ORIGINAL ARTICLE

A nomogram for assessment of breathing patterns during treadmill exercise

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Objective: To assess the breathing patterns of trained athletes under different conditions. The hypothesis is that the breathing pattern during a progressive treadmill exercise is independent of the protocol, at least in healthy people, and can be assessed using a nomogram.
Methods: A total of 43 male and 21 female athletes from different sports were studied. They performed one of two different protocols (steps or ramp) on a treadmill. The two protocols started at the same speed and had the same rate of increase in work. During the test, the expired air was analysed for CO_2 and O_2. Ventilation (VE) was continuously recorded, and tidal volume (Vt) and breathing frequency (BF) at the same intensity were analysed for both protocols, as well as Vt/T_i and T_i/T_{tot}.
Results: No significant differences were observed in Vt and BF between the two protocols in either the men or women at any level (confidence intervals up to 0.958 in all the groups). T_i/T_{tot} remained constant, and all increases in VE were strongly related to the respective increases in Vt/T_i. Plots of data for men and women showed a curvilinear relation between Vt and BF which could be fitted with an exponential function with a strong correlation ($R^2 = 0.98$ for men and 0.97 for women).
Conclusions: Graphic expression of Vt *v* BF is a useful nomogram for the routine assessment of ventilatory response during exercise in healthy trained subjects.

The most common way to assess changes in ventilation (VE) is analysis of tidal volume (Vt) and breathing frequency (BF). Changes in Vt and BF were studied by Milic-Emili and Cajani in 1957,[1] and were in common clinical use in 1966.[2] Ventilation can be broken down into two components: (*a*) central inspiratory activity (''driving''); (*b*) inspiration-expiration alternation mechanism (''timing'').[3] The realisation of this represented significant progress in the assessment of respiratory performance during exercise or during other stimuli such as CO_2 inhalation.[4]

It is known that the ventilatory response to submaximal exercise with constant intensity has three stages. Stage I consists of an abrupt increase in VE during the first 30–50 seconds; it is not clear if the origin is neural or humoral.[5] In stage II there is a slow increase in VE over three to five minutes until a steady state is reached (stage III); the origin is predominantly humoral. However, when the increase in VE is progressive (for example during exercise with increasing intensity up to exhaustion), neural regulation is predominant and seems to be independent of the stimulus used.[4]

The breathing pattern depends on a variety of factors, such as the direct action of the central nervous system, relatively unknown humoral mechanisms, and the activation of several central or peripheral receptors. Most experts agree that the quotient between Vt and inspiratory time (T_i)—called inspiratory flow, Vt/T_i, or ''driving'' component—increases with progressive effort.[6] However, the situation is different if we consider the relation between T_i and total respiratory time (T_i/T_{tot})—duty cycle or ''timing'' component. Some authors have reported a fall in T_i/T_{tot} in response to a VE increase in sedentary people,[7] but others found an increase in the same circumstances[4] or during exercise.[8 9] However, many studies that only included athletes[10–13] suggest stabilisation of T_i/T_{tot} during exercise, maintaining a similar duration for inspiration and expiration.

In a trial carried out in our laboratory with 34 male athletes,[14] the T_i/T_{tot} remained constant throughout a progressive treadmill test using two different protocols. The hypothesis that the changes in VE are closely linked to changes in Vt/T_i[6] allows us to reintroduce the simple evaluation of VE during exercise using Vt and BF. It is known that respiratory work is inefficient when BF is high relative to a given VT.

The aim of this work was to assess breathing patterns in athletes during two different effort protocols, in terms of Vt and BF.

MATERIALS AND METHODS

Subjects

We studied 43 men (mean (SD) age 24.5 (6.17) years) and 21 women (22.33 (4.07) years). All were trained athletes from seven different sports: athletics (endurance, n = 21; speed, n = 10; jumps, n = 1), football (n = 7), taekwondo (n = 3), gymnastics (n = 3), tennis (n = 6), triathlon (n = 5), and pentathlon (n = 8).

Methods

All the subjects performed an effort test to exhaustion on a treadmill (Power Jog, GXC-200) following one of two different protocols (fig 1): (*a*) a step protocol with a prior warm up for three minutes at 8 km/h, starting at 9 km/h for women and 10.8 km/h for men and increasing 1.8 km/h every three minutes (n = 27; 17 men and 10 women); (*b*) a ramp protocol with a prior warm up for three minutes at 8 km/h, starting at 9 km/h for women and 10.8 km/h for men and increasing 0.2 km/h every 20 seconds (n = 37; 26 men and 11 women). In both protocols the slope was fixed at 1%, and the rate of increase in work was identical.

All the subjects had an electrocardiogram and a spirogram at rest before the test.

During the test the expired air was collected through a face mask and analysed in a CPX Medical Graphics analyser

Abbreviations: BF, breathing frequency; T_i, inspiratory time; T_{tot}, total respiratory time; VE, ventilation; Vt, tidal volume

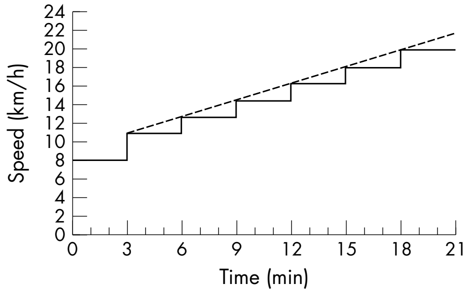

Figure 1 Rate of increase in work in both protocols (ramp and steps).

(infrared for CO_2 and zirconium cell for O_2). Recording the instantaneous flow by a pneumotachometer attached to a differential pressure transducer, we registered the average inspiratory and expiratory flow. Taking this record as a starting point, we analysed Vt, inspiratory and expiratory duration, and BF, obtaining the mean value from the last minute for every intensity in the step protocol, and the mean of 30 seconds at the same intensity for the ramp protocol.

All the subjects gave written and informed consent. The study was approved by the ethics committee of the Andalusian Center for Sports Medicine.

All the tests were carried out in the same conditions, by the same researchers, and with previous calibration of all the measuring instruments.

Statistical analysis

The results were included in a database for statistical and graphic analysis applying tendency studies and its respective correlation rates (R^2). The confidence intervals were determined through the correlation coefficient. Student's t test was used to determine significance, with $p<0.05$ taken to indicate significance.

Table 1 Basic details of the subjects

	Men (n = 43)	Women (n = 21)
Age (years)	24.50 (6.17)	22.33 (4.07
Weight (kg)	69.40 (6.56)	57.71 (7.55)
Height (cm)	175.44 (5.74)	162.81 (7.46)
Vital capacity (litres)	5.21 (0.53)	3.85 (0.44)
VO_2MAX (ml/kg/min)	56.65 (6.40)	48.55 (4.07)

Values are mean (SD).

RESULTS

Table 1 shows basic details of the subjects.

All the subjects reached maximal effort, and all criteria for the tests performed were maximum. The mean top speed was higher in the step protocol than in the ramp protocol for both men and women.

We focused on VE and the relations between its components. Tables 2 and 3 show Vt and BF for men and women respectively at different work levels and for the two protocols.

Vt/T_i showed a strong correlation with VE in both men and women, regardless of the protocol used (fig 2), whereas T_i/T_{tot} remained nearly constant (table 4).

There were no significant differences between the Vt and BF data from the two protocols: $p>0.1$ for Vt for the men and $p>0.3$ for the rest, which are very far from the significance level fixed at 0.05. The correlation coefficient between Vt and BF was 0.958 for men on the step protocol, 0.965 for men on the ramp protocol, 0.954 for women on the step protocol, and 0.922 for women on the ramp protocol. Vt *v* BF was exponential for the four groups and similar for men and women (ramp or step; fig 3) with R^2 values above 0.95. This relation is maintained even if we express Vt as a percentage of vital capacity (fig 4).

No significant differences were observed in Vt and BF between the two protocols in men or women at any level. This is true even if Vt is expressed as a percentage of vital

Table 2 Tidal volume and breathing frequency for men at different work levels for the step and ramp protocols

	Step (n = 17)		Ramp (n = 26)	
	Vt	BF	Vt	BF
Rest	0.82 (0.26)	16.00 (4.04)	0.86 (0.27)	15.88 (3.49)
Warm up	1.81 (0.44)	29.55 (7.60)	1.73 (0.43)	30.12 (7.28)
10.8 km/h	1.96 (0.35)	34.44 (8.16)	1.94 (0.35)	34.58 (8.55)
12.6 km/h	2.07 (0.35)	39.61 (9.27)	2.01 (0.32)	39.38 (9.51)
14.4 km/h	2.21 (0.31)	45.25 (9.40)	2.13 (0.28)	44.62 (10.17)
16.2 km/h	2.40 (0.30)	51.92 (9.29)	2.34 (0.31)	51.73 (9.46)
18.0 km/h	2.70 (0.32)	62.00 (9.15)		

Values are mean (SD).
Vt, Tidal volume (litres); BF, breathing frequency.

Table 3 Tidal volume and breathing frequency for women at different work levels for the step and ramp protocols

	Step (n = 10)		Ramp (n = 11)	
	Vt	BF	Vt	BF
Rest	0.60 (0.20)	17.29 (4.79)	0.60 (0.22)	17.45 (4.54)
Warm up	1.37 (0.30)	33.10 (6.80)	1.40 (0.34)	32.36 (7.15)
9.0 km/h	1.44 (0.32)	36.14 (6.04)	1.44 (0.38)	35.55 (6.85)
10.8 km/h	1.58 (0.35)	39.24 (6.11)	1.56 (0.42)	39.09 (7.15)
12.6 km/h	1.67 (0.37)	45.70 (8.70)	1.63 (0.44)	45.91 (10.28)
14.4 km/h	1.71 (0.36)	52.90 (7.84)	1.67 (0.42)	52.55 (8.69)
16.2 km/h	1.95 (0.34)	59.00 (7.20)		

Values are mean (SD).
Vt, Tidal volume (litres); BF, breathing frequency.

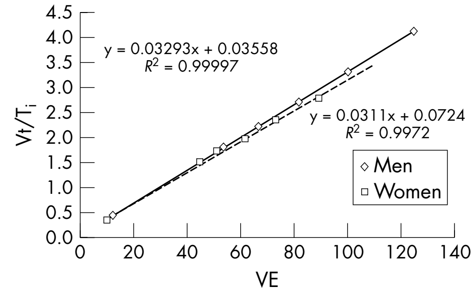

Figure 2 Relation between the ratio of tidal volume to inspiratory time (Vt/T_i) and ventilation (VE). It is linear in both men and women. Data from the two protocols are averaged.

capacity. Therefore analysis of all data for men and women shows an exponential relation (fig 5) with a strong correlation (R^2 = 0.98 for men and 0.97 for women).

DISCUSSION

It is known that Vt/T_i is the order to switch on the system and T_i/T_{tot} is the order to switch off inspiration, determining the rate of Vt and BF. The two parameters have a similar response in healthy people when ventilation is stimulated, no matter what the stimulus (exercise, CO_2 inhalation, etc),[4 15] and this response maintains the T_i/T_{tot} relation, with a resulting increase in inspiratory flow. Grunstein *et al*[16] demonstrated with anaesthetised cats that the control of T_{tot} depends on both the T_i of the preceding breath (phasic component) and a separate vagal mechanism specifically

Table 4 Correlation between ventilation and tidal volume to inspiratory time ratio (Vt/T_i) and inspiratory time to total respiratory time ratio (T_i/T_{tot})

	Men		Women	
	Vt/T_i	T_i/T_{tot}	Vt/T_i	T_i/T_{tot}
Warm up	0.44	0.49	0.34	0.50
10.8 km/h	1.79	0.49	1.51	0.49
12.6 km/h	2.21	0.50	1.72	0.49
14.4 km/h	2.71	0.50	1.97	0.51
16.2 km/h	3.33	0.50	2.35	0.52
18.0 km/h	4.13	0.50	2.80	0.52

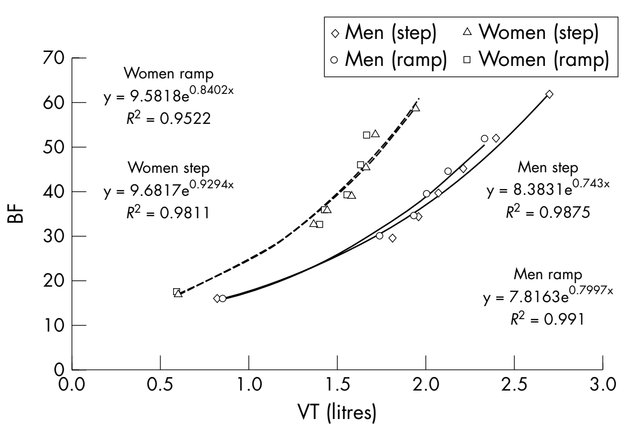

Figure 3 Relation between tidal volume (Vt) and breathing frequency (BF) in men and women on the step and ramp protocols.

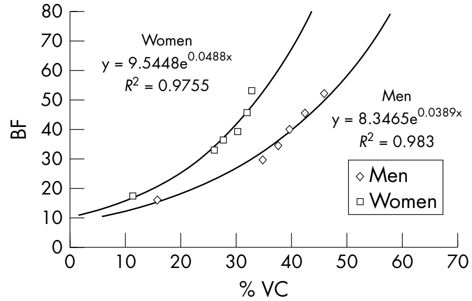

Figure 4 Relation between tidal volume (Vt) and breathing frequency (BF) in men and women expressed as a percentage of vital capacity (VC).

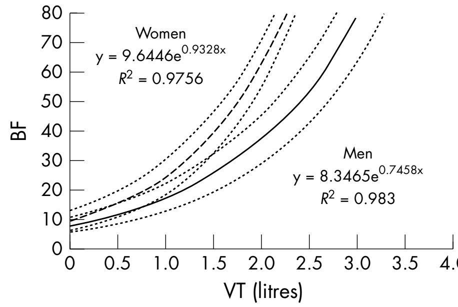

Figure 5 Graph showing the exponential relation between tidal volume (Vt) and breathing frequency (BF) for both men and women. This can be used as a nomogram for assessing breathing patterns in healthy people during exercise regardless of the protocol. Means and standard deviations are shown.

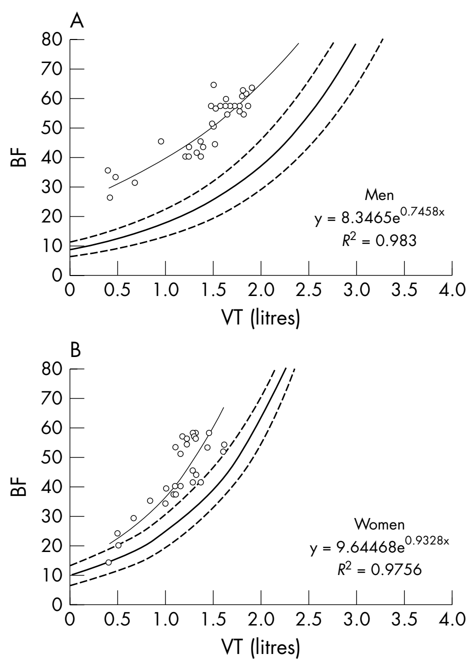

Figure 6 Two examples of inappropriate use of breathing pattern during exercise assessed with the proposed nomogram. (A) Effort test of a professional male soccer player (VO_2MAX = 61 ml/kg/min; VEMAX = 112 litres/min) with a previous diagnosis of overtraining syndrome; (B) effort test of an elite female 400 m runner (VO_2MAX = 53.4 ml/kg/min; VEMAX = 90.2 litres/min) with a previous diagnosis of exercise induced asthma.

What is already known on this topic

- Vt/T_i increases with progressive exercise
- Most authors agree that T_i/T_{tot} remains constant in healthy people during exercise
- The relation of Vt to BF is no longer used in the routine assessment of ventilatory response to exercise
- Most studies have been carried out with cycle ergometers

What this study adds

- VE is closely linked to changes in Vt/T_i, so it is possible to reintroduce simple evaluation of Vt and BF during exercise
- The response has been assessed using a treadmill comparing two different protocols
- Vt and BF show an exponential relation independent of the protocol used and of how well trained the subject is

affecting the duration of expiration in response to changes in the absolute end expiratory lung volume.

In people with chronic airflow limitation, BF may be conditioned by an increase in duration of expiration, but in healthy people the ratio between inspiration and expiration is remarkably constant during exercise,[17] and so the increase in VE depends on changes in Vt/T_i. This allows us to analyse the relation between Vt and BF during exercise, accepting that a high BF relative to a given Vt will result in a less effective ventilation.

Some studies report that different step durations alter mean inspiratory flow,[18] but others found that Vt/T_i and T_i/T_{tot} were similar at different intensities of the ramp protocol.[11] However, these studies were comparing two durations or two intensities in the same protocol (ramp or step), but are there differences in breathing patterns between the two different protocols? Although we could expect a different response between the ramp and step protocols, given that one is progressive and the other one tends to the steady state, we found the same response regardless of the protocol. In agreement with other studies,[6 12 13] we believe that, no matter how well trained the subject is or what protocol is used to assess it, for a given intensity of effort, ventilation behaves in a similar way after a central order (Vt/T_i).

The constant relation between Vt and BF in healthy people during exercise responds to the intensity of effort but not to the way of achieving it. This is in accordance with previous observations from our laboratory[14] and suggests that, at least in athletes, all ventilation effectively becomes alveolar during exercise. It requires reasonable use of BF and suggests that the respiratory muscle endurance in trained subjects is a consequence of the adopted breathing pattern,[19] and this may be trained.[20]

Figure 6 shows two examples of the practical application of this nomogram. In both cases we observe an inappropriate use of BF for each Vt.

In conclusion, as we consider that the sample (n = 64) is adequate with a variety of sports represented, we propose this graphic expression of the relation Vt *v* BF as a useful nomogram for assessing ventilatory response during exercise. We believe that it can provide useful information in the routine assessment of the response to exercise in healthy people.

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