period samples of expired air were collected and analyzed at 0.5-min intervals.

Statistical analysis. In another communication by us the control group in this paper is also used as the control group when studying high altitude natives and high altitude residents (49). Therefore the data were all analyzed together by one-way analysis of variance and Scheffé's test was applied to judge appropriate contrasts.

RESULTS

Anthropometric data are listed in Table 1. There was no significant difference in the height, weight, and body surface area between the two groups, but the athletes were significantly younger ($P < 0.05$). To quantitate physical working capacity, maximal oxygen uptake was measured in both groups. As expected the athletes had a significantly higher maximal oxygen uptake as compared with controls, the mean value for the athletes being 60.1 ± 2.0 (SEM) ml/kg per min and for the controls 40.2 ± 2.4 ml/kg per min ($P < 0.01$).

Hypoxic ventilatory drive at rest. The two curves relating ventilation to alveolar P_{O_2} in Fig. 1 are representative studies in a control subject (*MJ*) and in an athlete (*CM*). The computed curves show the data points and the fitted lines for subjects with a normal and a decreased hypoxic ventilatory drive. In all studies, the curve fit was significant ($P < 0.005$). The individual values for parameters A and $\dot{V}_{E_o}$ are also given in Table 1. Individual curves of all control subjects are compared with curves of all the athletes in Fig. 2. The mean value for A, the shape-determining parameter was 180.2 ± 14.5 (SEM) for the controls and 62.4 ± 10.6 for the athletes indicating a marked decrease in hypoxic ventilatory drive in the athletes ($P < 0.01$). The ventilatory asymptote $\dot{V}_{E_o}$ was 4.8 ± 0.3 liters/min for the controls and 5.5 ± 0.3 liters/min for the athletes ($P > 0.05$). Mean curves for the group of controls and the group of athletes computed from the above mean values are shown in Fig. 3.

Normal resting $P_{A_{CO_2}}$ in Denver (altitude 1,600 m) is 36.0 mm Hg. The mean resting normoxic $P_{A_{CO_2}}$ for the control subjects was 36.5 ± 0.9 mm Hg and during hypoxia averaged 36.0 ± 0.9. Similarly for the athletes the values were 36.6 ± 0.6 and 36.5 ± 0.6, respectively, showing that isocapnia was well maintained in both groups.

The effect of hypercapnia upon the hypoxic curves was also studied in four athletes (Table 2). Hypercapnia of 5

TABLE 1. *Anthropometric data and results*

	Age, yr	Ht, cm	Wt, kg	BSA, m²	$\dot{V}O_{2\,max}$	Hypoxic Ventilatory Drive at Rest					Hypercapnic Ventilatory Drive	
						N	P_{ACO_2}		*A*	$\dot{V}E_o$		
							Control	Hypoxia			*S*	*B*
Controls												
EB-Q	33	175	74.1	1.90	40.3	7	36.1	35.0	159.7	5.3	2.54	27.7
VC	22	181	68.6	1.87	38.2	3	41.9	41.0	99.5	4.4	0.97	30.7
RFG	45	180	71.0	1.91	29.5	4	39.0	38.7	194.8	4.9	1.13	28.3
MJ	22	180	88.6	2.09	47.7	2	32.2	31.9	169.6	5.0	1.43	29.5
RMcG	26	185	93.9	2.19	49.8	3	39.1	37.8	170.1	6.2	3.01	34.8
MR	23	180	105.5	2.25	30.9	2	33.1	33.8	176.9	4.8	2.14	28.2
IES	35	182	67.7	1.88	49.1	5	32.9	32.7	142.5	5.8	1.52	27.1
BU	30	182	67.7	1.88	45.4	4	38.2	38.2	272.2	4.3	2.58	34.2
JVW	34	175	75.5	1.91	31.6	7	36.8	35.6	217.2	2.6	2.48	35.0
RY	22	179	88.6	2.08	39.8	2	36.1	34.8	199.8	5.0	2.41	31.9
Mean	29	180	77.1	2.00	40.2		36.5	36.0	180.2	4.8	2.02	30.7
±SE	2	±1	±5.8	±0.05	±2.4		±1.0	±0.9	±14.5	±0.3	±0.22	±1.0
Athletes												
PA	22	182	66.8	1.86	64.2	3	37.3	37.6	38.7	5.6	1.06	31.5
RB	24	170	59.5	1.69	60.5	2	36.8	36.5	45.4	4.5	0.62	30.9
PE	21	175	68.5	1.84	63.1	2	33.3	33.7	39.8	4.6	0.82	28.2
JF	19	193	90.9	2.22	43.6	2	37.9	38.0	69.7	4.7	0.93	32.7
FG	24	185	71.8	1.95	69.7	3	34.0	33.5	66.4	6.4	1.17	29.5
DH	18	195	88.6	2.22	50.8	3	35.8	35.0	184.4	6.1	1.18	29.0
TK	22	184	80.7	2.04	60.8	2	37.9	38.5	36.7	4.6	0.60	32.1
JL	21	185	71.1	1.94	68.4	3	36.7	36.9	52.5	6.8	0.76	26.2
KL	28	182	68.2	1.88	63.2	2	35.0	35.3	44.2	6.4	0.70	27.6
CM	22	178	64.6	1.81	62.9	2	39.2	39.1	58.0	4.3	0.53	24.8
WM	19	170	67.0	1.78	59.5	2	40.4	39.7	67.5	4.7	1.24	35.8
WR	20	188	76.8	2.03	60.1	1	32.6	32.6	48.1	6.5	1.45	25.7
GT	22	181	71.8	1.95	54.5	3	38.5	37.7	60.3	6.4	1.14	32.8
Mean	22	182	72.8	1.94	60.1		36.6	36.5	62.4	5.5	0.94	29.8
±SE	±1	±2	±2.5	±0.04	±2.0		±0.6	±0.6	±10.6	±0.3	±0.08	±0.9

A is the shape parameter of the $\dot{V}E - P_{AO_2}$ curves. $\dot{V}E_o$ is the ventilatory asymptote of the $\dot{V}E - P_{AO_2}$ curves. *S* is the slope of the $\dot{V}E - P_{ACO_2}$ lines. *V* is the P_{ACO_2} intercept of the $\dot{V}E - P_{ACO_2}$ lines.

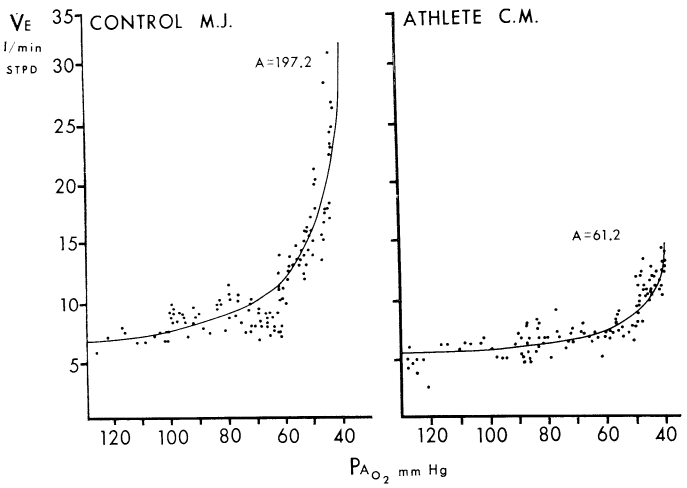

FIG. 1. Ventilatory response to isocapnic hypoxia in a typical control subject and a typical athlete. Measured data points are shown in relation to the computed curve in both studies.

mm Hg above resting alveolar P_{CO_2} was produced by adding 100% CO_2 to the inspired air and maintained at this value while inducing hypoxia in the regular manner. The mean *A* value in these four subjects rose from 52.7 ± 6.2 (SEM) to 118.7 ± 18.8 ($P < 0.01$), this latter being significantly lower than mean value for the controls during normocapnia ($P < 0.05$). Furthermore, in a previous report (50) 5-mm hypercapnia was induced in six of the present control subjects and the mean *A* value for these was 453 ± 103.

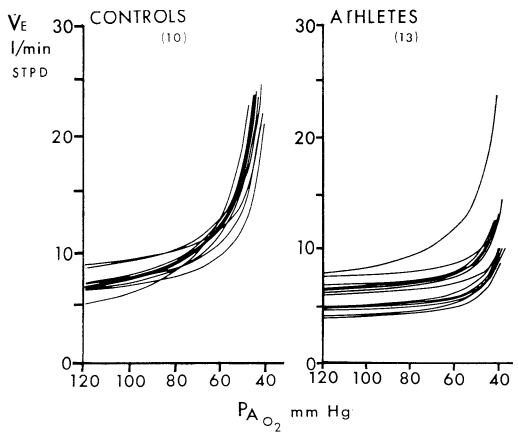

FIG. 2. Individual curves relating alveolar oxygen tension and minute ventilation showing the contrast between 10 controls and 13 athletes.

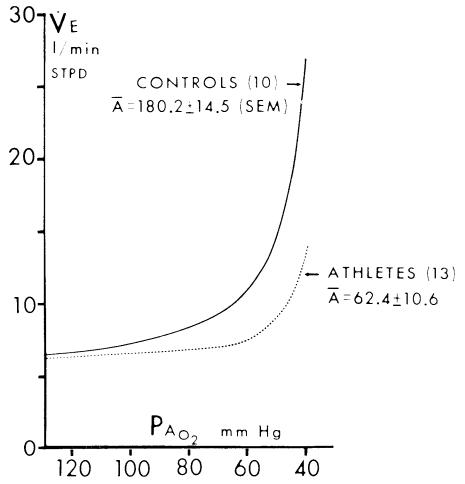

FIG. 3. Mean curves relating $P_{A_{O_2}}$ and $\dot{V}_E$ for the two groups showing decreased hypoxic ventilatory drive in athletes as a group.

TABLE 2. *Interaction between hypoxia and hypercapnia in four athletes*

Subj	Normocapnia			Hypercapnia		
	P_{ACO_2}	*A*	$\dot{V}_{E_0}$	P_{ACO_2}	*A*	$\dot{V}_{E_0}$
RB	36.8	45.4	4.5	41.6	133.7	5.0
PE	33.3	39.8	4.7	39.6	65.0	8.9
CM	39.2	58.0	4.3	44.8	124.4	9.1
WM	40.4	67.5	4.7	45.4	151.8	13.4
Mean	37.4	52.7	4.6	42.9	118.7	9.1
±SE	1.6	6.2	1.0	1.4 *	18.8 *	1.7 †

* $P < 0.01$. † $P < 0.05$.

Hypercapnic ventilatory drive. The two studies relating ventilation and alveolar P_{CO_2} in Fig. 4 are representative of a control subject (*RY*) and an athlete (*PA*) and consist of the actual data points and the line fitted by linear regression. In all studies the regression was significant ($P < 0.01$). Individual studies of all 10 control subjects and all 13 athletes are shown in Fig. 5. Individual values for parameters *S* and *B* are given in Table 1, the mean value for *S* being 2.02 ± 0.22 for the controls and 0.94 ± 0.08 for the athletes ($P < 0.01$). The intercept on the $P_{A_{CO_2}}$ axis, *B*, is 30.7 ± 1.0 for the controls and 29.8 ± 0.7 for the athletes which is not significantly different. The mean lines relating $\dot{V}_E$ and $P_{A_{CO_2}}$ for both groups are shown in Fig. 6 and reveal the decrease in hypercapnic ventilatory drive occurring in association with the decrease in hypoxic ventilatory drive in the athletes.

Hypoxic ventilatory drive during exercise. This was studied in seven control subjects and seven athletes. Analysis of the data was based on the linear relationship between $\dot{V}_E$ and $\dot{V}_{O_2}$ during submaximal exercise. For the seven control subjects breathing 100% oxygen (controls 100%), $\dot{V}_E$ was plotted against $\dot{V}_{O_2}$ at three different levels of $\dot{V}_{O_2}$ and analyzed by linear regression. A mean line was calculated from the seven individual regressions. Similarly, the mean line for this control group was calculated when breathing 14% oxygen (control 14%). The same technique of analysis

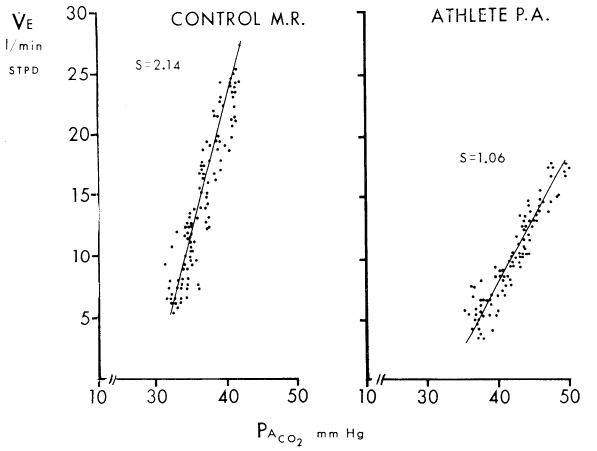

FIG. 4. Ventilatory response to hypercapnia in a typical control subject and a typical athlete. Measured data points are shown in relation to the line obtained by linear regression in both studies.

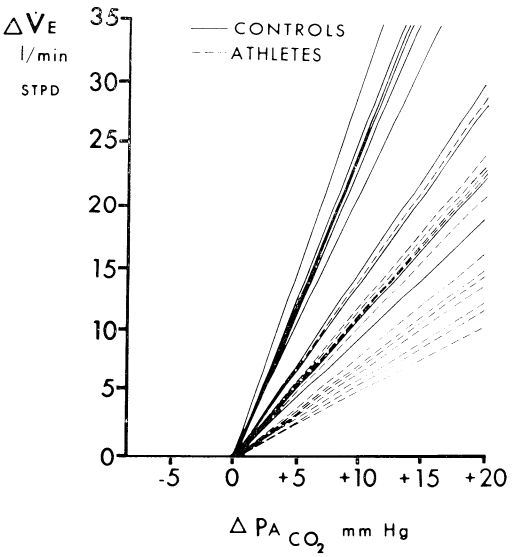

FIG. 5. Individual lines relating change in minute ventilation to change in alveolar carbon dioxide tension in all 10 controls and all 13 athletes.

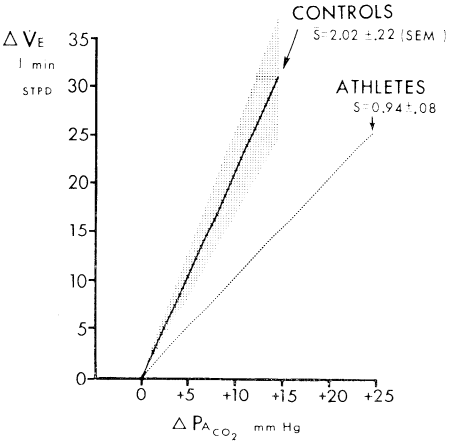

FIG. 6. Mean lines relating $\Delta P_{A_{CO_2}}$ and $\Delta\dot{V}_E$ in both groups showing the decreased hypercapnic ventilatory drive in the athletes. Shaded area encompasses ± 2 SEM.

was applied to the data from the seven athletes to obtain the mean line when they were breathing 100% oxygen (athletes 100%) and when breathing 14% oxygen (athletes 14%). Mean lines are plotted in Fig. 7*A* from the following regression equations (standard deviations in parentheses):

$$\text{Controls } 100\% \quad \dot{V}_E = \underset{(3.5)}{1.2} + \underset{(0.0064)}{0.0268}\,\dot{V}_{O_2} \quad \text{(BTPS)} \quad \text{(STPD)}$$

$$\text{Controls } 14\% \quad \dot{V}_E = \underset{(5.0)}{-6.3} + \underset{(0.0142)}{0.0454}\,\dot{V}_{O_2}$$

$$\text{Athletes } 100\% \quad \dot{V}_E = \underset{(4.5)}{9.7} + \underset{(0.0060)}{0.0160}\,\dot{V}_{O_2}$$

$$\text{Athletes } 14\% \quad \dot{V}_E = \underset{(9.7)}{2.8} + \underset{(0.0071)}{0.0309}\,\dot{V}_{O_2}$$

Ventilation for a given oxygen consumption was lower in the athletes than in the controls when breathing 100% oxygen ($P < 0.01$) and this was also true when breathing 14% oxygen. However, both groups significantly increased ventilation when inspired oxygen was switched from 100 to 14%. This can be more easily assessed by obtaining the mean regression lines for each group relating the increase in ventilation from 100 to 14% oxygen ($\Delta\dot{V}_E$ 14–100%) to oxygen uptake:

$$\text{Controls} \quad \Delta\dot{V}_E\ (14\%\text{–}100\%) = \underset{(3.9)}{-7.5} + \underset{(0.0091)}{0.0186}\,\dot{V}_{O_2}$$

$$\text{Athletes} \quad \Delta\dot{V}_E\ (14\%\text{–}100\%) = \underset{(5.6)}{-6.9} + \underset{(0.0031)}{0.0150}\,\dot{V}_{O_2}$$

These lines are plotted in Fig. 7*B* where it is shown that the slope for the athletes is not significantly different from that for the controls ($P > 0.5$), thus the increase in ventilation from breathing hyperoxic to hypoxic gases is similar for both groups on exercise.

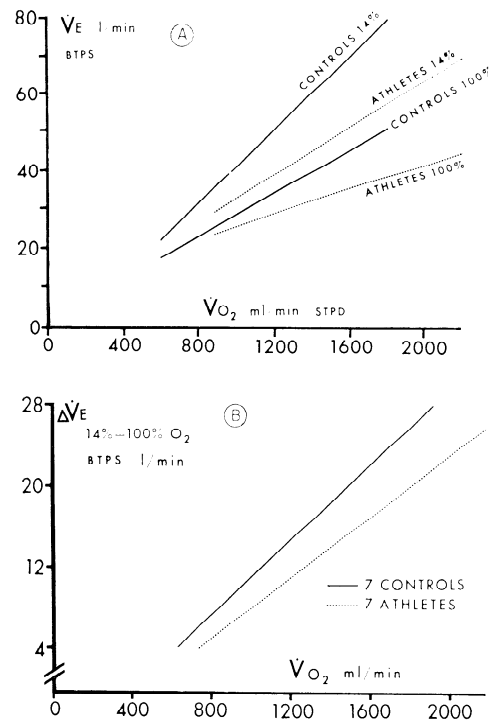

FIG. 7. *A:* mean lines relating minute ventilation and oxygen uptake in 7 controls and 7 athletes breathing 100% O_2 and 14% O_2. *B:* mean lines relating the increase in ventilation by changing inspired oxygen from 100 to 14% and oxygen uptake in controls and athletes. Lines are not significantly different in either position or slope.

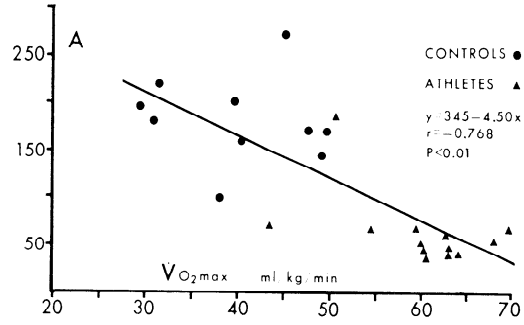

FIG. 8. Decreasing hypoxic ventilatory drive, as measured by *A*, with increasing maximal oxygen uptake.

DISCUSSION

Conclusions to be drawn from this study are that athletes, compared with nonathletes, have a decreased hypoxic ventilatory drive accompanied by a decreased hypercapnic ventilatory drive at rest. However, on exercise the increase in ventilation with hypoxia was similar in both groups. There are no previous reports of decreased chemoreceptor function in athletes at rest but on exercise it has been suggested that physically conditioned subjects have decreased sensitivity to hypoxia because when pure oxygen is administered their decrease in ventilation is less than in unfit subjects (9). This response has also been shown to diminish after training (16).

In comparing these two groups, it is realized that they consist of two populations as regards physical fitness. However, there was some overlap in maximal oxygen uptake, so that in fact these groups present a continuous spectrum of physical fitness. Therefore, it appeared reasonable to combine the two groups and examine the relationship between maximal oxygen uptake and hypoxic ventilatory drive as measured by *A* (Fig. 8), as well as hypercapnic ventilatory drive as measured by *S* (Fig. 9). There is a significant negative correlation with both, and it follows that there would be a positive correlation between *A* and *S* (Fig. 10).

Schaefer and colleagues (39, 40) also observed that subjects with a low ventilatory response to carbon dioxide also have a low response to hypoxia (10.5% O_2 in N_2 without CO_2 replacement). Decrease in the ventilatory responses to both hypoxia and hypercapnia were also found by Chiodi (12) in his original observations of high altitude subjects and we have recently confirmed this (50). However, a number of studies of high-altitude natives, while showing decrease in hypoxic drive, have failed to observe any change in the response to hypercapnia (5, 6, 23, 31).

It is well established that the ventilatory response to hypoxia is mediated via the peripheral chemoreceptors and in man marked decrease in the ventilatory response to hypoxia has been shown to occur after vagus and glossopharyngeal nerve block (25), after glomectomy for asthma (28), and after denervation of the glomus by carotid endarterectomy (48). The mechanisms of ventilatory response to

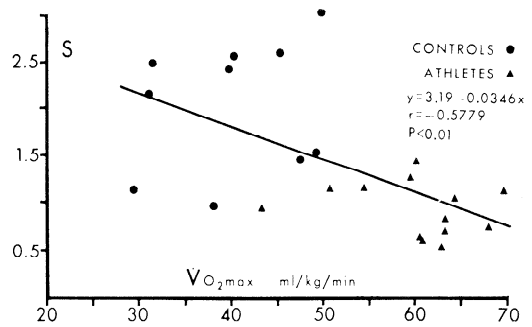

FIG. 9. Decreasing hypercapnic ventilatory drive, as measured by *S*, with increasing maximal oxygen uptake.

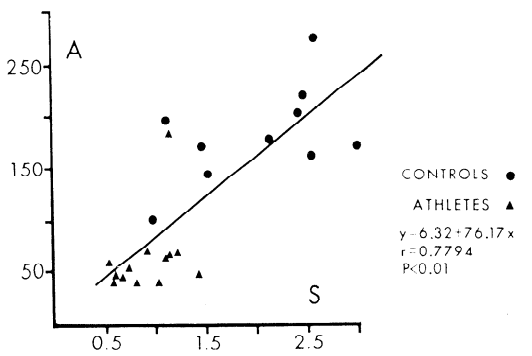

FIG. 10. Positive correlation between hypoxic and hypercapnic ventilatory drives.

increased carbon dioxide are more complex. Mainly it is mediated centrally via medullary chemoreceptors. However, the peripheral chemoreceptors are also stimulated by hypercapnia and these can account for between 20 and 55% of the ventilatory response (45). This is the order of magnitude of the reduction in hypercapnic drive in the athletes of the present study. Single afferent fiber preparations from the carotid body have been shown to convey information about both hypoxia and hypercapnia (8, 22) and it has recently been shown that high-altitude natives with decreased hypoxic drive also have a decreased ventilatory response to a single breath of carbon dioxide as well (44), suggesting diminished peripheral chemoreceptor function. These observations suggest that the alterations in ventilatory control in the athelete are also due to decreased peripheral chemoreceptor function. This interpretation is further supported by the marked decrease in the interaction between hypoxia and hypercapnia in the four athletes so studied. At the present time, however, it is impossible to adduce whether this alteration is in the function of the carotid body itself or in the central integration of its afferent impulses.

It is well known that acute hypoxia increases ventilation in normal men exercising at sea level (1, 3, 4, 13). The present exercise studies were performed in athletes to see if their decreased chemoreceptor function at rest would modify the increase in their ventilation during hypoxic exercise. When $F_{I_{O_2}}$ was reduced from 100 to 14% during exercise, the athletes increased their ventilation a similar amount to the controls. However, end-tidal P_{CO_2} was not held constant nor were alveolar P_{O_2} and P_{CO_2} monitored. It is possible that the ventilatory response to hypoxia during exercise was underestimated in the control subjects because their higher absolute ventilation may have rendered them more hypocapnic than the athletes. Hence, the interpretation of these results as regards pure hypoxic drive should be viewed with this in mind. These data do, however, provide information concerning ventilation during exercise under conditions simulating acute exposure to high altitude. We have observed a similar discrepency between a decreased response to hypoxia at rest, undoubtably mediated via the peripheral chemoreceptors, and a normal response to hypoxia during exercise in long-term residents and natives of high altitude (3,100 m) (49). However, Lahiri et al. (32) have found a diminished response to hypoxia during exercise in natives to 4,540 m.

The contribution of the peripheral chemoreceptors to the increase in ventilation during normoxic exercise is thought by some to be minimal (14) since the normal chemical stimuli do not change. However, when inspired P_{O_2} is increased abruptly, ventilation decreases so rapidly (2, 6, 19) that a reflex mediated by peripheral chemoreceptor activity is strongly suggested (18). A possible interpretation of the present results is that there is some mechanism other than the peripheral chemoreceptor system responding to hypoxia during exercise, e.g., cerebral anerobic metabolism producing an increased intracellular hydrogen ion concentration in medullary chemoreceptors. But it has also been postulated (18, 26) that during exercise there is enhanced activity of the peripheral arterial chemoreceptors such that they respond more to a given level of oxygenation than at rest, serving to explain the usual discrepancy which exists between ventilation actually measured and that calculated from the sum of known neurogenic and chemical stimuli. Recently Biscoe and Purves (7) have shown that, with normoxemia, carotid body activity is increased during passive exercise in the cat. Hence either an increase in carotid body activity or an increase in the "gain" of the central integrating mechanism could be operative.

The finding that the decreased chemoreceptor function in the athletes at rest is related to maximal oxygen intake would suggest that training a sedentary individual up to the maximal oxygen intake of an athlete might reduce his hypoxic and hypercapnic ventilatory drives. Unfortunately, regular training can in most cases only increase the maximal oxygen intake 10–20% (5); thus a sedentary man with a $\dot{V}_{O_{2\,max}}$ of 40 ml/kg per min could only increase this to 44–48 ml/kg per min by training. It is probable that athletes have to be born with natural endowment. Whether their decreased hypoxic and hypercapnic ventilatory drives are linked to this or are acquired through prolonged training is not resolved by this study.

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