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ABSTRACT

There are conflicting reports on the reproducibility of the visual analogue scale (VAS) and the modified Borg scale for the estimation of breathlessness during exercise. In an attempt to clarify the situation, two groups of healthy subjects undertook a progressive exercise test either daily (Group A) or weekly (Group B) on 10 separate occasions. Breathlessness was estimated every 1 min using the VAS. After 10 occasions, both Group A (P < 0.05) and Group B (P < 0.01) showed a significant increase in the mean intercept of the breathlessness/ventilation (VAS/\(V_I\)) relationship. The increase was not progressive; using change point regression, reproducible values were found to occur after approximately the fifth occasion in both subject groups. As the slope of the VAS/\(V_I\) relationship was highly reproducible and did not change with repeat testing, it would appear that at least two mechanisms are involved in the generation of the sensation of breathlessness. A decrease in the exercise heart rate over the same time period was significantly correlated with changes in the VAS/\(V_I\) intercept in both groups (P < 0.01 and P < 0.005 respectively). The relationship is unlikely to be causal, but may be indicative of a common underlying mechanism. It is suggested that breathlessness scores are likely to decrease as a direct result of repetitive testing over, on average, the first five periods of assessment. On the basis of this study, it may be inferred that a physiological mechanism contributes to the modulation of breathlessness during repetitive exercise testing.

INTRODUCTION

The reproducibility of the reported estimations of breathlessness is crucial in the investigation of the mechanisms of dyspnoea, both for clinical purposes and for mechanistic studies of the effects of dyspogenic agents in healthy volunteers. It is, therefore, reassuring that, despite large inter-subject variations [1–3], the use of the visual analogue scale (VAS) and the modified Borg scale for the estimation of breathlessness during exercise has been reported to be highly reproducible over time periods ranging from min to weeks [1,4–7]. However, not all such studies have reported such good reproducibility. Thus Stark et al. [8] found the breathlessness/ventilation (VAS/\(V_I\)) relationship to be adequately reproducible in only three out of five patients studied. Similarly, Wilson and Jones [9], in a study comparing the Borg and VAS scores, found that neither scale was highly reproducible over a 2–6-week period. In the latter case it was suggested that this could indicate a change in the perception of breathlessness or in use of the scales. In a study involving patients with chronic obstructive pulmonary disease (COPD) [10], the authors stated that some patients may require more than one test...
to establish reliability. Others have shown a significant visit effect for the VAS during submaximal exercise in healthy subjects [11]. It is apparent that repeat estimates of breathlessness frequently give lower values than the initial levels, at any given ventilation or workload. Although these changes have been attributed to a psychological effect [9,12], it has been noted that variations in breathlessness scores during exercise are associated with indices of physical fitness [2]. This implies a physiological mechanism, presumably related to habitual activity, contributing to the reduction in breathlessness seen on re-testing. If this were so, then any increase in habitual activity, which produces a physiological training effect, might be expected to be accompanied by a reduction in estimations of breathlessness independently of any change in ventilation.

The present study has, therefore, addressed two questions. First, is the VAS reproducible on a daily or weekly basis? Secondly, is the variation in the VAS associated with a training effect? If the mechanism underlying the anticipated reduction in breathlessness is dependent upon a training effect, then it should presumably be related to an accepted index of efficacy of training. The index chosen as an indicator was the exercise heart rate, which is widely used as such.

METHODS

Protocol

The effect of repetitive testing on the perceived intensity of breathlessness during bicycle ergometry was examined in two groups of healthy subjects. Both groups undertook a progressive exercise test to a symptom-limited maximum, during the course of which breathlessness was estimated each 1 min using a VAS.

Group A exercised daily on 10 occasions, while Group B exercised weekly on 10 occasions. For Group A, experiments were conducted only on weekdays; the first day of experimentation was varied, so that the positions of the weekends (i.e. Saturday and Sunday) were staggered.

Subjects

The subjects were recruited from staff and students of the University of Newcastle upon Tyne and from a local athletics club, and were naive as to the aims of the study. All were non-smokers with no history of cardio-pulmonary disease. Experiments were performed at approximately the same time of day, at least 2 h after a light meal. Informed consent was obtained before the study commenced, and the study was approved by the local ethical committee and performed according to the Declaration of Helsinki (1989). All subjects had normal lung function with respect to reference values [13].

Group A contained 10 subjects (nine male), with a mean (+ S.D.) age of 24.5 ± 4.7 years (range 19–37 years). They were sedentary individuals with minimal levels of habitual activity. The daily exercise procedures were expected to induce a training effect in this group. Group B contained 12 subjects (all male), with a mean age of 33.0 ± 8.2 years (range 24–48 years). These subjects had high levels of habitual activity; eight were members of an athletics club, and were familiar with cycling as an exercise training mode. This group was exposed to the same number of exercise tests and assessments as Group A, but the additional weekly exercise test was not expected to produce any training effect; in the event all members of this group increased their training levels progressively over the period of the study as they approached a competitive athletic season.

Exercise protocol

The exercise tests were conducted on an electrically braked cycle ergometer (Ergomed 740; Siemens). Mixed expired air was sampled by an IR carbon dioxide analyser and a paramagnetic oxygen analyser (Morgan). Inspired ventilation and respiratory frequency were measured using a rotating vane anemometer (Morgan). The ECG (Diascope; Simonsen & Weel) was monitored throughout. The data from the ECG, gas analysers and ventilation monitor were processed and recorded every 15 s.

The VAS incorporated a 100 mm linear potentiometer, which controlled a 100 mm horizontal linear scale consisting of a series of light-emitting diodes, the extremes of which were labelled ‘not at all breathless’ (0 mm) and ‘extremely breathless’ (100 mm). The output went to a pen recorder (Euroscribe Y-T; Houston Instruments), so that every response was recorded on a scale of 0–100 mm. Estimations of breathlessness were requested at the end of each 1 min of the exercise procedure. After each estimation, the slider was returned to the resting position (0 mm).

Before the start of each experiment, the term ‘breathlessness’ was defined to the subjects as a sense of ‘air-hunger’, a feeling that breathing was not sufficient for the needs they thought they had, or a shortness of breath. It was emphasized that they should not confuse breathlessness with other sensations associated with exercise, such as leg fatigue or the awareness of increased breathing.

After 2 min at rest, the subject started unloaded pedalling at a frequency of between 50 and 60 rev./min. At 1 min intervals thereafter, the resistance was increased by increments of 20 W up to a symptom-limited maximum. The test was stopped if the heart rate was within 10 beats·min⁻¹ of the maximum predicted [210–(0.65 × age)] or when the VAS estimation was greater than 90 mm.
Figure 1  VAS/Vᵋ relationship for two subjects from Group A
Shown is the linear regression between breathlessness and ventilation during exercise, with the regression equation, for (A) a subject with a low correlation, and (B) a subject with a high correlation.

Statistical analyses
When the subjects’ VAS estimations were plotted against their inspired ventilations, a linear VAS/Vᵋ relationship was observed (Figure 1). Linear regression was applied, and from this the x-axis intercept (l·min⁻¹) and the slope (mm·min·l⁻¹) were calculated.

As the relationship between intercept and experiment number proved to be biphasic, change-point regression was used to find the point of inversion in terms of the number of experiments. This change-point is defined as the point that minimizes the residual variation, and was estimated by an iterative method (Department of Medical Statistics, University of Newcastle upon Tyne), based on the work of Vieth [14]. In this application, the model constraints were that the two segments of the regression were continuous at the change-point and that the slope of the regression line after the change-point was zero.

Potential physiological training effects were assessed from the linear regression of cardiac frequency against oxygen uptake. The index used was the cardiac frequency at an oxygen uptake of 1.5 l·min⁻¹ (f₁₁.₅) [13], which takes into account both the initial resting heart rate and the rate of increase during exercise.

A paired t test was used to compare the mean results between the first and last occasions, while an unpaired t test was used to compare differences between groups. The slope of the relationship between VAS/Vᵋ intercept and f₁₁.₅ was analysed using a one-sample t test. All t tests were two-tailed, and the level of probability taken as significance was 5 % (P < 0.05).

RESULTS
Linearity of the VAS/Vᵋ relationship
The VAS/Vᵋ relationship was highly significant (P < 0.001) and effectively linear for both groups. The raw data from two subjects on the first occasion are shown in Figure 1. One subject’s data show a relatively higher correlation and the other’s a lower correlation. The mean r² values, together with the range for slopes and intercepts for all initial experiments in both groups, are shown in Table 1. The r² value was significantly higher for Group A compared with Group B.

Table 1  Inter-subject values for indices of the VAS/Vᵋ relationship on the first occasion of testing

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group A (n = 10)</th>
<th>Group B (n = 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>r² value</td>
<td>0.956 ± 0.003</td>
<td>0.94 ± 0.004*</td>
</tr>
<tr>
<td>Slope (mm·min·l⁻¹)</td>
<td>0.30–1.50</td>
<td>0.59–1.36</td>
</tr>
<tr>
<td>Intercept (l·min⁻¹)</td>
<td>10.08–32.40</td>
<td>9.84–49.66</td>
</tr>
<tr>
<td>f₁₁.₅ (beats·min⁻¹)</td>
<td>125.24 ± 4.26</td>
<td>119.84 ± 3.95</td>
</tr>
</tbody>
</table>

Inter-subject variation in the VAS/Vᵋ relationship
There was a wide range of values for both the slope and the intercept of the VAS/Vᵋ relationship on the first occasion of testing (Table 1), with no significant differences between groups. The mean values are given in Table 2.

Effect of repetitive testing on the slope of the VAS/Vᵋ relationship
The mean slopes of the VAS/Vᵋ relationship for each test occasion for Groups A and B are shown in Figure 2. The mean values on the first and tenth occasions for both groups are given in Table 2. There were no significant differences between groups.
Table 2  Comparison of indices of the VAS/V₁ relationship and submaximal cardiac frequency on the first and tenth occasions of testing

Values are means ± S.E.M. (Group A, n = 10; Group B, n = 12). NS, not significant.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Occasion 1</th>
<th>Occasion 10</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAS/V₁ slope (mm·min⁻¹)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group A</td>
<td>0.78 ± 0.13</td>
<td>0.74 ± 0.10</td>
<td>NS</td>
</tr>
<tr>
<td>Group B</td>
<td>0.96 ± 0.07</td>
<td>1.11 ± 0.14</td>
<td>NS</td>
</tr>
<tr>
<td>VAS/V₁ intercept (l·min⁻¹)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group A</td>
<td>20.34 ± 2.18</td>
<td>41.96 ± 8.55</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Group B</td>
<td>25.57 ± 3.41</td>
<td>46.14 ± 6.46</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>f_C1.5 (beats·min⁻¹)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group A</td>
<td>125.24 ± 4.26</td>
<td>119.11 ± 7.84</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Group B</td>
<td>119.84 ± 3.95</td>
<td>108.63 ± 6.25</td>
<td>&lt; 0.005</td>
</tr>
</tbody>
</table>

differences between occasions for either group, nor were the values different between the groups.

Effect of repetitive testing on the intercept of the VAS/V₁ relationship

The change in the VAS/V₁ relationship in one subject from occasion 1 to occasion 10 is shown in Figure 3. The mean intercepts of the VAS/V₁ relationship for each test occasion for Groups A and B are shown in Figure 4. The mean values on the first and tenth occasions for both groups are given in Table 2. After 10 occasions, both groups showed a significant increase in the mean intercept of the VAS/V₁ relationship. The increase was not progressive; using change-point regression, the mean point in time where the VAS/V₁ intercept reached reproducible values was 5.3 days for Group A and
Breathlessness during repetitive exercise

5.7 weeks for Group B, i.e. between the fifth and sixth occasions of testing. The timing of the assessments in relation to the 2-day weekend breaks did not influence this plateau in threshold values.

Effect of repetitive testing on cardiac frequency during exercise

Values for mean $f_{C1.5}$ on the first and tenth occasions for both groups are given in Table 2. After 10 occasions, both groups exhibited a significant decrease in heart rate during submaximal exercise compared with the first occasion. The decrease was progressive, with no indication of plateaux in the individual data comparable with those observed in the VAS/$V_i$ intercept data.

At the first assessment (occasion 1), the mean exercise $f_{C1.5}$ was lower for Group B than for Group A, but the difference was not statistically significant. The initial resting heart rate on occasion 1 was also lower for Group B ($69.6 \pm 2.5$ beats·min$^{-1}$ compared with $78.9 \pm 1.1$ beats·min$^{-1}$; means ± S.E.M.), but again the difference was not significant.

Relationship between the VAS/$V_i$ intercept and exercise cardiac frequency

There was a significant negative correlation ($P < 0.05$) between the intercept of the VAS/$V_i$ relationship and the exercise $f_{C1.5}$ on occasion 1, for subjects pooled from Groups A and B (Figure 5).

Over the 10 test occasions, the increase in the mean intercept of the VAS/$V_i$ relationship and the decrease in the mean $f_{C1.5}$ (Figure 6) were significantly correlated for both Group A ($P < 0.01$) and Group B ($P = 0.005$). Although the majority of the subjects conformed to the mean response, two subjects from each group reported a material decrease in breathlessness without any accompanying reduction in exercise heart rate.

DISCUSSION

Over the period of testing, it is clear that the slope of the VAS/$V_i$ relationship remained constant. The intercept, however, increased with repetitive testing (i.e. a shift to the right, indicating reduced breathlessness at all levels of ventilation) until it reached a plateau after approximately the fifth to sixth occasion of testing. The occurrence of the plateau, in terms of the occasion of testing, was not dependent upon the frequency of testing, or the positioning of the 2-day weekend break.

Previous authors have used an index of breathlessness at a given ventilation [2] or the mean VAS score [9], although in the present study neither would have the sensitivity to detect specific changes in the intercept or slope of the relationship. The mechanisms responsible for this change in the VAS/$V_i$ relationship could include (a) effects such as an alteration in the criteria used by...
Figure 6  Relationship between VAS/VI intercept and exercise heart rate during repetitive exercise

Shown is the linear regression between mean VAS/VI intercept (± S.E.M.) and mean exercise heart rate (fC1.5), over 10 occasions, for (A) Group A (n = 10) and (B) Group B (n = 12).

the subjects to estimate the magnitude of the sensation (i.e. a habituation or conditioning), and/or (b) a reduced fC1.5 resulting from repetitive exposure to the exercise (a physical training effect).

There are published data to support both models. Levine and associates [15], studying ventilatory muscle training in patients, suggested that a decrease in anxiety over breathlessness led to a decrease in breathlessness itself. Similarly, Wilson and Jones [9] reported falls in breathlessness scores in normal subjects during subsequent exercise testing, and suggested that this could be due to a psychological effect. Belman et al. [12] assessed the reproducibility of breathlessness in patients with COPD, using the Borg scale. Four exercise tests were conducted on separate days within a period of 10 days. The dyspnoea score showed a consistent and significant decline over this time period, with no related decrease in heart rate or ventilation. The authors attributed this decrease to ‘desensitization’, a psychological effect in patients for overcoming their fears of dyspnoea. Other authors [16] have also mentioned desensitization of dyspnoea in patients as a result of a habituation process.

There have been many attempts to relate exercise training to breathlessness, with varying success. In an early study, a decrease in exercise dyspnoea in COPD patients, who exercised regularly over a 6–18-month period, was judged to be a training effect [17]. Other studies in similar patient groups have demonstrated increased exercise capacity and tolerance with [18] or without [19] simultaneous decreases in exercise ventilation. In healthy subjects, physical fitness and breathlessness have been shown to be related [2], with sedentary subjects having higher exercise heart rates associated with higher scores of breathlessness. These authors suggested that afferent information from the thorax could change with physical training. It could be postulated that this may alter central motor command. The current working hypothesis for the genesis of breathlessness is central motor command from the brainstem to the respiratory muscles and also projected to the sensory cortex [20].

Human neuroimaging has shown several regions of the brain that are activated under conditions of increased breathlessness, including the insula, cingulate area, cerebellum and other areas in the limbic system. Techniques used to stimulate dyspnoea in healthy subjects were hypercapnia [21,22], hypoventilation [23], resistive loading [24] and lowering of the tidal volume [25]. However, the insula was the only structure identified that was common to all studies. Oppenheimer and co-workers [26] first demonstrated that cardiovascular changes were elicitable during intra-operative insular stimulation in epileptic patients. The insula has been also shown to be active during various forms of bicycle ergometry and handgrip exercise [27,28], and recently has been seen to be related to central command per se [28]. It has also been suggested that changes in the ratings of perceived effort may partly regulate insular cortical activation [27]. It may be possible that the insula cortex is involved with the interaction between cardiovascular fitness and breathlessness sensations. It is suggested that the sensory cortex interacts with the insular cortex to modulate the intercept of the VAS/VI relationship.

Our findings of a significant negative correlation between exercise heart rate and the intercept of the VAS/VI relationship on the first occasion of testing are in agreement with those of Adams et al. [2], and are consistent with the concept of the subjective sensations of breathlessness being attenuated in the physically fit, at least at submaximal levels of exercise. That being so, it was anticipated that a reduction in exercise heart rate occurring as a consequence of increased activity in Group A would be accompanied by a delay in the onset
of breathlessness. Exercise levels were not expected to increase materially in Group B, and thus any change in reported breathlessness in this group could not be attributable to a direct training effect. In the event, for external reasons, Group B did in fact increase their exercise regimens and became therefore a second training group.

Since both subject groups increased their levels of activity over the duration of the study, both demonstrated a significant reduction in exercise heart rate, indicative of a successful cardiovascular training regime. This decrease was significantly correlated with an increase in the intercept of the \( VAS/V_1 \) relationship, suggesting that at least some of the changes in breathlessness were associated with a cardiovascular training effect. However, the functional significance of this association between breathlessness and cardiovascular fitness needs to be addressed with caution. For the grouped mean data, over the periods of testing, the \( VAS/V_1 \) intercept ceased to increase after the fifth or sixth occasion. Over the same 10 testing periods, the exercise heart rate decreased progressively, with no indication of a plateau either in the grouped mean data or in the individual responses. In fact, in four subjects the breathlessness score decreased materially without any reduction in exercise heart rate.

The relationship between physical training and breathlessness is not, therefore, likely to be causal. It is possible that there is a common underlying mechanism, but this would have to accommodate the differential responses of the \( VAS/V_1 \) intercept and the exercise cardiac frequency. Those factors that could potentially contribute to a plateau in the breathlessness score would include habituation or the use of the ratings scales themselves. Although such an effect might take place over the first two assessments, it seems unlikely to continue for, on average, five occasions. To rule out such factors, it would be necessary to make a comparison between anxious and non-anxious subjects or between experienced and naive subjects. A study related to the use of the ratings scales compared the reliability of dyspnoea perceptions using four types of scales, in literate and illiterate COPD patients [29]. There were no significant differences, although only spirometry and not exercise activity over the duration of the study, both demonstrated a critical evaluation and application to analyse the acute effects of diazepam and promethazine on breathlessness induced by exercise or by exposure to raised levels of carbon dioxide. Clin. Sci. 61, 429–439


REFERENCES

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