Seasonal Variations of Ventilatory Response to Hypercapnia at Rest

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Summary In order to examine the seasonal variation of CO₂ sensitivity, the slope (S) of the ventilatory response to CO₂ was determined in 10 healthy males throughout a year. It was found that the average value of logarithm S was significantly ($p < 0.05$) higher in the September than in the annual average, though average magnitude of S was not significantly different. In addition, the average value of ventilation ($\dot{V}_E(60)$) corresponding of $P_{A_{CO_2}}$ 60 mmHg was significantly ($p < 0.05$) lower in January than in September. These results indicate that the timing of the start and/or finish of training is an important factor in the effect of physical training on the S and $\dot{V}_E(60)$.

Key words: CO₂ sensitivity, seasonal variation.

It has hitherto been reported that the slope of the ventilatory response to CO₂ (S), which is considered to be an index of central chemosensitivity to hypercapnia, is generally lower in a group of highly trained athletes. This blunted chemosensitivity of well-trained athletes may have been due to a reduced drive that occurred as a result of training. However, it is not yet certain whether hypercapnic ventilatory response is altered by physical training. In fact, the ventilatory response to hypercapnia after training has been reported to be decreased (BLUM *et al.*, 1979), unchanged (BRADLEY *et al.*, 1980), or increased (KELLEY *et al.*, 1984), as compared with pretraining. The discrepancy in the effects of physical training on CO₂ sensitivity might have resulted from the differences in several factors such as training intensity, kind of training, and training periods.

In the previous study, we found that during training periods S decreased in July as compared with April and increased in December as compared with July. These tendencies were also observed during deconditioning periods (MIYAMURA and ISHIDA, 1990). These results suggest that some seasonal variation in resting CO₂ sensitivity may exist. The purpose of this study, therefore, was to confirm

whether or not the ventilatory response to hypercapnia changes according to season.

Ten male students, aged 18–22 years, in our university participated in this study as subjects. All the subjects received detailed explanations as to the experimental nature before participating. At first, all subjects came to the laboratory twice on separate days. On the first day, each subject was only familiarized with the apparatus and testing procedures in order to exclude the possible effect of strain or behavioral influence on breathing; at the beginning of July they were made to perform a preliminary test to sufficiently accustom them to rebreathing. The actual measurement of ventilatory response line for each subject was then performed 6 times in 1 year; the first measurement was made at the middle of July and it was repeated at 2-month intervals. The subjects were studied in the afternoon at least 1 h or more after their lunch.

The ventilatory response line to carbon dioxide was determined in the sitting position by the rebreathing method (READ, 1967). The subject rested on a comfortable chair for 30 min before the test. The experimental set-up was similar to that described previously (MIYAMURA and ISHIDA, 1990). A rubber bag with a capacity of about 10 l was placed in an air-tight plastic box, which was connected at one end to a spirometer (Benedict-type, Fukuda, Tokyo) for recording tidal volume by means of the bag-in-box principle. The opposite end of the rubber bag was connected to a three-way stop cock. The rebreathing bag was filled with 6 l of a gas mixture of about 7% CO₂ in O₂. The nose was occluded with a nosegrip and the mouth was connected to the mouthpiece. After 5–6 breaths of room air, rebreathing started at the end of a maximal expiration and continued for 4 min. Minute ventilation ($\dot{V}_E$) was calculated for successive 30-s intervals from tidal volume, and gas volume was corrected to BTPS conditions. To estimate alveolar CO₂ partial pressure ($P_{A_{CO_2}}$), CO₂ concentration was recorded continuously by drawing gas from the mouthpiece through an infrared CO₂ analyzer (Capnograph, Godart, Holland). After passing through the analyzer, the sample gas was returned to the rebreathing bag. The CO₂ analyzer was calibrated with three calibration gases that had been checked by a Scholander microgas analyzer.

The slope of the ventilatory response line to hypercapnia was determined by fitting a straight line by the least squares to 30-s data points during 4 min of rebreathing: $\dot{V}_E = S(P_{A_{CO_2}} - B)$, where S is the slope expressed as change in ventilation per unit change in $P_{A_{CO_2}}$ and B is the extrapolated intercept in the abscissa. The ventilation ($\dot{V}_E(60)$) corresponding to $P_{A_{CO_2}}$ of 60 mmHg was also calculated from the equation $\dot{V}_E(60) = S(60 - B)$. Since the above equation can be expressed as $\log \dot{V}_E(60) = \log S + \log(60 - B)$, furthermore, $\Delta \log \dot{V}_E(60)$, $\Delta \log S$, and $\Delta \log(60 - B)$ were estimated from the differences between the monthly average and the annual average for each subject.

Values were given in terms of mean and standard deviation. Comparison of ventilatory drive was performed using the paired t -test, and differences of $p < 0.05$ were considered significant.

Table 1 summarizes monthly and annual average values and standard deviations

Table 1. Monthly and annual averages and standard deviations for S , B , and $\dot{V}_{E(60)}$.

Variable	Jul	Sep	Nov	Jan	Mar	May	Annual
S ($l \cdot \text{min}^{-1} \cdot \text{mmHg}^{-1}$)	1.50 (± 0.37)	1.70 (± 0.66)	1.54 (± 0.68)	1.49 (± 0.65)	1.45 (± 0.62)	1.57 (± 0.73)	1.54 (± 0.54)
B (mmHg)	42.2 (± 3.5)	43.9 (± 4.1)	43.0 (± 4.5)	44.0 (± 5.6)	43.2 (± 5.6)	43.1 (± 6.4)	43.2 (± 4.0)
$\dot{V}_{E(60)}$ ($l \cdot \text{min}^{-1}$)	26.8 ^{a,b} (± 8.7)	26.1 ^{c,d} (± 8.1)	24.3 (± 6.7)	21.3 ^{a,c} (± 7.3)	21.9 ^{a,b,d} (± 5.7)	23.7 (± 6.1)	24.0 (± 6.1)

Values are means ($\pm$ S.D.) for 10 subjects. * The difference between monthly and annual average is significant ($p < 0.05$). ^{a,b,c,d} Variables sharing the same subscript are significantly different ($p < 0.05$).

Fig. 1. Seasonal variation of the $\dot{V}_{E(60)}$, B , and S . The zero of the ordinate represents the annual average for each subject. The * mark and the variables a, b, c are the same in Table 1.

for S , B , and $\dot{V}_{E(60)}$. The average values of the coefficient of variation in S , B , and $\dot{V}_{E(60)}$ were 17.0, 6.6, and 16.0% for each subject, and it was 4.7, 1.1, and 6.5% for the 10 subjects, respectively. It was found in this study that the S value in 8 out of the 10 subjects was higher in September as compared with the annual average, and for 3 out of 10 subjects in March; the average values of S were about 11.6% higher in September than in March, though this difference is not statistically significant. Similar tendencies were observed in the $\dot{V}_{E(60)}$. Therefore, the average

value of $\dot{V}_E(60)$ was significantly ($p < 0.05$) lower in January (20.7 ± 7.2 l/min) than in September (25.1 ± 8.4 l/min). Figure 1 shows the results of $\Delta \log(\dot{V}_E(60))$, $\Delta \log S$, and $\Delta \log(60 - B)$. The average value of $\log S$ was significantly ($p < 0.05$) higher in September than in the annual average. The coefficients of correlation between $\Delta \log(\dot{V}_E(60))$ and $\Delta \log S$ or $\Delta \log(60 - B)$ were 0.82 ($p < 0.05$) and 0.44 (not significant).

As described previously, we have observed that during training periods the slope of ventilatory response to hypercapnia at rest decreased in July as compared with April and increased in December as compared with July. These tendencies were also observed during deconditioning periods (MIYAMURA and ISHIDA, 1990). From these results, we hypothesized the existence of seasonal variation in the CO_2 sensitivity in man. It was found in this study that S was higher in the summer than in the winter; the difference in the average S between summer and winter was 11.6% though this difference was not statistically significant (Table 1). In addition, the average value of $\log S$ in September was significantly higher than the annual average and $\dot{V}_E(60)$ was significantly ($p < 0.05$) higher in the summer than in the winter. Since the coefficient of correlation between $\Delta \log(\dot{V}_E(60))$ and $\Delta \log S$ was $r = 0.82$ ($p < 0.05$), variation of $\dot{V}_E(60)$ seems to be mainly affected by the variation of S as shown in Fig. 1.

At present, we cannot explain the reason for higher S in the summer, based on definite physiological grounds. In this experiment, the subjects performed a preliminary test in order to sufficiently accustom them to rebreathing and to exclude the possible effects of strain or unfamiliarity with the technique. However, it is well known that ventilatory response to CO_2 is affected by various factors such as race, heredity, sex, body size, hormones, temperature, etc. In conjunction with the last factor, warming the skin stimulates breathing and can initiate thermal polypnea, whereas cold applied to the face causes bronchoconstriction and inhibits breathing; BURGESS and WHITELAW (1984) found that the mean slope was reduced significantly ($p < 0.05$) from 3.0 to $2.5 \text{ l} \cdot \text{min}^{-1} \cdot \text{mmHg}^{-1}$ by the cold air, when the subjects rebreathed through their nose 8% CO_2 in O_2 at warm ($23\text{--}30^\circ\text{C}$) and at cold ($-4\text{--}10^\circ\text{C}$) temperature. In the present year-long study, the subject rebreathed 7% CO_2 in O_2 from a rebreathing bag through his mouth with his nose occluded at the room temperature. Although the experimental room temperatures were $28\text{--}30^\circ\text{C}$ in the summer and $16\text{--}19^\circ\text{C}$ in the winter, respectively, the room or rebreathing gas temperature may influence nasal temperature or the slope of ventilatory response to CO_2 .

On the other hand, until now it has been widely accepted that in Japanese the basal metabolic rate is higher in the winter than summer, though the difference between the winter and summer rate is now diminishing as compared with 40 years ago (SASAKI, 1987). Furthermore, MASKREY and NICOL (1979) have observed that in rabbits, increased ventilation produced by breathing CO_2 caused greater heat loss than did thermally induced panting. Since nasal temperature, body temperature, metabolic rate, and heat loss were not measured in the present study,

the relationship between seasonal variation of CO₂ sensitivity and these factors mentioned above is uncertain. To elucidate this problem, further investigation is necessary. However, our results obtained here indicate that the start and/or stopping of physical training is an important factor to assess the effect of training on the hypercapnic ventilatory response in man when the training periods are relatively long.

REFERENCES

- BLUM, J., KANAREK, D., CALLAHAN, B., BRASLOW, N., and KAZEMI, H. (1979) The effect of training on CO₂ ventilatory responsiveness in normal subjects. *Am. Rev. Respir. Dis. (Suppl.)*, **4**: 119.
- BRADLEY, B. L., MESTAS, J., FORMAN, J., and UNGER, K. M. (1980) The effect on respiratory drive of a prolonged physical conditioning program. *Am. Rev. Respir. Dis.*, **122**: 741–746.
- BURGESS, K. R. and WHITELAW, W. A. (1984) Reducing ventilatory response to carbon dioxide by breathing cold air. *Am. Rev. Respir. Dis.*, **129**: 687–690.
- ENGEL, L. A. and RITCHIE, B. (1971) Ventilatory response to inhaled carbon dioxide in hyperthyroidism. *J. Appl. Physiol.*, **30**: 173–177.
- KELLEY, M. A., LAUFE, M. D., MILLMAN, R. P., and PETERSON, D. D. (1984) Ventilatory response to hypercapnia before and after athletic training. *Respir. Physiol.*, **55**: 393–400.
- MASKREY, M. and NICOL, S. C. (1979) Responses of conscious rabbits to CO₂ at ambient temperatures of 5, 20, and 35°C. *J. Appl. Physiol.*, **47**: 522–526.
- MIYAMURA, M. and ISHIDA, K. (1990) Adaptive changes in hypercapnic ventilatory response during training and detraining. *Eur. J. Appl. Physiol.*, **60**: 353–359.
- READ, D. J. C. (1967) A clinical method for assessing the ventilatory response to carbon dioxide. *Aust. Ann. Med.*, **16**: 20–32.
- SASAKI, T. (1987) Energy metabolism of human. In: *Handbook of Physiological Science*, ed. by NAKAYAMA, T. and IRIKI, M., Igakushoin, Tokyo, Vol. 22, pp. 56–75.