A nomogram for assessment of breathing patterns during treadmill exercise

J Naranjo, R A Centeno, D Galiano, M Beaus

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 CO2 and O2.

Ventilation (VE) was continuously recorded, and tidal volume (Vt) and breathing frequency (BF) at the same inspiration were analysed for both protocols, as well as Vt/Ti and T/Ttot.

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/Ttot remained constant, and all increases in VE were strongly related to the respective increases in Vt/Ti. 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 (R² = 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.

T he 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, and were in common clinical use in 1966. Ventilation can be broken down into two components: (a) central inspiratory activity ("driving"); (b) inspiration-expiration alternation mechanism ("timing"). The realisation of this represented significant progress in the assessment of respiratory performance during exercise or during other stimuli such as CO2 inhalation.

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. 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.

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 (Ti)—called inspiratory flow, Vt/Ti, or "driving" component—increases with progressive effort. However, the situation is different if we consider the relation between Ti and total respiratory time (T/Ttot)—duty cycle or "timing" component. Some authors have reported a fall in T/Ttot in response to a VE increase in sedentary people, but others found an increase in the same circumstances or during exercise. However, many studies that only included athletes suggest stabilisation of T/Ttot during exercise, maintaining a similar duration for inspiration and expiration.

In a trial carried out in our laboratory with 34 male athletes, the T/Ttot 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/Ti 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; Ti, inspiratory time; Ttot, total respiratory time; VE, ventilation; Vt, tidal volume
Assessment of breathing patterns during treadmill exercise

Table 1  Basic details of the subjects

<table>
<thead>
<tr>
<th></th>
<th>Men [n = 43]</th>
<th>Women [n = 21]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>24.50 (6.17)</td>
<td>22.33 (4.07)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>69.40 (6.56)</td>
<td>57.71 (7.55)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>175.44 (5.74)</td>
<td>162.81 (7.46)</td>
</tr>
<tr>
<td>Vital capacity (litres)</td>
<td>5.21 (0.53)</td>
<td>3.85 (0.44)</td>
</tr>
<tr>
<td>VO2MAX (ml/kg/min)</td>
<td>56.65 (6.40)</td>
<td>48.55 (4.07)</td>
</tr>
</tbody>
</table>

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/Ti showed a strong correlation with VE in both men and women, regardless of the protocol used (fig 2), whereas Ti/Ttot 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 x 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 capacity.

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

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

<table>
<thead>
<tr>
<th></th>
<th>Step (n = 17)</th>
<th>Ramp (n = 26)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vt</td>
<td>BF</td>
<td>Vt</td>
</tr>
<tr>
<td>Rest</td>
<td>0.82 (0.26)</td>
<td>16.00 (4.04)</td>
</tr>
<tr>
<td>Warm up</td>
<td>1.81 (0.44)</td>
<td>29.55 (7.60)</td>
</tr>
<tr>
<td>10.8 km/h</td>
<td>1.96 (0.35)</td>
<td>34.44 (8.16)</td>
</tr>
<tr>
<td>12.6 km/h</td>
<td>2.07 (0.35)</td>
<td>39.61 (9.27)</td>
</tr>
<tr>
<td>14.4 km/h</td>
<td>2.21 (0.31)</td>
<td>45.25 (9.40)</td>
</tr>
<tr>
<td>16.2 km/h</td>
<td>2.40 (0.30)</td>
<td>51.92 (9.29)</td>
</tr>
<tr>
<td>18.0 km/h</td>
<td>2.70 (0.32)</td>
<td>62.00 (9.15)</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th>Step (n = 10)</th>
<th>Ramp (n = 11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vt</td>
<td>BF</td>
<td>Vt</td>
</tr>
<tr>
<td>Rest</td>
<td>0.60 (0.20)</td>
<td>17.29 (4.79)</td>
</tr>
<tr>
<td>Warm up</td>
<td>1.37 (0.30)</td>
<td>33.10 (6.80)</td>
</tr>
<tr>
<td>9.0 km/h</td>
<td>1.44 (0.32)</td>
<td>36.14 (6.04)</td>
</tr>
<tr>
<td>10.8 km/h</td>
<td>1.58 (0.35)</td>
<td>39.24 (6.11)</td>
</tr>
<tr>
<td>12.6 km/h</td>
<td>1.67 (0.37)</td>
<td>45.70 (8.70)</td>
</tr>
<tr>
<td>14.4 km/h</td>
<td>1.71 (0.36)</td>
<td>52.90 (7.64)</td>
</tr>
<tr>
<td>16.2 km/h</td>
<td>1.95 (0.34)</td>
<td>59.00 (7.20)</td>
</tr>
</tbody>
</table>

Values are mean (SD).

Vt, Tidal volume (litres); BF, breathing frequency.
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 $Vt/Ti$ is the order to switch on the system and $Ti/Ttot$ 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), and this response maintains the $T_i/T_{tot}$ relation, with a resulting increase in inspiratory flow. Grunstein et al 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 ($Vt/Ti$) and inspiratory time to total respiratory time ratio ($T_i/T_{tot}$)

<table>
<thead>
<tr>
<th></th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Vt/Ti$</td>
<td>0.44</td>
<td>0.49</td>
</tr>
<tr>
<td>$T_i/T_{tot}$</td>
<td>0.34</td>
<td>0.50</td>
</tr>
</tbody>
</table>

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

**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 ($VO_{2\max} = 61$ ml/kg/min; $VEMAX = 112$ litres/min) with a previous diagnosis of overtraining syndrome; (B) effort test of an elite female 400 m runner ($VO_{2\max} = 53.4$ ml/kg/min; $VEMAX = 90.2$ litres/min) with a previous diagnosis of exercise induced asthma.
What is already known on this topic

- VT/Ti increases with progressive exercise
- Most authors agree that Ti/Ttot 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/Ti, 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

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