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Ventilatory Response to Pseudorandom Work Rate Exercise in Man

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ABSTRACT

The dynamics of the ventilatory response to moderate exercise on a bicycle ergometer was studied in two healthy males. The work rate was varied between 0 and 100 W as a pseudorandom binary sequence (PRBS). Four possible models were applied to describe the ventilatory dynamics. The dynamics of response was well represented by model III, which is characterized by parallel components of two first order dynamics. One was a fast component and accounted for a much smaller proportion of the total response. The other was a slow component with a large gain which followed after a delay.

KEYWORDS

Ventilatory response; Exercise hyperpnea; Pseudorandom binary sequence; Dynamic system; System identification;

INTRODUCTION

The ventilatory response to dynamic exercise in human subject provides a basis to identify the physiological system and to diagnose the clinical abnormality involved in the control of ventilation. To identify the ventilatory response, step, ramp, sinusoidal wave, or short-duration pulse have been utilized as exercise input in previous studies. Although these inputs are easy to implement, some repetitions of forcing are needed to estimate the model parameters with high S/N ratio of measurement (Lamarra et al., 1987). Moreover, the subjects can anticipate the variation in exercise and may adjust their ventilation voluntarily.

Recently, a system identification technique by white noise forcing has applied to the research in the dynamics of ventilatory response during exercise (Bennett et al., 1981, Greco et al., 1986, Eβfeld et al., 1987). The purpose of this study is to obtain the dynamics of ventilatory response to random exercise on a bicycle ergometer from two healthy subjects.

METHODS

Models

Four possible models (Laplace transform notation) for describing the dynamics of the ventilatory response to random work rate exercise are shown in Fig. 1. Model I and II are the first-order dynamics and characterized by a time constant (T_c) and a gain (K). Moreover, model II contains a dead time (T_d). Model III consists of two components, a fast component and a slow component which follows after a delay. Model IV is a second-order dynamics, which contains of two first-order dynamics in series.

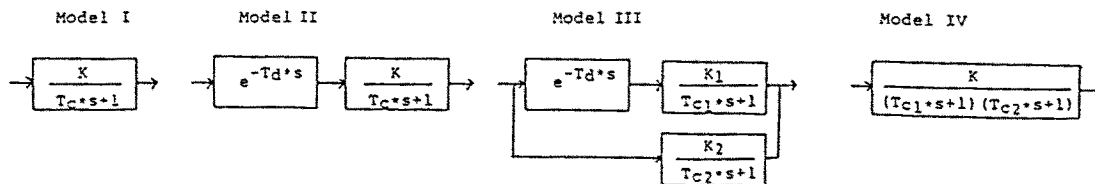


Fig. 1. Schematic representation of the model hypotheses for the relation of the ventilatory response to the input exercise. K:gain; T_d :dead time; T_c :time constant; s :Laplace notation of complex frequency variable.

Input work rate

To minimize the contributions of nonlinearities, the work load should not exceed the anaerobic threshold. The anaerobic threshold was determined during a 1-minute incremental work test and is presented as ventilatory threshold (VT) in Table 1. Based on VT of two subjects, the PRBS was switched between 0 and 100 W in this study.

The work rate was changed as a PRBS while subjects pedaled on a bicycle ergometer. The sequence was generated by an m -stage shift register. The sequence is characterized by Δt , the interval at which the sequence is updated, and N , the number of intervals in a sequence. Therefore, the duration of a sequence is $N\Delta t$. At the end of Δt second, the algorithm decides whether the work load will be high or low for the next Δt second. During the sequence the work load may remain in a given state for a number of consecutive intervals.

Experimental protocol

Subjects used in this study were two healthy males. Their physical characteristics data are presented in Table 1. The subject exercised on a bicycle ergometer and was instructed to maintain pedaling rate constant at 50 rpm. The work rate was at 0 W during warm-up period, and then varied as a PRBS. The experimental procedure was divided into four experiments. The differences between experiments were Δt and N in PRBS and the work rate (Table 2).

Data acquisition and model fitting

Throughout the exercise period, the ventilatory response data were collected by a respiratory gas analyzer (Magna88, Morgan, and Aerobic processor-391, NEC Sanei) at every 10 seconds. The fitting of models to experimental data was performed on a Nyquist plot using nonlinear least squares method (Fig. 2).

Table 1. Physical characteristics of subjects.

subject	age	ht	wt	$\dot{V}O_2$ -max	VT($\dot{V}O_2$)
Y	32 (yrs)	176 (cm)	68.5 (kg)	38.8 (ml/kg/min)	18.3 (ml/kg/min)
S	35	169	65.0	46.2	29.5

Table 2. Protocols of four experiments.

experiment number	work rate	PRBS		exercise duration
		Δt	N	
1	0 - 50 w	30 sec	63	31 min 30 sec
2	0 - 50 w	20 sec	127	42 min 20 sec
3	0 - 100 w	20 sec	127	42 min 20 sec
4	50 - 100 w	20 sec	127	42 min 20 sec

RESULTS AND DISCUSSION

Fig. 2 displays an example of ventilatory response and its Nyquist plot. Table 3 indicates the estimates for the model parameters for each of two subjects and each of four experiments. The values of AIC, one of the criteria for the goodness of fit, suggests that model III, that is parallel two first order models, can simulate most adequately the dynamics of the ventilatory response.

It should be noted that the time constant parameter Tc1 is larger than Tc2 in model III, then Tc1 indicates a slow component and Tc2 does a fast mode. The fast component takes place immediately after the onset of exercise stimulus and followed by the slow component in some dead time. Since K2, gain of the fast component, represents much smaller portion of total gain, the over all response is mainly determined by the slow component. The results obtained from this study are consistent with previous investigators suggesting the hypothesis of exercise hyperpnea, that is the initial fast component caused by a neural factor and slow component was in response to a humoral stimulus.

To identify the ventilatory response, comparing the usual input such as step, ramp, or sinusoidal work, the stochastic exercise input according to PRBS has two main advantages: 1) to stimulate the fast component adequately without the effect of volitional factor such as anticipation, and 2) to be able to estimate the parameters of fast component in a single measurement. The estimated parameters, however, have some variations in this experiments.

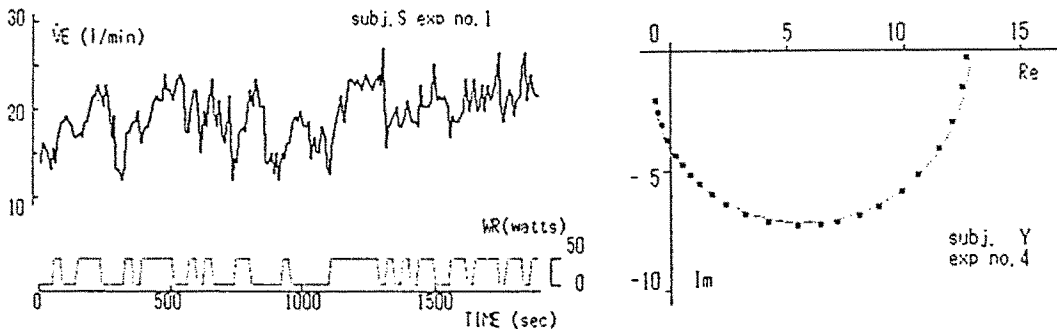


Fig. 2. An example of ventilatory response and Nyquist diagram. left: ventilation response (upper solid curve) to PRBS exercise work rate (lower dotted line). right: Nyquist plot of measured dynamics (closed squares) and its predicted dynamics (dotted curve) by model III.

Table 3. Parameters estimated by four models.

subj	exp. no.	work rate [0 - 1]	model	K1 (1/min)	Tc1 (sec)	Td1 (sec)	K2 (1/min)	Tc2 (sec)	AIC
Y	1	0 - 50 w	I	9.11	61.3				1995
			II	8.42	49.9	6.1			1698
			III	6.60	51.7	17.0	1.95	12.9	1644
			IV	8.40	47.5			6.9	1608
Y	2	0 - 50 w	I	12.71	90.0				2337
			II	11.57	69.3	11.2			1480
			III	8.84	66.3	26.9	2.81	20.7	962
			IV	11.43	59.5			14.9	986
Y	3	0 - 100 w	I	15.95	105.2				2046
			II	12.92	62.5	6.7			1359
			III	9.96	58.2	22.8	2.99	12.0	631
			IV	12.83	58.6			8.1	1047
Y	4	50 - 100 w	I	14.05	74.1				2883
			II	11.95	43.5	17.4			1580
			III	10.11	39.3	25.4	1.95	15.3	972
			IV	12.44	28.2			28.2	1803
S	1	0 - 50 w	I	10.11	53.6				2548
			II	8.86	35.6	12.1			2089
			III	6.36	21.5	30.5	2.64	5.65	922
			IV	8.99	22.0			22.0	1806
S	2	0 - 50 w	I	15.93	105.2				2046
			II	15.62	100.4	2.8			2002
			III	13.36	84.7	20.6	2.17	0.003	872
			IV	15.45	97.0			4.4	1974
S	3	0 - 100 w	I	17.37	90.4				1642
			II	16.87	84.3	3.3			907
			III	15.81	82.9	9.1	1.05	2.5	850
			IV	16.85	83.6			3.5	860
S	4	50 - 100 w	I	15.76	113.8				2256
			II	14.71	95.6	9.6			1666
			III	11.86	88.3	29.2	2.90	16.5	505
			IV	14.52	86.5			12.6	1247

K:gain modified corresponding to 50 w. Tc:time constant. Td:dead time.
AIC:Akaike's information criterion.

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