Eur Respir J, 1994, 7, 875–880
DOI: 10.1183/09031936.94.07050875
Printed in UK - all rights reserved


European Respiratory Journal
ISSN 0903 - 1936

# Experience of a standardised method for assessing respiratory disability

J.E. Cotes*, D.J. Chinn*, J.W. Reed*, J.E.M. Hutchinson**

*Experience of a standardised method for assessing respiratory disability. J.E. Cotes, D.J. Chinn, J.W. Reed, J.E.M. Hutchinson. ©ERS Journals Ltd 1994.*

**ABSTRACT: A standardised method of scoring respiratory disability based on measurement and/or estimation of maximal oxygen uptake has recently been developed by the European Society for Clinical Respiratory Physiology. In the present study, we wanted to determine how the results obtained using this objective method compared with those by the more traditional empirical method used in a Medical Boarding Centre (MBC) for Respiratory Diseases.**

**The subjects were 62 men who were claiming industrial injuries benefit on account of prior exposure to a respiratory hazard.**

**The MBC ratings and the disability scores were correlated and, in the case of men with moderate or severe disability, numerically equivalent. The results provided independent confirmation that the MBC ratings were influenced by the forced expiratory volume, radiological category of pneumoconiosis and grade of breathlessness. In subjects in whom the measured and estimated maximal oxygen uptakes were inconsistent, the information obtained during the exercise test could identify which of several factors contributed to the exercise limitation.**

**Since the new method might be expected to reduce the difficulties experienced in assessing respiratory disability, its use is recommended.**

*Eur Respir J., 1994, 7, 875–880.*

*Respiration & Exercise Laboratory, Dept of Physiological Sciences, Medical School, Newcastle-upon-Tyne, UK. **Medical Boarding Centre, Respiratory Diseases, Newcastle-upon-Tyne, UK.

Correspondence: J.E. Cotes
Respiration & Exercise Laboratory
Dept of Physiological Sciences
Medical School
Newcastle-upon-Tyne
NE2 4HH, UK

Keywords: Breathlessness
chronic lung disease
disability assessment
exercise capacity
standardisation

Received: June 23 1993
Accepted after revision November 21 1993

Respiratory disability is defined here as loss of capacity for exercise caused by impaired lung function [1]. Procedures for assessing the disability have been influenced by historical, legal and medical circumstances, which have varied between countries. In most, the basis for assessment has moved from clinical impressions to objective measurements of respiratory impairment defined in terms of a subnormal forced expiratory volume in one second ($FEV_1$), forced vital capacity (FVC) and transfer factor of the lungs for carbon monoxide (TLCO) [2, 3]. However, the association between the disability and the underlying impairment is weak [4, 5]. This is partly because the commonly used tests provide an incomplete description of the overall damage to the lungs [6].

Recently, a working party of the European Society for Clinical Respiratory Physiology recommended that assessment should be in terms of maximal oxygen uptake [7]. One hundred percent disability was defined as an inability to achieve during exercise a rate of energy expenditure in excess of twice that used at rest (*i.e.* ≤2 metabolic equivalent of the task (MET)). This implied that the fully disabled person was unable to walk more than a few paces before being stopped by breathlessness and was, therefore, effectively confined to the house. The threshold for respiratory disability was a maximal oxygen uptake at the lower limit of the normal range (defined as reference value minus 1.64 RSD) [8]. Within these limits, the disability was to be assessed on a linear scale (fig. 1).

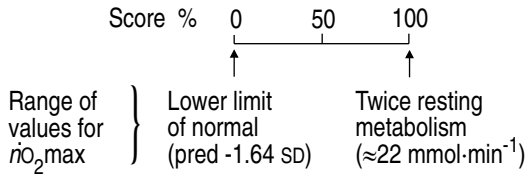


Fig. 1. – Diagram illustrating the method for scoring respiratory disability $\dot{V}O_2$ max is maximal oxygen uptake in mmol·min$^{-1}$

In this study, we wanted to determine whether assessments made by the new objective method were correlated with those made by a traditional empirical method. We also wanted to find out if, compared with the traditional method, the new method could provide additional relevent information.

## Subjects and protocol

The subjects were men who were claiming industrial injuries benefit on account of prior exposure to a respiratory hazard. They had been referred to the laboratory for physiological assessment by the Department of Social Security's local Medical Boarding Centre (MBC), where a rating for total cardiorespiratory disability had previously been made; the rating procedure is given below. The MBC ratings were compared with

the disability scores obtained by the new standard method. The interval between the assessments was 1–4 weeks.*

The criteria for inclusion in the study were that a detailed physiological assessment had been carried out, that the man's lung function was impaired and the Medical Boarding Centre had rated the total cardiorespiratory disability; this was almost always the case up to 1988, when the practice was discontinued. A letter was sent to each of the men who met these criteria, and the 62 men who gave permission for their ratings to be disclosed were included in the study. There were no refusals, but four men did not reply and could not be contacted. The study had been approved by the local Ethical Committee.

The subjects were mainly former coal-miners or workers with asbestos, of whom 27 had extensive radiographic abnormalities [9]: progressive massive fibrosis of coal-worker's pneumoconiosis category B or above (9 cases), asbestosis radiological category 3 (13 cases), and asbestos pleural disease (5 cases). Four men had asthma, one had farmer's lung and the remainder had simple pneumoconiosis (including category A), or some radiographic changes associated with exposure to asbestos.

## Methods

### *At the Medical Boarding Centre*

Attendance at the Centre was preceded by screening to establish that the applicant might possibly have an occupational lung disorder. Men who met this criterion underwent a clinical interview and examination, chest radiography and simple spirometry using a bellows wedge-spirometer (Vitalograph) for measurement of $FEV_1$ and FVC. The spirometer was not calibrated during use, but the results for $FEV_1$ were similar to those subsequently obtained in the laboratory. The previous medical records were scrutinised. Rating for disability was based on all four sets of information and was in the range 0–100% for both occupational disability and total cardiorespiratory disability. The latter was used for the present study.

### *In the Laboratory*

Here the subjects again had a medical interview, which included a clinical history, respiratory symptom questionnaire [10], examination of the chest, measurement of blood pressure and scrutiny of the chest radiograph. Breathlessness was scored using an extended version of Fletcher's clinical grades [6]. $FEV_1$ and FVC were measured using a dry bellows spirometer [11]. Before use, this was calibrated for volume and time with a standard orifice and weight. For each index, the recorded value was the highest of three technically satisfactory estimates according to the criteria of the European Coal and Steel Community [8]. The subjects then inhaled a bronchodilator aerosol (salbutamol 0.2 mg), after which the measurements were repeated.

Total lung capacity and its subdivisions were measured by the closed circuit helium dilution method using a Resparameter (P.K. Morgan Ltd). The dead space of the apparatus and the linearity of the helium analyser were checked using standard methods [6]. Transfer factor of the lungs for carbon monoxide ($T_{LCO}$) was measured by the single-breath holding carbon monoxide method, with helium as the indicator gas. The alveolar volume used in the calculation was the sum of the residual volume by closed circuit spirometry and the volume of test gas inspired [6]. Transfer test apparatus (P.K. Morgan Ltd) was employed and the gas analysers (katharometer and infra-red) were calibrated before use [12]. The reference values were those reported previously [6]. The reference variables were age and stature. The latter was measured using a stadiometer (Harpenden). In addition, fat free mass was estimated from body mass and skinfold thickness at four sites [6]. Respiratory impairment was considered to be present if the measured value for any one of the indices $FEV_1$, FVC, $FEV_1$% ($100 \times FEV_1/FVC$) or $T_{LCO}$ was below the normal range as defined.

Exercise was performed on a treadmill using a progressive protocol; this entailed increasing first the belt velocity and then the incline, from, respectively, 1.5 or 3 kph and 0 or 4°, at rates of 0.5 or 1 kph and 1° per min. The rates were chosen with a view to raising the level of activity from rest up to the symptom-limited maximum over approximately 10 min [9]. However, in the event of the subject becoming ataxic, or developing electrocardiographic ST depression (>2 mm), or consecutive or frequent ventricular ectopic beats, the exercise was discontinued. The measurements, which were made each 15 s, included ventilation by a vane anemometer, oxygen uptake by analysis of mixed expired gas for oxygen and carbon dioxide using paramagnetic and infrared analysers, and cardiac frequency by electrocardiography with electrodes in the CM5 configuration [13]. Morgan equipment was used. The ventilation meter was calibrated using a 1 *l* syringe, which was emptied at different rates. The gas analysers were calibrated using gas mixtures of known composition (Cryoservices) and the cardiac frequency was checked by counting R waves on the electrocardiogram. The exercise data were processed and displayed each 15 s during the test.

Graphs relating ventilation, cardiac frequency and respiratory exchange ratio to uptake of oxygen, and ventilation to tidal volume were then constructed automatically and used to obtain the maximal ventilation ($\dot{V}_E max$), cardiac frequency ($f_c$,max) and uptake of oxygen ($\dot{n}O_2 max$), the ventilation ($\dot{V}_{E_{45}}$) and cardiac frequency ($f_{c_{45}}$), at an oxygen uptake of 45 mmol·min$^{-1}$ (1.0 *l*·min$^{-1}$) and the tidal volume ($V_T$) at a ventilation of 30 *l*·min$^{-1}$ ($V_{T_{30}}$). Where the subject did not achieve an oxygen uptake of 45 mmol·min$^{-1}$ the $\dot{V}_{E_{45}}$ was taken as twice that at an oxygen uptake of 22 mmol·min$^{-1}$ [4]. The submaximal indices and also the maximal indices were verified by manual calculation from the raw data. At the end of exercise, the subject was immediately encouraged to talk by being asked to describe his symptoms; whilst he spoke,

*The views expressed are those of the authors and not the Department.

or attempted to speak, the observer made an assessment of the level of breathlessness on a four point scale. The subject then rated the severity of exercise subjectively, using a BORG scale [14].

The subject was considered to have respiratory disability if: 1) respiratory impairment was present (as defined above); 2) the subject reported that he had discontinued exercise on account of breathlessness, which had also been evident to the observer; and 3) the maximal exercise ventilation was considered to be truly maximal, in that it was within 1.64 SD of the average achieved by fully co-operative subjects having similar levels of $FEV_1$ [15].

Symptom-limited maximal oxygen uptake was measured directly. It was also estimated from $FEV_1$ (measured without additional bronchodilatation), $\dot{V}E_{45}$, age and fat free mass (FFM) using the following relationship [4]:

$$\dot{n}O_2max,est = 66.4+13.4\ FEV_1\ (l) -0.94\ \dot{V}E_{45}\ (l\cdot min^{-1}) \quad (1)$$
$$(mmol\cdot min^{-1}) \quad +0.45\ FFM-0.31\ age\ (yrs)\ (RSD\ 11.6 mmol\cdot min^{-1})$$

The disability score was calculated using both the observed and estimated maximal oxygen uptakes, as follows:

$$\text{Disability score (obs or est):} = \frac{100(\dot{n}O_2max,ref - 1.64\ RSD) - \dot{n}O_2\ max,obs\ (or\ est)\ (\%)}{(\dot{n}O_2\ max,ref - 1.64\ RSD) - 22} \quad (2)$$

where $\dot{n}O_2$ max,ref and $\dot{n}O_2$ max,obs are the reference and observed (or estimated) maximal oxygen uptakes, the term within the brackets is the lower limit of normal for $\dot{n}O_2$ max,ref, and 22 is twice the average resting oxygen uptake [7]. The reference values for maximal oxygen uptake in working men were those of WELLER *et al*. [16]

$$\dot{n}O_2max,ref = 70+1.43\ FFM\ (kg)+6.3AS-0.95\ age\ (yrs) \quad (3)$$
$$(mmol\cdot min^{-1}) \quad -8.1\ if\ Sm\ (RSD\ 17.3\ mmol\cdot min^{-1})$$

where FFM is fat free mass, AS is activity score (from 1 inactive to 4 very active, for example participation in athletic events) and Sm is current smoker.

Using equation (2), a result with a positive sign gave the percentage disability. A result with a negative sign gave the extent to which $\dot{n}O_2$max,obs exceeded the lower limit of normal.

### *Statistical analysis*

Statistical analysis was performed using an Amdahl mainframe computer and the statistical package for the Social Sciences of the University of Michigan (SPSS$^X$). A 5% level of probability was taken as significant.

## Results

The 62 subjects exhibited a wide range of levels of respiratory impairment, grade of breathlessness and rating for total cardiorespiratory disability (table 1).

The results for the exercise test also extended from the grossly abnormal to results which were apparently normal (table 2).

Table 1. – Features of subjects (n=62)

| | | |
|---|---|---|
| Age yrs | 56 | (23–80) |
| $FEV_1$ *l* | 1.92 | (0.49–4.27) |
| $FEV_1$ % pred | 62 | (17–115) |
| TLCO $mmol\cdot min^{-1}\cdot kPa^{-1}$ | 7.0 | (2.9–14.0) |
| Grade of breathlessness | 2.7 | (1–6) |
| Rating for total cardiorespiratory disability | 33 | (3–100) |

Data are presented as mean, and range in parenthesis. $FEV_1$: forced expiratory volume in one second; TLCO: transfer factor of the lungs for carbon monoxide.

Table 2 – Results of the exercise test

| | | | |
|---|---|---|---|
| Exercise ventilation $\dot{V}E$ $l\cdot min^{-1}$ | | | |
| | $\dot{V}E_{45}$ | 38.3 | (24–64) |
| | $\dot{V}E$max,ex | 52.0 | (23–92) |
| Maximal oxygen uptake ($\dot{n}O_2$) $mmol\cdot min^{-1}$ | | | |
| | Observed | 61.1 | (28–109) |
| | Estimated | 63.4 | (31–107) |
| | Reference | 96.4 | (65–144) |
| Disability score % | | | |
| | From $\dot{n}O_2$ max,obs | 23.1 | (-43–83) |
| | From $\dot{n}O_2$ max,est | 18.4 | (-62–74) |

Data are presented as mean, and range in parenthesis. $\dot{V}E$: minute ventilation; $\dot{V}E_{45}$: ventilation at an oxygen uptake of 45 $mmol\cdot min^{-1}$; $\dot{V}$emax, ex: maximum exercise ventilation; $\dot{n}O_2max_1obs$: observed maximal oxygen uptake; $\dot{n}O_2$max, est: estimated maximal oxygen uptake.

The disability scores calculated using $\dot{n}O_2$max,obs and $\dot{n}O_2$max,est were moderately well correlated (r=0.72), and both were correlated with the MBC ratings for total cardiorespiratory disability (r=0.51). The ratings and the disability scores using the $\dot{n}O_2$max,est, but not $\dot{n}O_2$ max,obs were correlated with the clinical grade of breathlessness (r=0.3), whilst both forms of the disability score, but not the rating, were correlated with age (table 3).

The MBC ratings for total cardiorespiratory disability could be described in terms of the disability score and whether or not the subjects had radiological evidence for progressive massive fibrosis (PMF) of coal workers pneumoconiosis according to the following relationships:

*Using $\dot{n}o_2$ max,obs*

$$\text{MBC rating (\%)} = 0.38\ \text{disability score (\%)} + 15.5\ \text{if PMF} + 22.1\ (RSD\ 17.5\%)\ R^2\ 0.33 \quad (4)$$

*Using $\dot{n}o_2$ max,est.*

$$\text{MBC rating (\%)} = 0.49\ \text{disability score (\%)} + 24.1\ (RSD\ 18.1\%)\ R^2\ 0.26 \quad (5)$$

Additional variance in the ratings was explained by the forced expiratory volume, which was the largest single contributor, and by the clinical grade of breathlessness, but not by age, indices of body composition, smoking history, or any radiographic feature other than progressive massive fibrosis.

Table 3. – Cross correlation matrix

| | Grade of breathlessness | Disability score ($\dot{V}O_2$max,obs) | Disability score ($\dot{V}O_2$max,est) | Age |
|---|---|---|---|---|
| MBC rating | 0.34 | 0.51 | 0.51 | 0.03NS |
| Grade of breathlessness | | 0.19NS | 0.32 | 0.17NS |
| Disability score ($\dot{V}O_2$max,obs) | | | 0.72 | -0.23 |
| Disability score ($\dot{V}O_2$max,est) | | | | -0.31 |

NS: not significant at 5% level of probability; MBC: Medical Boarding Centre. For further definitions see legend to table 2.

A number of subjects with low ratings had maximal oxygen uptakes within the normal range (negative disability scores) (fig. 2). By contrast, the relationship of the ratings to the scores for subjects with moderate and high disability scores (40–59% and >60%, respectively) approximated to the line of identity, but with a wide scatter. The results for 10 of the outliers identified in figure 2 were selected for additional scrutiny (table 4).

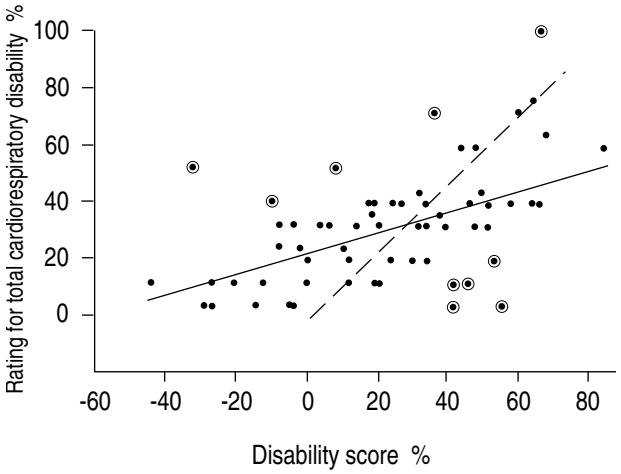


Fig. 2. – Relationship of the rating for total cardiorespiratory disability of the Medical Boarding Centre to the score for respiratory disability based on maximal observed oxygen uptake ($\dot{V}O_2$ max,obs). The continuous line is the relationship fitted by the method of least squares and the dashes the line of identity. The ringed points are the outliers described in table 4.

In most instances the causes of the discrepancy were apparent from the result of the maximal exercise test and comparison of the observed with the estimated maximal oxygen uptakes. In subjects Nos 1 and 2, the estimated disability score (EDS) was moderately increased, due to a somewhat raised submaximal exercise ventilation (not given in the table). The observed disability score (ODS) was greatly increased by hyperventilation (h), whilst the low MBC rating was mainly attributable to the normal $FEV_1$. The disability was probably best described by the EDS. In subjects Nos 3–5 the MBC rating and the EDS were reasonably concordant, the ODS was in one instance reduced by exceptional perseverence (p) and in the others increased by hyperventilation (associated with a high respiratory exchange ratio), and by the subject not persevering at the exercise (np). In subjects Nos 6–8, the EDS and ODS were concordant and lower than the MBC rating; the latter was possibly increased by a reported high clinical grade of breathlessness. In subjects Nos 9 and 10, the ODS was out of line. Subject No. 9 developed ventricular ectopic beats concurrent with the onset of severe breathlessness; the two features could have interacted to bring forward the point of cessation of exercise. In subject No.10, the cessation was postponed by exceptional perseverence.

The disability scores calculated using $\dot{V}O_2$max,obs and $\dot{V}O_2$max,est differed by more than 25% in 11 subjects; they included five of the subjects in table 4 (subjects Nos 1, 3, 4, 9 and 10). The factors responsible for the discrepancies were discernable from the data, and, as in the cases described above, their identification contributed to understanding the mechanisms responsible for the disability.

Table 4. – Details of some outliers (for details see text)

| Pt No. | Diagnosis rating % | MBC rating % | Disability score Obs. % | Disability score Est. % | $FEV_1$ *l* | Δ $FEV_1$* % | Comment |
|---|---|---|---|---|---|---|---|
| 1 | Asthma | 5 | 57h | 30 | 2.96 | 0 | Hyperventilation |
| 2 | Asthma | 5 | 43h | 28 | 3.46 | 4 | Hyperventilation |
| 3 | Asthma | 70 | 35p | 64($V_D$) | 0.68 | 23 | $V_D$ increased |
| 4 | Simple pnc | 10 | 42h | 10 | 2.35 | 4 | Hyperventilation |
| 5 | Simple pnc | 10 | 47np | 23 | 1.48 | 14 | $\dot{V}E$max rel. low |
| 6 | Simple pnc | 50 | 7 | 15 | 1.18 | 17 | |
| 7 | Asbestosis | 100 | 66 ($f_R$) | 49($f_R$) | 2.03 | 6 | Rapid breathing |
| 8 | Asbestosis | 40 | -9 | 6 | 1.69 | 19 | $Sa_{O_2}$ fell on ex. |
| 9 | Asbestosis | 20 | 53ECG | 25 | 1.29 | 5 | |
| 10 | Asb. pl. dis.† | 50 | -32p | 17 | 1.18 | 18 | Pt persevered |

*: change after bronchodilatation; †: asbestos pleural disease. pnc: pneumoconiosis; $V_D$: physiological dead space; $f_R$: respiratory frequency; $Sa_{O_2}$: arterial oxygen saturation; ex: exercise; h: hyperventilation; p: perseverence; np: nonperseverence; $\dot{V}E$max: maximal exercise ventilation; Pt: patient; ECG: electrocardiographic abnormality.

## Discussion

The disability scores by the new objective method were found to be reasonably well-correlated with the ratings made by the traditional empirical method (r=0.5). The correlation was increased to 0.7 ($R^2$=0.49) when allowance was made for the level of $FEV_1$ and grade of progressive massive fibrosis (PMF), both of which were shown to have influenced the MBC ratings. The presence of PMF contributed to the MBC awarding 10 or 20% disability to some men, whose capacity for exercise was within the normal range. In these instances the new method of assessing disability might be said to have yielded the more accurate estimate. However, validation of the new method can only be empirical, as there is no other agreed standard available for comparison. This is partly due to the many factors which can contribute to respiratory disability; they include the extent to which the different aspects of lung function are impaired, the individual tolerance of breathlessness and other sensations, and the mental attitudes of the subject to himself, his illness, his social circumstances and to taking exercise.

Negative attitudes depress the directly measured maximal oxygen uptake and inflate the disability scores [17]. In these circumstances, the score for disability is improved when it is based on the $\dot{n}O_2$max estimated from submaximal data. The score then more nearly reflects the respiratory impairment. By contrast, the score based on the directly measured maximal oxygen uptake is probably more representative of the overall disability. In the present instance it also proved to be informative for evaluating the MBC ratings. On average, the directly and indirectly derived scores yielded similar results. A material difference between the two was usually due to a complicating factor, such as poor motivation, hyperventilation, cardiac ischaemia or an apparently atypical exercise ventilation ($\dot{V}E_{45}$).

The present results might have been modified if different criteria had been used. For example, the subjects were selected as having respiratory impairment defined by a subnormal $FEV_1$ FVC or transfer factor and being limited on exercise by breathlessness. These criteria have a long tradition behind them (2, 3, 18). The use of alternative criteria (*e.g.* the presence of uneven lung function) could have led to a different group of subjects being studied. Similarly, the end-point of exercise could have been defined in terms of fatigue of the respiratory muscles. This approach was not adopted because of the perceived practical difficulties of the assessment. The estimation of maximal oxygen uptake could have taken into account the maximal inspiratory flow rate [18], and the extent of arterial desaturation during exercise [19]; however, the evidence for the usefulness of these indices comes mainly from study of subgroups of patients with specific classes of disorders, for example, chronic obstructive pulmonary disease or interstitial fibrosis. In our hands, these indices were not helpful for predicting $\dot{n}O_2$max in patients unclassified with respect to aetiology. Broad entry criteria were necessary in order that the assessment procedure should be applicable to a wide range of respiratory disorders.

The method for calculating respiratory disability [7] was based on a lower limit of normal defined in the manner recommended for tests of lung function [8], and an arbitrarily chosen level for 100% disability of 2 MET. The latter was consistent with clinical experience. The reference values for maximal oxygen uptake were for cycle ergometry, for which concordant values were available from UK and USA [16, 21]. Both included an allowance for grade of activity, whilst the former also included smoking as a reference variable, so that allowance could be made for these features of the subject as well as for his age and body mass and/or body composition. The use of reference values for cycle ergometry for patients exercising on a treadmill was not ideal, but whilst the practice would have led to a 10% underestimation of the maximal oxygen uptake in healthy subjects [22], the error was probably less in the patients [23]. The index of disability was expressed as a disability score with both positive and negative values; it could also have been expressed as a grade of disability when the negative (normal) results were ignored [7]. This would have led to loss of information. Thus, the criteria were weighted in the direction of what was practical and informative. The results suggest that they were adequate for the purpose.

## Conclusion

Scores for chronic respiratory disability obtained using the European Society for Clinical Respiratory Physiology recommended procedure [7] are correlated with, and can illuminate, those made by a traditional method. The scores are based on measurements of symtom-limited maximal oxygen uptake [7]. The additional use of the estimated $\dot{n}O_2$max can provide an internal confirmation [24], and can sometimes help to distinguish between the respective contributions to respiratory disability of impaired lung function, lack of effort, excessive effort, hyperventilation and shallow breathing. The new method might be expected to reduce the difficulties experienced in assessing respiratory disability [2, 3], and now merits further testing by regular use.

***Acknowledgements:*** The authors are indebted to H.S. Fulton, T. Quinn and I. Giles of the Newcastle Medical Boarding Centre for their help, and to the UK Department of Social Security for access to their records. Many members of staff of the Respiration and Exercise Laboratory contributed to the physiological assessments; these were made using facilities provided by the University of Newcastle-upon-Tyne. J.E.C. was in receipt of a personal support grant from the Wellcome Trust. A.B. Blackhall typed the manuscript.

### References

1. World Health Organisation. International classification of impairments, disabilities and handicaps. Geneva; WHO, 1980.
2. De Coster A. Respiratory impairment and disablement. *Bull Eur Physiopathol Respir* 1983; 19: 1p–3p.

3. American Thoracic Society. Evaluation of impairment/disability secondary to respiratory disorders. *Am Rev Respir Dis* 1986; 133: 1205–1209.
4. Cotes JE, Zejda J, King B. Lung function impairment as a guide to exercise limitation in work-related lung disorders. *Am Rev Respir Dis* 1988; 137: 1089–1093.
5. Killian KH, Campbell EJM, Summers E, Jones NL. Relationship between pulmonary impairment, exercise capacity and intensity of dyspnoea. *Eur Respir J* 1993; 6 (suppl 17): 571s.
6. Cotes JE. *In*: Lung Function: Assessment and Application in Medicine. 5th Edn. Oxford, Blackwell Scientific Publications, 1993.
7. Cotes JE. Rating respiratory disability: a report on behalf of a working group of the European Society for Clinical Respiratory Physiology. *Eur Respir J* 1990; 3: 1074–1077.
8. Quanjer PhH, (ed). Standardized lung function testing. *Bull Eur Physiopathol Respir* 1983; 19: (Suppl. 5): 1–95.
9. Cotes JE, Steel J. *In*: Work-related lung disorders. Oxford, Blackwell Scientific Publications, 1987.
10. Medical Research Council. Questionnaire of respiratory symptoms (1976). Obtainable from MRC, 20 Park Crescent, London W1N 4AL, UK.
11. McDermott M, McDermott TJ. Digital incremental techniques applied to spirometry. *Proc R Soc Med* 1977; 70: 169–171.
12. Chinn DJ, Naruse Y, Cotes JE. Accuracy of gas analysis in lung function laboratories. *Thorax* 1986; 41: 133–137.
13. Blackburn H, Taylor HL, Okamoto N, Rautaharj P, Mitchell PL, Kirkhof AC. Standardisation of the exercise electrocardiogram. A systematic comparison of chest lead configurations employed for monitoring during exercise. *In*: Karvonen MJ, Barry AJ, Eds. Physical Activity and the Heart: Proceedings. Springfield, Ill, Thomas, 1967: pp. 101–133.
14. Borg G. Subjective effort and physical activities. *Scand J Rehab Med* 1978; 6: 108–113.
15. Cotes JE, Posner V, Reed JW. Estimation of maximal exercise ventilation and oxygen uptake in patients with chronic lung disease. *Bull Eur Physiopathol Respir* 1982; 18: 221–228.
16. Weller JJ, El-Gamal FM, Parker L, Reed JW, Cotes JE. Indirect estimation of maximal oxygen uptake for study of working populations. *Br J Ind Med* 1988; 45: 532–537.
17. King B, Cotes JE. Relationships of lung function and exercise capacity to mood and attitudes to health. *Thorax* 1989; 44: 402–409.
18. Wright GW. Disability evaluation in industrial pulmonary disease. *J Am Med Assoc* 1949; 141: 1218–1222.
19. Dillard TA, Piantadosi S, Rajagopal KR. Prediction of ventilation at maximal exercise in chronic airflow obstruction. *Am Rev Respir Dis* 1985; 132: 230–235.
20. Dempsey JA, Hanson PG, Henderson KS. Exercise-induced arterial hypoxaemia in healthy human subjects at sea level. *J Physiol (Lond)* 1984; 355: 161–175.
21. Jones NL, Makrides L, Hitchcock C, Chypchar T, McCartney N. Normal standards for an incremental progressive cycle ergometer test. *Am Rev Respir Dis* 1985; 131: 700–708.
22. Åstrand P-O, Rodahl K. *In*: Textbook of Work Physiology. 3rd edn. London, McGraw-Hill, 1986.
23. King B, Craik MC, Stevenson IC, McCann K, Cotes JE. Validation of progressive exercise in respiratory patients. *Clin Sci* 1987; 73 (Suppl. 17): 3P.
24. Cotes JE. Respiratory disablement: problems and opportunities. *J Soc Occup Med* 1983; 33: 5–12.