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Ventilatory Response to Hypercapnia before and after Harvest Season in the Ama.

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The present study was undertaken to confirm whether hypercapnic drive in the Ama changes before and after harvest season. The subjects were five active unassisted Amas (Kachido), aged 41—65 years, with 24 to 27 years of diving carrer, at Izu in Shizuoka Prefecture, Japan. Ventilatory response line to CO_2 was determined twice by CO_2 rebreathing method on different days both in March and September for each subject. It was found that mean slopes of the ventilatory response lines were 1.22 l/min/mmHg (0.76 l/min/m^2/mmHg) for the March and 1.18 l/min/mmHg (0.73 l/min/m^2/mmHg) for the September, respectively, this difference being insignificant.

Though several studies have been conducted to compare ventilatory response to exercise or hypercapnia either in breath-holding or skin divers, concerning the difference in the ventilatory response to CO_2 between divers and non-divers are conflicting; Studies by Song *et al.* (1963)[20] of breath-hold divers and non-divers and Froeb (1960)[7] of SCUBA (self-contained underwater breathing apparatus) divers and non-divers showed no significant difference between absolute magnitude of ventilatory response to CO_2 of the diving and non-diving groups under ambient conditions. However, Schaefer (1955)[18] and Broussolle *et al.* (1969) have shown that divers exhibited a lower ventilatory response to CO_2 than non-divers. Florio *et al.* (1979)[6] also demonstrated statistically significant differences in the breathing pattern and ventilatory response to carbon dioxide between the divers using underwater breathing apparatuses and non-divers.

On the other hand, it can be assumed that lower ventilatory response to hypercapnia in the divers may be due to the reduced exitability of respiratory system to the repetitional breath-hold diving for long periods because a few authors found that the slope of the ventilatory response line to CO_2 was significantly lower in the athletes than that in the untrained subjects(Byrne-Quinn *et al.*, 1971[3]; Miyamura *et al.*, 1976[13]). In fact Schaefer (1965)[19] reported the aquirement of a high tolerance against CO_2 when submarine escape instructors trained for a one year from the depth of 90 feet, and this tolerance remians a same level for three months after termination of training. Furthermore, Igarashi (1969)[8] observed that sensitivity of the respiratory response to CO_2 just after the harvest season was significantly lower than that three months or six months later, although the method of his study was not properly performed from the present day's standard (Cherniack *et al.*, 1977). The present study was undertaken to obtain further information about the difference in the ventilatory response to CO_2 between breath-holding divers and non-divers and to confirm whether hypercapnic drive in the Ama

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changes before and after harvest seasons.

Methods

The subjects were 5 active unassisted Ama (Kachido), aged 41–65 years, with 24 to 27 years of diving carrer, at Izu peninsula in Shizuoka prefecture, Japan. All subjects consented after the nature of experiments had been explained. No particular clinical examination was carried out but all subjects were physically active female divers in good health. Their physical characteristics and lung volume are shown in Table 1. The subjects were studied in one room of Japanese inn near the sea side where they have been working for about 4 hours each day throughout a year except from December to February. The subjects were briefly informed about the experimental procedure, but not about the results of any of the experiments until the study had been completed. The experiments were performed midmorning at least one hour after their last meal. Ventilatory response line to carbon dioxide was determined by the Read's rebreathing technique (Read, 1967)[16]. As shown in Fig. 1, the rebreathing bag with a capacity of 10 liter was placed in an air-tight plastic box which was connected to a respirometer (Benedict type, 13.5 L, Fukuda, Tokyo, Japan) to record ventilation. After the subjects had rested in sitting position on a comfortable chair for 30 min, the subject rebreathed a gas mixture of about 7% CO_2 in O_2 of 5–6 liter for 4 min. A continuous record of alveolar P_{CO_2} (P_{ACO_2}) during rebreathing was obtained by drawing a sample of gas from the mouthpiece through the infrared CO_2 analyzer (Capnograph, Godart, Holland). This CO_2 analyzer was calibrated after rebreathing with two mixture gas of known

Table 1. Physical characteristics and lung volume of the subject.

Subject	Age (yr)	Height (cm)	Weight (kg)	BSA (m^2)	VC (L)	$FEV_{1.0}$ (L)
H. Y	43	155	62	1.60	3.15	2.41
K. F	41	154	75	1.72	2.59	1.77
A. Y	45	150	60	1.54	2.64	1.95
M. Y	64	149	64	1.58	1.79	1.28
M. F	54	154	60	1.58	2.64	1.52
Mean	49.4	152.4	64.4	1.60	2.56	1.78
±SD	8.5	2.4	5.6	0.06	0.43	0.38

BSA; Body surface area, VC; Vital capacity, $FEV_{1.0}$; Forced expiratory volume in one second.

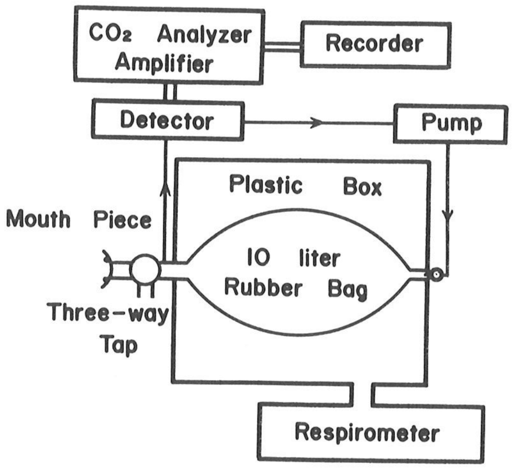

Fig. 1 Experimental set-up for determination of ventilatory response to CO_2 by the rebreathing method.

CO_2 concentration that had been checked by the Scholander micro-gas analyzer. After passing through the CO_2 analyzer, the sample gas was returned to the rebreathing bag via the three-way stopcock to prevent changes in the bag volume as shown in Fig. 1.

Minute ventilation ($\dot{V}_E$) was calculated for successive 30 sec intervals from spriographic recording, and gas volumes were corrected to BTPS conditions. From these P_{ACO_2} and $\dot{V}_E$ thus obtained, we calculated the slope of the ventilatory response line to CO_2 by the least-squares method as following: $\dot{V}_E = S\ (P_{ACO_2} - B)$, where S is the slope of the line expressed as change in ventilation per unit change in P_{ACO_2} and B is the extrapolated intercept on the abscissa (P_{ACO_2} axis). In order to ascertain the reproducibility of the slope of ventilatory response line for each subject, duplicate determinations were conducted for each subject of different days both in March and September in 1979, respectively.

Since none of the subjects were experienced maximal exercise, submaximal exercise test was performed by a mechanically braked bicycle ergometer (Monark, Sweden) with work load of 360 kgm/min for 5 min before and after harvest season except subject M. Y.; both force and pedaling rate were kept constant al 1 kp and 60 rpm, respectively. Oxygen uptake was measured by the Douglas bag method. Expired gas was collected into a Douglas bag during final one minute of exercise. The collected gas volume was determined with gasometer (Shinagawa, Japan), and gas analysis was performed with an oxygen analyzer (Morgan S-3A, England) and an infrared CO_2 analyzer (Capnograph, Godart, Holland). These analyzers calibrated frequently with two known calibration gases, and output from these analyzer were connected to two channel pen recorder (Yokogawa, Japan). Heart rate during exercise was continuously monitered from a bipolar chest lead equipped with digital display of minute heart rate. All probability values were derived by applying paired t test, and differences in $p < 0.05$ were considered significant.

Results

Table 2 indicates the individual values of heart rate (HR), pulmonary ventilation ($\dot{V}_E$) and oxygen uptake ($\dot{V}O_2$) during submaximal bicycle exercise both before (March) and after (September) harvest seasons in the Ama. The average values of heart rate during last one min (4–5) in exercise was significantly higher in September than that in March

Table 2. Heart rate, pulmonary ventilation and oxygen uptake during submaximal bicycle exercise before and during harvest season in the Ama.

Subject	Heart rate (beats/min)		Ventilation (l/min)		Oxygen uptake (l/min)	
	March	September	March	September	March	September
H. Y	94	107	24.5	25.7	0.84	0.80
K. F	113	127	23.1	26.9	0.95	0.98
A. Y	115	130	24.5	29.8	1.04	1.09
M. Y	–	–	–	–	–	–
M. F	88	93	23.5	21.1	0.92	0.75
Mean	102	114	23.9	25.8	0.93	0.91
±SD	11.7	15.1	0.61	3.1	0.07	0.13

($p < 0.05$). However, the mean values of pulmonary ventilation and oxygen uptake during exercise were almost the same both in March and September, the difference being statistically not significant. As described above, reliability of the slope of $\dot{V}_E$ − P_{ACO_2} line, both in March and September, was examined by duplicate determinations for each subject. Ventilation ($\dot{V}_E$) is plotted againt P_{ACO_2} in Fig. 2, both in March and September, for all subjects in the first and second measurement. As shown in this Figure, $\dot{V}_E$ − P_{ACO_2} response line scatter more or less as a whole. The slopes of the ventilatory

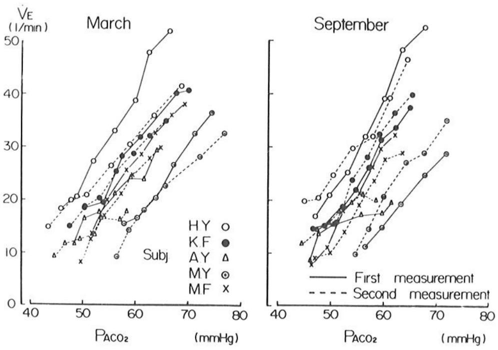

Fig. 2 Ventilatory response line to hypercapnia on March (left) and September (right) for each subject.

Table 3. Ventilatory response to carbon dioxide in the Ama as represented $\dot{V}_E = S(P_{ACO_2} - B)$.

Subject	March						September					
	I		II		Mean		I		II		Mean	
	S	B	S	B	S	B	S	B	S	B	S	B
H. Y	1.06	29.7	1.39	48.5	1.37	38.5	1.37	31.7	1.83	37.8	1.60	34.7
K. F	1.12	33.9	1.22	35.0	1.17	34.4	1.57	38.6	1.45	38.5	1.51	38.5
A. Y	0.59	28.1	1.02	35.7	0.80	31.9	0.67	25.2	0.55	24.5	0.61	24.8
M. Y	1.17	46.8	1.57	50.5	1.37	48.6	0.77	38.1	0.66	37.4	0.71	37.7
M. F	1.45	42.9	1.36	40.2	1.40	41.5	1.39	41.1	1.64	41.4	1.51	41.2
mean	1.07	36.2	1.38	41.9	1.22	38.9	1.15	34.9	1.23	35.9	1.18	35.3
± SD	0.27	7.3	0.25	6.4	0.22	5.8	0.36	5.7	0.52	5.8	0.43	5.6

I; First measurement, II; Second measurement, S; slope of the ventilatory response line (l/min/mmHg), B; extrapolated intercept on P_{ACO_2} (mmHg).

response line to hypercapnia in all subjects were shown in Table 3. The ranges of the slope of $\dot{V}_E$ − P_{ACO_2} line before harvest season (March) in the first and second measurements were from 0.59 to 1.45 l/min/mmHg and from 1.02 to 1.73 l/min/mmHg, respectively. The mean values of the slopes in March were 1.07 for the first and 1.38 l/min/mmHg for the second measurements. The difference between these two values was statistically not significant. Furthermore, the ranges of the slopes of $\dot{V}_E$ − P_{ACO_2} line during (nearly end of) harvest season (September) in the first and second measurements were from 0.67 to 1.57 and from 0.55 to 1.83 l/min/mmHg, respectively. The average slopes of the first and second measurements in September were 1.15 and 1.23 l/min/mmHg, respectively, this difference being again insignificant. As a results, the mean values and standard deviation of the slope of the $\dot{V}_E$ − P_{ACO_2} line were 1.22 ± 0.22 l/min/mmHg in March and 1.18 ± 0.43 l/min/mmHg in September when the mean value of duplicate determinations was taken as the slope of $\dot{V}_E$ − P_{ACO_2} line of each individual subjects (Table 3).

The mean values of the B were 36.2 mmHg for the first measurement and 41.9 mmHg for the second measurement in March, and it was 34.9 and 35.9 mmHg is September. The overall average values and standard deviation of B were 38.9 ± 5.8 mmHg in March and 35.3 ± 5.6 mmHg in September as shown in Table 3.

Discussion

It is well known that miximum oxygen uptake increased by physical training, and oxygen uptake and heart rate decreased at given work load after training for long periods (Åstrand and Rodahl, 1970)[1]. However, Ikai *et al.* (1975) observed no significant difference in maximum oxygen uptake between Ama and control women. It was found in this study that pulmonary ventilation and oxygen uptake during submaximal bicycle exercise were almost the same before (March) and nearly end (September) of the harvest season, while heart rate was significantly higher in September than that in March. Since heart rate during submaximal exercise is closely related to the environmental temperature, higher heart rate in March may be due to the difference in the room temperature (Rowell *et al.*, 1966;[17] Pandolf *et al.* 1975[15]; McAdle *et al.* 1976[12]). It may be also possible to assume that harvesting work of the Ama seems to be not so strong enough as to cause an increase in aerobic work capacity as described by Ikai *et al.* (1975)[9].

The Amas participated in the present study engage in the diving work with breath-holding almost all the year round except winter seasons. It is conceivable that, being accustomed to such breath-holding, the Ama may have acquired tolerance to hypercapnia and/or hypoxia. In fact Schaefer (1955)[18] found that submarine escape training instructors exhibited a lower ventilatory response to hypercapnia than non-divers and attributed this to adaptation to breath-hold diving (Schaefer, 1965)[19].

It has also been demonstrated by Florio *et al.* (1979)[6] that the hypercapnic ventilatory drive as measured by the slope of the $\dot{V}_E - P_{ACO_2}$ line was reduced significantly to 33% of control in divers using underwater breathing apparatus and B values was significantly higher in the divers than non-divers, whereas Froeb (1960)[7] observed no significant difference between absolute ventilatilatory response to CO_2 of the SCUBA (self-contained underwater breathing apparatus) diving and non-diving groups.

In 1969, Igarashi[8] have determined the ventilatory response to CO_2 in the eight active Amas, 34–42 years old, with 10–30 years of diving careers, at three different periods, — just after the harvest season, then three month later, and just before the opening next season, *i. e.*, six months after non-harvesting activity. In all eight subjects, the sensitivity of the respiratory system to CO_2 just after (0.48 $l/min/m^2/mmHg$) the harvest season was significantly lower than that observed in three months (0.89 $l/min/m^2/mmHg$) or six months (0.91 $l/min/m^2/mmHg$) later ($p < 0.001$). Furthermore, Igarashi (1969)[8] was shown experimentally that daily practice of repetitive breath-holding on land could rapidly reduce the sensitivity to carbon dioxide in man, and suggested that the decrease in CO_2 sensitivity of the Ama during harvest season may result of physiological adaptation to diving work, which rapidly develops and rapidly disappears. However, it was found in this study that mean slopes of ventilatory response lines were 1.22 $l/min/mmHg$ (0.76 $l/min/m^2/mmHg$) in March and 1.18 $l/min/mmHg$ (0.73 $l/min/m^2/mmHg$) in September, respectively, this difference being insignificant. These results suggest that the ventilatory response to hypercapnia in the Ama 23–27 years of diving career does not different between before and nearly end of the harvest seasons.

At present no difinite explanation for the discrepancy in the results between the present and Igarashi's studies can be presented on definite physiological grounds. It may be attributed the various factors such as subjects, breath-holding time, diving carrer and depth, method of calculating the slope. Possible reasons so far considered were as follows: 1) Difference in the subjects; Although the Ama in both studies are unassisted breath-hold divers (Kachido) with comparable diving career, length of diving period in the year is much shorter (May to October) in Igarashi's than in our subjects (March to November). A brief interruption in diving activities could have been a cause of insufficient deacclimatization from adaptation to CO_2 stimulation in our subjects, thus no difference in CO_2 response was seen between the beginning and mid-harvest season. However, Masuda *et al.* (1980)[11] also found no significant difference in slope of ventilatory response line between the same subjects with the present study and the control female group with comparable ages. 2) Method of study; Igarashi (1969)[8] estimated CO_2 response slope from the ratio of change in ventilation ($\dot{V}_E$) to change in alveolar P_{CO_2} ($PACO_2$) between room air breathing and at the end of 5% CO_2 inhalation for 15 min. Since the respiratory data in room air breathing are not recommended to include in evaluation of CO_2 response slope due to large deviation from the response line frequently encountered (Cherniac *et al.*, 1977)[4], physiological significance of Igarashi's data seems to be evaluated with some reservation. On the other hand, we used the rebreathing method for the following reasons; (1) The so-called steady state method is very time consuming because 7–13 min were needed in order to obtain a steady state during which the measurements were made, and ventilation and alveolar P_{CO_2} were recommended to determine at 4 to 5 level of increasing P_{CO_2} (Miyamura *et al.*, 1976)[13]. (2) The rebreathing method is rapidly and simple, so that the response line can be obtained within a single trial lasting only four minute. (3) The slope of the response line at rest were reported to be the same both in the steady state and rebreathing methods (Read, 1967[16]; Clark, 1968[5]; Linton *et al.*, 1973[10]. (4) There was a high correlation between the first and second slopes when the slope of the response line was compared with duplicate determination by the rebreathing method (Ohkuwa *et al.*, 1980)[14]. In order to confirm whether hypercapnic drive in the Ama changes before and after harvest season, accordingly, it will need further investigation to examine whether the slope of ventilatory response to CO_2 obtained by rebreathing and Igarashi's methods is the same.

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References

1) Åstrand, P. O. and K. Rodahl : Textbook of work physiology, McGraw-Hill Book Comp., New York, 1970, p. 337—382.
2) Broussolle, B., E. Bensimon, and J. Lonjon : La Sensibilite ventilatorie au gaz carbonique des plongeurs sous-marins. *C. R. Seances Soc. Biol. Paris*, **163** : 2641, 1969.
3) Byrne-Quinn, E., J. W. Weil, I. E. Sodal, G. F. Filley, and R. F. Grover : Ventilatory control in the athlete. *J. Appl. Physiol.*, **30** : 91—98, 1971.
4) Cherniac, N. S., J. Dempsy, V. Fencl, R. S. Fitzgerald, R. V. Lourenco, A. S. Rebuck, J. Rigg, J. W. Severinghaus, J. W. Weil, W. A. Whitelaw and C. W. Zwilich : Workshop on assessment of respiratory control in humans. I. Methods of measurement of ventilatory response to hypoxia and hypercapnia. *Amer. Rev. respir. Dis.*, **115** : 177—181, 1977.
5) Clark, T. J. H. : The ventilatory response to CO_2 in chronic airway obstruction measured by a rebreathing method. *Clin. Sci.*, **34** : 559—568, 1968.
6) Florio, J. T., J. B. Morrlson, and W. S. Butt : Breathing pattern and ventilatory response to carbon dioxide in divers. *J. Appl. Physiol. : Respirat. Environ. Exercise Physiol.*, **46** : 1076—1080, 1979.

7) Froeb, H. F. : Ventilatory response of SCUBA divers to CO_2 inhalations. *J. Appl. Physiol.*, **16** : 8—10, 1960.
8) Igarashi, A. : A respiratory adaptation of the Ama. *Bull. Tokyo Med. Dent. Univ.*, **16** : 327—241, 1969.
9) Ikai, M., T. Fukunaga, K. Yamaji and K. Hirota : Aerobic work capacity of the Ama. In : JIBP synthesis, Vol. 3, Physiological adaptability and nutritional status of the Japanese. Edt. by Yoshimura, H. and S. Kobayashi, University of Tokyo Press, 1975, p. 251—254.
10) Linton, R. A. F., P. A. Poole-Wilson, R. J. Davies, and I. R. Cameron : A comparison of the ventilatory response to carbon dioxide by steady state and rebreathing methods during metabolic acidosis and alkalosis. *Clin. Sci. Mole. Med.*, **45** : 239—249, 1973.
11) Matsuda, Y., A. Yoshida, F. Hayashi, K. Sasaki and Y. Honda : The ventilatory responses to hypoxia and hypercapnia in the Ama. *Jap. J. Physiol.*, Accepted for publication, 1980.
12) McArdle, W. D., J. R. Magel, G. R. Magel, G. R. Lesmes, and G. S. Pechar : Metabolic and cardiovascular adjustment to work in air and water at 18, 25 and 33 °C. *J. Appl. Physiol.*, **40** : 85—90, 1976.
13) Miyamura M., T. Yamashina, and Y. Honda : Ventilatory response to CO_2 rebreathing at rest and during exercise in untrained subjects and athletes. *Jap. J. Physiol.*, **26** : 245—254, 1976.
14) Ohkuwa, T., N. Fujitsuka, T. Utsuno, and M. Miyamura : Ventilatory response to hypercapnia in sprint and long distance swimmers. *Eur. J. Appl. Physiol.*, **43** : 235—241, 1980.
15) Pandolf, K. B., E. Cafarelli, B. J. Noble, and K. F. Metz : Hyperthermia : Effect of exercise prescription. *Arch. Phys. Med. Rehab.*, **56** : 524—526, 1975.
16) Read, D. J. C : A clinical method for assessing the ventilatory response to CO_2. *Aust. Ann. Med.*, **16** : 20—32, 1967.
17) Rowell, L. B., H. J. Marx, R. A. Bruce, R. D. Conn, and F. Kusumi : Reductions in cardiac output, central blood volume, and stroke volume with thermal stress in normal men during exercise. *J. Clin. Invest.*, **45** : 1801—1816, 1966.
18) Schaefer, K. E. : The role of carbon dioxide in the physiology of human diving. In : Proceedings of the underwater physiology symposium, Edt. by Goff, L. G., Washington D. C., *Natl, Acad. Sci-Natl. Res. Council*, 1955, p. 131—139.
19) Schaefer, K. E. : Adaptation to breath-hold diving. In : Physiology of breath-hold diving and the Ama of Japan, Edt. by Rahn, H. and T. Yokoyama, Washington, D. C., *Natl. Acad. Sci-Natl. Res. Council*, 1965, p. 237—252.
20) Song, S. H., D. H. Kang, B. S. Kang, and S. K. Hong : Lung volumes and ventilatory responses to high CO_2 and low O_2 in the Ama. *J. Appl. Physiol.*, **18** : 466—470, 1963.

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