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Comparison of bronchoconstriction induced by cycling and running

SANDRA D. ANDERSON, NICOLA M. CONNOLLY,
and S. GODFREY[1]

Institute of Diseases of the Chest, Fulham Road, London S.W.3

Bicycle ergometer, treadmill, and free range running exercise have been used to induce bronchoconstriction in 10 asthmatic subjects who were relatively well and free from symptoms at the time of study. Comparisons have been made with normal subjects under similar laboratory conditions. Bronchoconstriction was measured by peak expiratory flow rate before, during, and after each test. Ventilation, pulse rate, and gas exchange were also measured. The work involved in the different types of exercise was matched to produce similar ventilation and pulse rates for any one subject.

Exercise-induced bronchoconstriction was significantly less on the bicycle ergometer than on running (treadmill or free range). The normal subjects showed less than one quarter the bronchial lability of the asthmatic subjects in any one test. All subjects had lower respiratory exchange ratios during running compared with cycling and this appeared to correlate with the bronchial lability in the asthmatics, who also had rather higher pulse rates during running. Running involves a proportion of high-efficiency negative work which might partly account for the observed differences.

It is now well established that exercise may induce bronchoconstriction in asthmatic subjects (Jones, Buston, and Wharton, 1962). However, little attempt has been made to standardize the nature or quantity of exercise in the various studies. Although the test originally developed by Jones *et al.* (1962) involved free range running, exercise-induced bronchoconstriction has been reported following stair climbing (Davies, 1968), and clinical experience suggests that swimming, tennis, and other forms of exercise may also provoke bronchoconstriction. Paradoxically cycling has been stated to be a poor method of inducing bronchoconstriction (Jones, Wharton, and Buston, 1963; Beaudry, Wise, and Seely, 1967) and we certainly obtained this impression ourselves.

Comparisons between different types of exercise are complicated by such factors as the difficulty in matching work and the different environments encountered in free running, stair climbing, and ergometer exercise in the laboratory. We therefore compared different types of exercise in asthmatic subjects under controlled conditions.

SUBJECTS AND METHODS

Studies were made on 10 patients, three adults and seven children, all of whom had uncomplicated bronchial asthma according to the definition of Scadding (1966). Their physical characteristics are given in Table I. All tests were made while the subjects were relatively well and not during acute attacks of asthma. In four subjects all tests were completed in three consecutive days and in the remainder the

TABLE I

BASIC DATA AND RESTING PEAK EXPIRATORY FLOW RATES IN 10 ASTHMATIC PATIENTS

Subject	Sex	Age (yr)	Height (cm)	Resting PEF[1] (% Expected)		
				Ergometer	Treadmill	Free Range
1	F	8	124	97·8	82·9	102·0
2	M	8	129	65·4	80·7	45·0
3	M	9	128	69·2	69·0	48·0
4	F	10	153	81·1	72·9	87·8
5	M	12	145	80·1	58·0	92·5
6	F	13	139	90·6	123·0	112·0
7	M	15	161	119·5	100·0	97·5
8	M	26	188	78·6	70·5	87·5
9	M	27	167	44·0	68·8	52·4
10	F	36	153	91·1	82·2	102·5

[1] The PEF is expressed as a percentage of the expected value and the resting value before each type of exercise test is given.

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[1] Correspondence to Dr. S. Godfrey

tests were completed over a period of a few weeks, but care was taken that the patient's clinical condition was similar on each occasion. No patient was receiving corticosteroids at the time of study and none had received any sympathomimetic or other drug for at least 24 hours before the test. In addition some observations were made on six boys and five girls aged 7 to 14 years who were normal children from local schools, entirely free from asthma or other significant disease.

Each test consisted of steady state exercise for 6 minutes except for two tests in two adults which lasted 8 minutes. Exercise was performed in each of three ways in random order by each subject—

(*a*) seated on a cycle ergometer in the laboratory
(*b*) running on a treadmill in the laboratory
(*c*) free range running in a corridor for the children and around the hospital grounds for the adults.

Peak expiratory flow (PEF) was measured before and at 2-minute intervals during exercise and then for 15 minutes after stopping. The PEF was measured with a pneumotachograph (Fleisch No. 4) on the ergometer and treadmill and by a Wright peak flow meter which was calibrated against the pneumotachograph for the free range running. Pulse rate was recorded throughout electrocardiographically, being transmitted by a radiotelemeter (Parks Electronics) during free range running. The subjects all breathed through a respiratory valve of low resistance and dead space. and expired gas was continuously flushed through the circuit. Over the last minute of exercise, a gas collection was made in a Tissot spirometer for ergometer and treadmill exercise and in a light meteorological balloon carried on the back during free range running. Expired gas was analysed by the standard methods previously reported from this laboratory (Godfrey and Davies, 1970). End tidal $P\text{CO}_2$ was monitored during ergometer and treadmill exercise with an infrared CO_2 analyser but this was impractical during free range running.

An attempt was made to ensure that the rate of working was similar in each type of test by adjusting the work load or speed of running to produce similar ventilation and pulse rates for any one subject.

All ventilations are expressed at B.T.P.S. and all oxygen consumptions at S.T.P.D.

CALCULATION OF INDICES Exercise-induced bronchoconstriction was expressed for each test in three ways:

(*a*) the Jones lability index (Jones and Jones, 1966) is given by:

$$\frac{\text{Highest PEF—Lowest PEF}}{\text{Expected normal PEF}} \times 100\ (\%)$$

where the highest PEF was that obtained by any means (including the administration of a bronchodilator after completion of the test) and the lowest PEF was the lowest overall obtained whether during exercise or in the 15 minutes afterwards;

(*b*) the exercise lability index given by:

$$\frac{\text{Highest exercise PEF—Lowest PEF}}{\text{Resting PEF}} \times 100\ (\%)$$

where the highest exercise PEF was that obtained during exercise and the lowest was as in (*a*) above. When the subject's resting PEF was close to his expected PEF, the Jones lability index and exercise lability index are virtually identical, but this is not necessarily so in other circumstances;

(*c*) the percent fall index which is the simplest index given by:

$$\frac{\text{Resting PEF—Lowest PEF}}{\text{Resting PEF}} \times 100\ (\%)$$

where the lowest PEF was as in (*a*) above. Normal values for PEF were taken from our own studies in this laboratory (Godfrey, Kamburoff, and Nairn, 1970).

RESULTS

A typical record showing bronchoconstriction induced by the three different types of exercise is given in Fig. 1 for subject 7. It can be seen that the free range (corridor) running produced more constriction than the treadmill, while the ergometer produced very little. The resting levels of PEF in this subject were all within 1 S.D. of his expected normal value of 435 l./minute. Constriction began during the last 2 minutes of ergometer or corridor exercise and reached its maximum from 3 to 5 minutes after stopping.

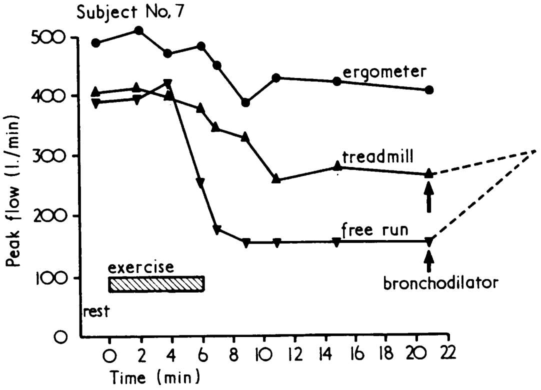

FIG. 1. *Response to three types of exercise in one subject.*

This difference in the degree of bronchoconstriction was observed in all but two of the patients, free range running being the most effective and ergometer exercise the least effective method of causing the bronchoconstriction. The

TABLE II

INDIVIDUAL RESULTS FOR ASTHMATIC SUBJECTS

Subject	Jones Lability Index (%)			Exercise Lability Index (%)			Fall Index (%)		
	Cycle Ergometer	Treadmill	Free Run	Cycle Ergometer	Treadmill	Free Run	Cycle Ergometer	Treadmill	Free Run
1	44·5	58·0	58·5	37·0	46·0	50·0	26·0	28·0	50·0
2	17·0	47·5	30·0	26·5	38·5	45·0	12·0	40·0	30·0
3	48·0	56·0	34·5	53·0	68·0	72·0	0·0	8·4	12·0
4	13·0	15·0	46·0	16·4	24·0	52·0	8·0	11·0	47·5
5	37·0	42·0	40·0	44·0	57·0	40·0	37·0	43·0	34·0
6	33·0	31·0	69·0	36·0	25·0	57·0	24·0	23·0	56·0
7	22·2	41·5	60·0	26·5	41·5	67·0	22·2	39·0	63·0
8	50·5	52·0	69·0	64·0	73·0	79·0	18·0	25·0	61·0
9	14·8	28·0	41·0	37·0	40·0	78·0	14·8	33·0	61·0
10	72·0	91·5	73·5	79·0	111·0	72·0	40·0	79·0	67·0

Each method of calculating bronchial lability as described in the text has been used for each type of exercise.

individual results for the three indices are given in Table II and the group results in Fig. 2 which includes the available results for normal subjects. With all three indices the differences between types of exercise in the asthmatic subjects were highly significant. Using the paired *t* test for exercise-induced bronchoconstriction on the ergometer and free running the probability of the differences being due to chance was less than 0·005. Likewise all the three indices were significantly different (P<0·01) for bronchoconstriction induced by the bicycle ergometer compared with the treadmill. The differences between the treadmill and free range running were not significant for the Jones or exercise lability indices, but the percent fall index was significantly different (P<0·01). This implies that free range running produces a greater fall from the resting level than the treadmill, but the rise during or after exercise is more variable.

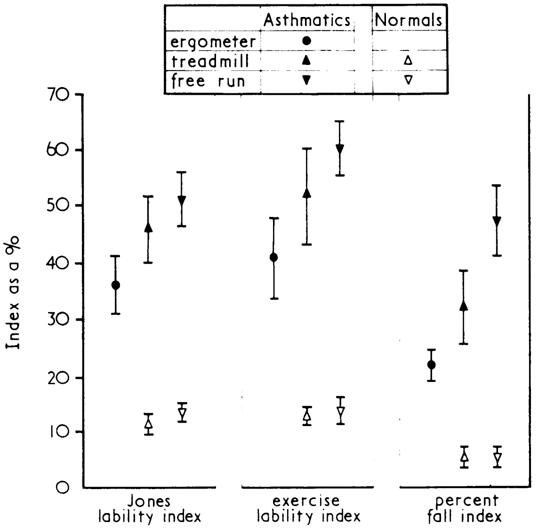

FIG. 2. *Bronchial lability in different types of exercise in asthmatic and normal subjects. The derivation of the indices of lability is described in the text. The normal group included the nine subjects described in Table IV and two others who did not have gas collections: lability was not studied during ergometer exercise. The points represent the means for each group and the limits indicate one standard error.*

The matching of work and ventilation and the mean values for lability in the three types of exercise are shown in Table III. Since the subjects varied considerably in size the individual results showed considerable scatter, but since each subject served as his own control, the mean values for the group could be compared and a paired *t* test used to assess significance. In fact the only significant difference in all the data shown in Table III besides the lability indices discussed above was for respiratory exchange ratio (R) comparing the ergometer test to either the treadmill or free range running. Comparable results in the group of normal subjects are given in Table IV. There was very little bronchial lability and it was less than one quarter of that seen in the asthmatics by whatever index it was assessed. It was not studied on the ergometer in this group. On the basis of the oxygen consumption the level of work performed in the corridor (which produced the highest lability) was similar in the normals compared to the asthmatics but it was rather lower on the treadmill. There were no significant differences in end-tidal P_{CO_2} between normals and asthmatics. Pulse rates could be compared only by predictions based on height and oxygen consumption (Godfrey, Davies, Wozniak, and Barnes, in preparation) since the normals and asthmatics were not exactly matched for size and work. This showed that whereas there was no difference in pulse rates in relation to the type of exercise in asthmatics, they were significantly higher on the

TABLE III

GROUP RESULTS FOR ASTHMATIC SUBJECTS

	Ergometer			Treadmill			Free Run		
	Mean	S.E.M.	n	Mean	S.E.M.	n	Mean	S.E.M.	n
Jones lability index	36·1	5·90	10	46·2	6·6	10	52·1	5·0	10
Exercise lability index	41·9	5·96	10	52·4	8·3	10	61·2	4·5	10
Percent fall index	20·2	3·90	10	32·9	6·3	10	48·1	5·6	10
Vo$_2$	1470	224	10	1636	310	10	1669	276	10
Ve	50·3	6·6	10	48·7	7·6	10	49·1	6·2	10
Ve/Vo$_2$	36·2	4·0	10	30·8	1·0	10	30·7	1·4	10
PETco$_2$	28·0	2·1	10	29·0	1·6	10	–	–	–
R	0·96	0·035	10	0·88	0·025	10	0·84	0·027	10
Pulse rate	164	7·0	10	175	3·0	10	180	4·0	10
Pulse % expected	96·3	3·1	10	101·5	4·1	10	98·7	3·6	10

The bronchial lability indices are given above and the ventilation, pulse rate, and gas exchange are given below. Pulse has also been expressed as a percentage of the expected value based on Vo$_2$, height, and sex for ergometer exercise. (Vo$_2$ = oxygen consumption, Ve = minute ventilation, PETco$_2$ = end-tidal PCO$_2$—not obtained during free range running)

TABLE IV

GROUP RESULTS FOR NORMAL SUBJECTS

	Ergometer			Treadmill			Free Run		
	Mean	S.E.M.	n	Mean	S.E.M.	n	Mean	S.E.M.	n
Jones lability index				9·4	1·3	9	14·1	1·9	9
Exercise lability index				11·0	1·5	9	15·4	2·4	9
Percent fall index				5·1	1·9	9	6·4	1·4	9
Vo$_2$	1034	132	9	1205	166	9	1478	200	9
Ve	35·1	3·0	9	37·6	3·98	9	44·6	4·5	9
Ve/Vo$_2$	35·6	2·1	9	32·8	2·68	9	31·9	2·4	9
PETco$_2$	30·3	1·6	8	30·3	2·1	9	–	–	–
R	1·10	0·017	7	0·91	0·016	9	0·90	0·030	9
Pulse rate	182	6·0	9	175·5	4·0	9	173	5·0	9
Pulse % expected	106·5	2·46	9	101	3·03	9	90·3	2·3	9

Results as in Table III but bronchial lability was not measured during ergometer exercise in these subjects.

ergometer compared with free running or the treadmill in normals.

DISCUSSION

This study has positively confirmed the clinical impression that running causes greater bronchoconstriction than cycling in asthmatic subjects.

Studies of this kind, by the very nature of asthma, are difficult to standardize. We attempted to avoid the natural variation in the disease by studying patients either over a very short space of time or while they were in similar clinical states. The difference in lability for the various types of exercise was not related to the resting PEF and was consistent despite the random order of the tests. This makes it highly unlikely that the differences were due to variations in the patient's condition.

Most asthmatic patients are sensitive to house dust and many also complain that cold provokes bronchospasm (Hsieh, Frayser, and Ross, 1968). Running in the corridor or in the open air could have exposed our patients to such factors, but the difference between cycling and running was almost as great when the running was performed on a treadmill. This apparatus was physically substituted for the ergometer and the identical respiratory circuit was used in the laboratory and hence environmental factors were largely excluded. Differences between treadmill and free range running were small as measured by the Jones and exercise labilities.

No real quantitative data are available on the exercise needed to provoke bronchoconstriction. However, Beaudry *et al.* (1967) did not obtain bronchoconstriction with ergometer exercise in children at oxygen consumptions of the order of 600 ml/minute. Irnell and Swartling (1966) did obtain exercise-induced bronchoconstriction with ergometer exercise in adults, but they used progressively hard levels of exercise for a maximum of 18 minutes, the last load (900 kpm/min) being equivalent to an oxygen consumption of 2,100 ml/minute. Even so, it is possible to calculate the mean exercise lability index from their data which was approximately 25% for the whole series and 40% for their more severely affected group. These figures are not unlike our ergometer results and certainly show less lability than our treadmill or free running studies. These facts suggest that absolute work load (or duration) may be important for the production of bronchoconstriction on the ergometer but this does not account for the differences in our study between types of exercise.

The only differences we noted in the parameters measured, besides PEF, was a lower respiratory exchange ratio (R) in the running compared with the ergometer. Indeed there seemed to be a direct relationship between the fall of PEF (% fall index) and the R (Fig. 3) for all but one subject who showed the opposite effect. It even appeared that the R was more important than whether the running was treadmill or free range. We noted that our normal subjects had lower R values during running compared with cycling and similarly low R values can be calculated for normal adults on a treadmill (Hanson, Tabakin, and Levy, 1967) compared with an ergometer (Naimark, Wasserman, and McIlroy, 1964). In fact our asthmatic patients had lower R values than the normals for comparable types of exercise. Their changes in R may reflect changes in blood lactate and acid-base balance but this needs considerable clarification because of the conflicting published results. Thus Beaudry *et al.* (1967) reported base deficits of the order of −8 mEq/l. with arterial P_{CO_2} values of 32 mmHg, representing severe metabolic (?lactic) acidosis during ergometer exercise, without obtaining bronchoconstriction. On the other hand, Seaton, Davies, Gaziano, and Hughes (1969) reported similar levels of acidosis with high measured lactates after free range running which did result in bronchoconstriction. The two studies suggest that it is the nature of the exercise rather than the level of acidosis or lactate which causes bronchoconstriction. We are planning to study these variables in relation to the type of exercise because the data suggest that acidosis associated with a low R (Fig. 3) is more likely than anything else to cause bronchoconstriction.

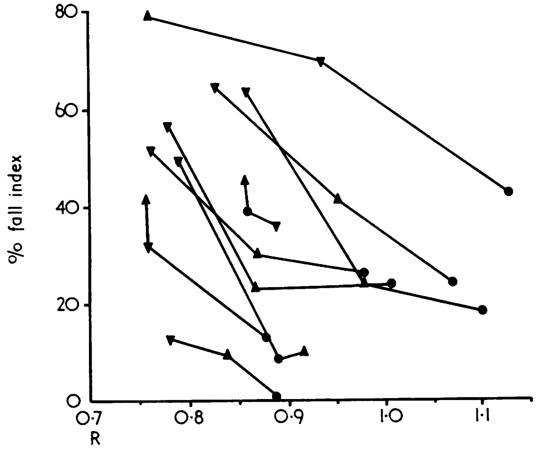

FIG. 3. *Relationship between the percentage fall in peak expiratory flow rate and the respiratory exchange ratio (R) of exercise. The symbols are the same as those in Figures* 1 *and* 2.

Many other factors which could have accounted for differences in bronchoconstriction produced by unquantitated cycling or running have been excluded by the design of the present study. These include end tidal P_{CO_2} and total minute ventilation which was virtually identical in running and cycling. Thus bronchoconstriction provoked by hypocapnic hyperventilation (Crompton, 1968) was not responsible for our observed differences. We may postulate that some other, as yet unknown, factor is operating more during running than cycling. One possibility is that the general level of neural activity is greater during running and here one may note that there is a considerable component of negative or eccentric work in running but not cycling. Negative work is performed when energy is absorbed by muscles as they are stretched during contraction. During running, energy is released as the centre of gravity of the body falls at the end of each step. Some of this kinetic energy is absorbed by leg muscles in landing. Since the mechanical efficiency for negative work is much higher than for positive work (Kamon, 1970) the muscles of our subjects were actually involved in more physical work for the same oxygen consumption during running compared with cycling.

We must conclude that as yet we have found no definite explanation for the greater ability of running to cause bronchoconstriction compared with cycling, but some obvious possibilities have been excluded and others suggested by the present study.

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