ENTRAINMENT DURING BICYCLE ERGOMETRY IN ELITE CYCLISTS

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While it is widely accepted that ventilation increases abruptly at the onset of muscular exercise (D'Angelo and Torelli, 1971; Jensen, Vejby-Christensen and Petersen, 1972; Krogh and Lindhard, 1913) the control of the respiratory pattern, i.e., the relationship between ventilation ($\dot{V}$, $\dot{V}_I$, $\dot{V}_E$), tidal volume (V_T), and respiratory frequency (f_R) or respiratory cycle times (T_T, T_I, T_E) is not clearly understood (Wasserman, 1978).

There are a number of factors, which may be classified as humoral, neurogenic, or neurohumoral, involved in respiratory regulation (Dejours, 1964), but the importance of any single factor is difficult to determine because of the associated problems of controlling for the other variables involved in the total response. One such factor is the coordination of the respiratory pattern to the movement pattern referred to as entrainment. The purpose of the present study was to examine the relationship between the variables that control the respiratory pattern and to test the hypothesis that entrainment would be more prevalent in athletes who were highly trained for a particular mode of exercise, based on a work minimization theory (Priban and Fincham, 1965; Yamashiro and Grodins, 1973; Cherniack, 1980), than in non-athletes unaccustomed to the exercise.

METHODS

The subjects (Table 1) were 12 adult males, six of whom were competitive road racing cyclists. The cyclists were members of a highly successful amateur cycling club.

TABLE 1
CHARACTERISTICS OF SUBJECTS

	N	AGE	HT (cm)	WT (kg)	VO_2 max (ml/kg/min)	FVC (ml)
Cyclists	6	25.5 $\pm$6.3	179.1 $\pm$6.3	76.3 $\pm$7.7	72.0* $\pm$7.2	6111 $\pm$1004
Sedentary	6	20 $\pm$2.8	176.9 $\pm$8.6	74.4 $\pm$13.8	47.3 $\pm$4.7	5459 $\pm$1056

* $p < 0.01$

The subjects each performed 3 distinctly different exercise tests on an electrically braked ergometer. (1) A progressive maximum exercise test during which the workload was raised 200 kpm/min every 2 min; (2) 10 minutes exercise at each of three steady-state submaximal workloads representing 40%, 60%, and 80% of VO_2 max; and (3) 10 minutes exercise at each of three pedal frequencies of 60, 75 and 90 rpm at a constant workoad of 60% $\dot{V}O_2$ max (n=10) or 80% $\dot{V}O_2$ max (n=2). For tests 1 and 2 pedalling frequency was 90/min for the cyclists and 60/min for the sedentary group. Pedalling frequency was primarily selected for subject convenience, Kay and co-workers (1975) having shown no difference in respiratory pattern at different frequencies.

A standard open-circuit oxygen uptake method was used. Carbon Dioxide of expired air was analyzed using a Beckman Infrared CO_2 Medical Gas Analyzer. Ventilation was determined by software integration of the flow signal from the pneumotachograph. The outputs from the measuring devices were input to a PDP 11/60 laboratory computer and the data were sampled at a frequency of 50 Hz. Tidal volumes were calculated as the differences between the accumulated minute ventilation from the start of one breath to the start of the next breath.

Attached to the ergometer was a magnetic reed switch positioned adjacent to the left pedal crank. The left crank was equipped with a permanent magnet that activated the reed switch once for every pedal revolution. The time between the left pedal down signal from the magnetic switch and the initiation of the next inspiration, the calculated pedal position at inspiration commencement, and the pedal frequency were all obtained by software counters activated via the magnetic switch. All measurements for each breath were transferred to a disk file for subsequent analysis.

To test for entrainment, each complete pedal revolution was divided into 8 segments of 45° each and the number of inspirations initiated by the subject in each segment was counted during each submaximal workload. A distribution of breaths among the segments significantly different from a random distribution was taken as indicating entrainment.

RESULTS AND DISCUSSION

Progressive Maximum Exercise Test

As expected, the cyclists group achieved a higher workload during $\dot{V}O_2$ max testing eliciting a higher $\dot{V}O_2$ max, ventilation, respiratory frequency and CO_2 production compared to the sedentary group (Table 2). As $\dot{V}CO_2$ increased during the test, T_E decreased for all

TABLE 2
MEANS FOR MAXIMAL AEROBIC CAPACITY, MAXIMAL CENTILATION, MAXIMAL RESPIRATORY FREQUENCY AND MAXIMAL CARBON DIOXIDE LEVELS DURING $\dot{V}O_2$ MAX TESTING

	VO_2 max* (ml/kg/min)	V_E* (liters/min)	f_R* (breaths/min)	CO_2 Production* (liters/min)
Cyclists	72.0 ±7.2	183.3 ±22.8	55.2 ±8.2	5.84 ±0.79
Sedentary	47.3 ±4.7	124.5 ±24.9	40.2 ±5.6	4.07 ±0.52

* $p < 0.01$

subjects as did T_I, with T_E decreasing more rapidly than T_I; although there was no significant difference between cyclists and sedentary subjects over their common $\dot{V}CO_2$ range for these variables.

To examine the relationship between $\dot{V}_E$ and $\dot{V}CO_2$ a linear regression was performed for each subject for CO_2 production with respect to increasing ventilation during this test. No significant difference was found between the group means, indicating a similar increase in $\dot{V}_E$ occurs with increasing $\dot{V}CO_2$ for all subjects. Therefore it follows that ventilation would be highly correlated with carbon dioxide output which supports a humoral theory of respiratory control.

An increase in tidal volume occurred with increasing $\dot{V}CO_2$ for all subjects. To examine differences between the groups tidal volumes were expressed as percentages of FVC for each subject to normalize for differences in lung size. When expressed in this way, the largest tidal volumes obtained during exercise were similar for the two groups (Table 3).

TABLE 3
TIDAL VOLUME MEANS AS A PERCENTAGE OF FVC AND MEAN RESPIRATORY FREQUENCIES (BREATHS/MINUTE) AT MAXIMUM EXERCISE

	V_T/FVC Per Cent	f_R*
Cyclists	43.37 ±4.46	55.2 ±8.2
Sedentary	41.35 ±4.29	40.2 ±5.6

* $p < 0.05$

Thus it would appear that the cyclists achieve a higher $\dot{V}_E$, associated with a higher workload, as a result of a higher respiratory frequency as opposed to a higher relative increase in tidal volume when compared to the sedentary group during maximum exercise.

Submaximal Exercise Tests

The contribution of V_T increases to the imposed increase in ventilation during the 3 submaximal tests (40%, 60%, 80% $\dot{V}O_2$ max) was also examined for each subject. Group means for V_T as a percentage of FVC are given in Table 4. While there was a significant difference between workloads for all subjects ($p < 0.01$), no significant difference was found

TABLE 4
TIDAL VOLUME MEANS DURING 3 SUBMAXIMAL EXERCISE TESTS AS A PERCENTAGE OF FVC

	V_T/FVC Per Cent		
	40%	60%	80% ($\dot{V}O_2$ max)
Cyclists	26.7 ±3.6	34.3 ±6.6	41.4 ±7.1
Sedentary	24.1 ±5.3	31.5 ±6.3	38.4 ±6.3

between the groups at any given workload, as was also seen with the maximum exercise test.

Respiratory frequencies (Table 5) were shown to be significantly different at different workloads ($p < 0.01$) for all subjects, with post hoc tests showing f_R increased as workload increased. Furthermore, f_R's were higher ($p < 0.05$) in the cyclists group at each workload which accounted for the higher ventilations achieved by this group.

TABLE 5
MEAN RESPIRATORY FREQUENCIES (BREATHS/MIN)
DURING 3 SUBMAXIMAL EXERCISE TESTS

		f_R*	
	40%	60%	80% (VO_2 max)
Cyclists	27.2 ±4.1	33.3 ±6.5	43.7 ±7.7
Sedentary	21.5 ±3.0	26.2 ±5.1	33.2 ±5.1

* Between groups $p < 0.05$
Within subjects $p < 0.01$

Entrainment during steady-state exercise

The data were analyzed for evidence of entrainment in each subject during exercise at the three submaximal workloads (Table 6). One subject in each group showed entrainment at

TABLE 6
ENTRAINMENT AT 3 DIFFERENT SUBMAXIMAL WORKLOADS
AT 90 RPM (CYCLISTS) AND 60 RPM (SEDENTARY)

Groups	Subjects	Per cent of $\dot{V}O_2$ max		
		40	60	80
Cyclists	1	-	+	+
	2	-	-	-
	3	-	+	+
	4	+	+	-
	5	-	-	+
	6	-	-	+
Sedentary	7	+	-	-
	8	-	-	-
	9	-	-	-
	10	-	+	+
	11	-	+	+
	12	-	-	+

\+ = Entrainment ($p < 0.05$)
\- = No Entrainment

the lowest workload, with 3 cyclists and 2 sedentary subjects showing entrainment at the middle workload, and 4 cyclists and 3 sedentary subjects being entrained at the highest workload. There was no difference between the groups at any given workload, and although there was a tendency for greater entrainment as the relative workload increased, this was not found to be significant.

Varied pedal frequency tests

To further test for evidence of entrainment, it was decided to hold the workload constant and vary the pedal frequency (Table 7).

TABLE 7
ENTRAINMENT AT 3 DIFFERENT PEDAL FREQUENCIES AT 60% $\dot{V}O_2$ MAX (SUBJECTS 1, 2, 5-12) AND 80% $\dot{V}O_2$ MAX (SUBJECTS 3 AND 4)

Groups	Subjects	Pedal Frequency (rpm)		
		60	75	90
Cyclists	1	-	-	+
	2	-	-	-
	3	+	-	+
	4	+	+	+
	5	-	-	-
	6	+	-	-
Sedentary	7	-	-	-
	8	-	-	-
	9	-	-	-
	10	+	+	+
	11	+	+	-
	12	-	-	-

+ = Entrainment ($p < 0.05$)
- = No Entrainment

At 60 rpm, 3 cyclists and 2 sedentary subjects showed entrainment, at 75 rpm 1 cyclist and 2 sedentary subjects were entrained, and at 90 rpm 3 cyclists and 1 sedentary subject were entrained. There was no difference between the groups for any given pedal frequency. The groups were collapsed and the results were examined for entrainment differences among pedal frequencies. No significant differences were found.

CONCLUSIONS AND RECOMMENDATIONS

Over all test conditions $\dot{V}_E$ was found to be closely related to $\dot{V}CO_2$ for all subjects. The cyclists achieved higher $\dot{V}_E$'s as expected, and since ventilation is the product of f_R and V_T it was possible to examine the relationship among these variables. It was seen that the higher ventilation of the cyclists was clearly the result of a higher f_R, and not by using a larger proportion of FVC as tidal volume. This decrease in total respiratory cycle duration was mainly due to a reduction in T_E which is in agreement with previous findings (Jennett, Russell and Warnock, 1974; Kay, Strange-Petersen, and Vejby-Christensen, 1975).

Many researchers have argued for a neurogenic drive accounting for the hyperpnea of muscular exercise (Agostoni and D'Angelo, 1976; Comroe and Schmidt, 1943; Jasinskas, Wilson, and Hoare, 1980). In this study, it was postulated that cyclists, through experience, would be more likely to coordinate their exercise movements with respiratory movements in order to minimize respiratory effort. It was found that there were no differences between the groups for any workload or any frequency. Even when all the subjects were considered as one group there were no differences between workloads or between pedal frequencies.

Thus it may be stated that respiratory patterns in cycling are controlled by metabolic demands imposed by the workload, and although respiratory pattern may be related to the movement pattern, there is no causal relationship; nor does any difference exist between highly-trained cyclists accustomed to the exercise and sedentary individuals unaccustomed to the exercise.

These findings would suggest to coaches and athletes involved in competitive cycling that no attempt should be made to consciously try to match the breathing pattern to the movement rhythm of the legs.

Recommendations For Future Study

The findings of entrainment studies (Agostoni and D'Angelo, 1976; Asmussen, 1965; Asmussen, 1973; Flandrois et al., 1967; and Kalia et al., 1972) are equivocal. Different methodologies were employed in these studies which may account for the differences observed in the levels of entrainment which occurred. Furthermore, it has been pointed out (Bechbache and Duffin, 1977) that abrupt changes in phase between breathing and movement may occur due to swallowing or sighing which would tend to obscure entrainment. Future study of entrainment should incorporate a system for breath-by-breath data analysis which takes these changes into account.

REFERENCES

1. Asmussen, E. Muscular exercise. In Fenn, W.O., and Rahn, H. (eds.) Handbook of Physiology, Section 3, Respiration Vol. II: 939-978, Washington, D.C., American Physiological Society, 1965.

2. Asmussen, E. Ventilation at transition from rest to exercise. Acta. Physiol. Scand. 89:68-78, 1973.

3. Bechbache, R.R., and J. Duffin. The entrainment of breathing frequency by exercise rhythm. J. Physiol. 272:553-561, 1977.

4. Cherniack, N.S. The control of breathing in COPD. Chest. 77:291-293, 1980 Suppl.

5. Comroe, J.H., and C.F. Schmidt. Reflexes from the limbs as a factor in the hyperpnea of muscular exercise. Am. J. Physiol. 138:546-547, 1943.

6. D'Angelo, E., and G. Torelli. Neural stimuli increasing respiration during different types of exercise. J. Appl. Physiol. 30:116-121, 1971.

7. Dejours, P. Control of respiration in muscular exercise. In Fenn, W.O. and Rahn, H. (eds.) Handbook of Physiology, Section 3, Respiration Vol. I: 631-648, Washington, D.C., American Physiological Society, 1964.

8. Flandrois, R., J.R. Lacour, J. Islas-Maroquin, and J. Charlot. Limbs mechanoreceptors inducing the reflex hyperpnea of exercise. Resp. Physiol. 2:335-343, 1967.

9. Jensen, J., H. Vejby-Christensen, and E.S. Petersen. Ventilatory response to work initiated at various times during the respiratory cycle. J. Appl. Physiol. 33:744-750, 1972.

10. Jasinskas, C.L., B.A. Wilson, and J. Hoare. Entrainment of breathing rate to movement frequency during work at two intensities. Resp. Physiol. 42:199-209, 1980.

11. Jennett, S., T. Russell, and K.A. Warnock. The duration of inspiration during changing states of ventilation in man. J. Physiol. 238:54P-55P, 1974.

12. Kalia, M., J.M. Senapati, B. Parida, and A. Panda. Reflex increase in ventilation by muscle receptors with nonmedullated fibers (C fibers). J. Appl. Physiol. 189-193, 1972.

13. Kay, J.D.S., E. Strange-Petersen, and H. Vejby-Christensen. Breathing in man during steady-state exercise on the bicycle at two pedalling frequencies, and during treadmill walking. J. Physiol. 251:645-656, 1975.

14. Krogh, A., and J. Lindhard. The regulation of respiration and circulation during the initial stages of muscular work. J. Physiol. 47:112-136, 1913.

15. Priban, I.P., and W.F. Fincham. Self-adaptive control and the respiratory system. Nature. 108:339-343, 1965.

16. Wasserman, K. Breathing during exercise, New Engl. J. Med. 298:78-785, 1978.

17. Yamashiro, S.M. and F.S. Grodins. Respiratory cycle optimization in exercise. J. Appl. Physiol. 35:522-525, 1973.