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Continuous measurement of breathlessness during exercise: validity, reliability, and responsiveness

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Mahler, Donald A., Roberto Mejia-Alfaro, Joseph Ward, and John C. Baird. Continuous measurement of breathlessness during exercise: validity, reliability, and responsiveness. J Appl Physiol 90: 2188–2196, 2001.—A continuous method for recording changes in breathlessness (dyspnea) during exercise is introduced and compared with the traditional discrete method. In study 1, a category-rating scale was presented on a computer screen, and 14 healthy, young female subjects exercised on a cycle ergometer until exhaustion. Two approaches were used to obtain ratings of breathlessness: a discrete method, in which subjects gave single judgments every minute, and a continuous method, in which subjects throughout exercise moved the mouse so that a bar on the screen extended to the desired location along the scale. Psychophysical results relating measures of breathlessness and the variables of work, oxygen consumption, and minute ventilation were statistically indistinguishable with the two methods, and both methods were highly reliable across test sessions. In study 2, both measurement methods were employed, and the subjects were 14 healthy, young males. In each of two sessions (discrete or continuous method), subjects first rated their breathlessness during an incremental test in which the workload was increased over time and levels of work, and minute ventilation were recorded. Subjects then exercised for 10 min at 60% of the maximal oxygen consumption achieved during the incremental test. At two points during steady-state exercise, a respiratory load was introduced that lasted for 1 min. It was possible to determine the responsiveness of subjects to onset and offset of the respiratory load for the continuous method but not for the discrete method. In study 3, patients with chronic obstructive pulmonary disease employed both methods, and it was found that the continuous method was better at determining whether subjects showed a significant positive slope of the regression line between breathlessness ratings and physiological variables.

chronic obstructive pulmonary disease; breathlessness ratings; continuous measurement during exercise; category-ratio scale; inspiratory load

THE STANDARD WAY TO MEASURE DYSPNEA during exercise is to ask the patient at specific time intervals (e.g., each minute of an incremental or ramp exercise test) to select a rating on a visual analog scale (VAS) or on the 0–10 category ratio (CR-10) scale that matches the subject’s perception of breathlessness (17, 19). This approach provides a discrete measure of respiratory sensation. There are, however, two major limitations of this methodology. First, if the duration of exercise is short (e.g., 3–5 min in a patient with severe lung disease), only a few ratings of breathlessness may be obtained. Second, the patient is usually asked “on cue” each minute to provide a rating. This discrete approach is convenient from the clinician’s standpoint but arbitrary in time from the patient’s perspective because the sensation of breathlessness can change continuously throughout the exercise test. Hence, valuable information may be lost about the progressive nature of dyspnea during exercise.

One approach to overcome these limitations for the measurement of dyspnea is to allow the subject to provide ratings continuously throughout the exercise task. By enabling the subject to provide continuous ratings, the individual can match his/her sensory experience with a measured value of breathlessness at any point in time. In 1993, Harty et al. (11) described the methodology and results of such a method (using a potentiometer to record the ratings on a VAS displayed on a monitor) in six healthy subjects.

To investigate the utility of the continuous method further, we developed a computer system for obtaining ratings with the CR-10 scale displayed on a monitor. The primary objectives of this investigation were to examine the validity, reliability and responsiveness of the method for measuring breathlessness during exercise. In study 1, we determined the validity of the continuous method by comparing its results with those of the standard approach of securing discrete ratings each minute in healthy adults and by examining the correlations between continuous ratings and exercise physiological variables. We also assessed the reliability of the continuous method by testing the same subjects on two occasions. In study 2, we determined the responsiveness of the method by having healthy subjects continuously track breathlessness during steady-state exercise when a respiratory load was added. In study 3,
we examined the clinical applicability by studying the ability of a small group of patients with chronic obstructive pulmonary disease (COPD) to use the continuous method for rating breathlessness.

METHODS

In all three studies, subjects were informed that the purpose was to learn about a new method to measure breathlessness during exercise.

Study 1

Subjects. Fourteen undergraduate women enrolled in an introductory psychology course at Dartmouth College agreed to participate. Each received nominal course credit. Inclusion criteria were age ≥ 18 yr, good eyesight (corrected or uncorrected), no history of cardiorespiratory disease, normal spirometry and 12-lead electrocardiogram (ECG), and an ability and willingness to perform strenuous exercise on a cycle ergometer. Anthropometric characteristics of the subjects were age = 19 ± 0.9 yr, height = 1.69 ± 0.07 m, and weight = 63 ± 9.7 kg. Each of the subjects stated that she was in excellent physical health.

Apparatus. All breathlessness ratings for discrete and continuous methods were obtained using a computer system (Macintosh), which presented numbers from 0 (top of the screen) to 10 (bottom of the screen) listed on the left and phrases (descriptors) describing severity of breathlessness listed on the right (Fig. 1). The nature and spacing of the numbers and descriptive categories were identical to the CR-10 scale developed by Borg (5). The total length of the scale was 15.25 cm, and the Geneva font size of letters for the category descriptors was no. 12. When subjects were seated on the cycle ergometer, the screen was ~70 cm from their eyes, allowing an unobstructed view of the numerical and verbal descriptors.

Procedure. Each subject participated in three visits over a 5-day time period. At visit 1, a 12-lead ECG was performed and spirometry was measured to ensure that each subject met the inclusion criteria. No subjects were excluded from the study because of failure to meet these requirements. After these tests, the subject was familiarized with the cycle ergometer, mouthpiece, and two methods for measuring breathlessness. Each subject then exercised on the cycle ergometer for ~5 min and practiced using the computer system for rating breathlessness.

At visits 2 (2 days after visit 1) and 3 (2 days after visit 2), subjects performed two incremental exercise tests separated by a 30-min rest. The method for measuring breathlessness was assigned by an alternating schedule. At visit 2, seven subjects used the discrete method first and the continuous method second; the other seven subjects rated breathlessness in the opposite order. At visit 3, the method for measuring breathlessness was reversed.

At each visit, spirometry was performed using a standard testing system (SensorMedics 2200, Yorba Linda, CA). The maximum inspiratory and expiratory flows were selected from a range of three for the forced vital capacity maneuvers. Predicted normal values were taken from Crapo et al. (8).

Cardiopulmonary exercise testing (CPX) was conducted while the subject, breathing ambient air through a mouthpiece and low-resistance two-way valve (Hans-Rudolph), was seated on the electronically braked cycle ergometer (SensorMedics Ergo-metrics 800S). Expired gas was analyzed for minute ventilation (V\text{e}), oxygen consumption (V\text{O}2), and carbon dioxide production every 20 s using a metabolic measurement system (SensorMedics V\text{max} system). After a 5-min equilibration period, the subject pedaled at a speed of 50 rpm at zero load for 1 min. The resistance of the cycle ergometer was then increased by 15 W/min using a ramp protocol until the subject reached exhaustion or stopped because of symptom limitation. In the first session at visit 2, a 12-lead ECG and oxygen saturation by pulse oximetry (Oxyshuttle, SensorMedics) were continuously monitored.

Two methods were used to obtain ratings of breathlessness. For the discrete method, the subject provided a rating of breathlessness each minute during exercise on cue by an investigator by adjusting crosshairs (0.5 cm by 0.5 cm) to a position on the scale (see Fig. 1) and then pressing the mouse button. For the continuous method, the subject adjusted the vertical length of a black bar (0.7 cm wide) on the screen by changing the location of the mouse (in a direction toward or away from their body) to express the perceived level of breathlessness (see Fig. 1). The mouse rested on a small horizontal platform attached to the handlebars of the cycle ergometer. In the continuous method, no verbal cues were given as to when ratings were to be made. Subjects were instructed to move the mouse whenever they felt a change in the severity of their breathlessness. At the onset of exercise, the black bar (or cursor) appeared at the lowest end of the scale. The computer program and monitor were used to present the scale and to store all ratings of breathlessness in files for later analysis.

For the discrete method, the subjects were given the following instructions before performing the exercise test:

This is a scale for rating breathlessness. The number 0 represents no breathlessness. The number 10 represents the strongest or greatest breathlessness that you have ever experienced. Each minute during the exercise test you will be asked to select a number that represents your perceived level of breathlessness by positioning the crosshairs of the cursor on your selection and pressing the mouse button. Use the written descriptions to the right of the numbers to help guide your selection.

The subjects were told that they could use the entire scale, including values between integers.
For the continuous method, the subjects were given the following instructions before performing the exercise test.

This is a scale for rating breathlessness. The number 0 represents no breathlessness. The number 10 represents the strongest or greatest breathlessness that you have ever experienced. You should adjust the length of the solid black bar to represent your perceived level of breathlessness by moving the position of the mouse. Use the written descriptions to the right of the numbers to help guide your selection. You should adjust the length of the bar (up or down) at any time during the exercise when you experience a change in your breathlessness.

Statistical analysis. Psychophysical functions. A linear regression model was used to relate breathlessness ratings (B) as a function of each of three X variables: work (watts), $V_{O2}$ (l/min), and $V_{E}$ (l/min)

$$B = aX + b \quad (1)$$

Regression functions were obtained for individual subjects for each session at visits 2 and 3.

Statistical tests. Slopes and y-intercepts of the regression equation were compared for the discrete and continuous methods for rating breathlessness at visits 2 and 3 using paired t-tests (SPSS 6.1). Pearson correlation coefficients were calculated to examine the relationship between B and each of the three X variables. All data are reported as means ± SD. Statistical significance was accepted at the $P < 0.05$ level (2 tailed).

Threshold measures. Assuming that the subject only moved the mouse to indicate a change in breathlessness in the continuous method, we computed an absolute threshold and a series of thresholds considered as just noticeable differences (JND). The decision about when an actual change in breathlessness occurred was made as follows.

The sampling rate of the mouse location was four times per second, but data were recorded only when a change in mouse position (length of the visible bar) occurred. Examination of the distribution of times between moves (over the course of a session) as a function of time indicated that most (59%) intermove times were ≤ 1 s. These values represent the occasions when the subject was in the process of continuously adjusting the mouse from one position to the next and, hence, should not be counted as a JND in perceived breathlessness. Longer intermove times indicate a situation in which the mouse was stationary for a period of time > 1 s and then was moved. Only the latter moves indicate a "true" change in perceived breathlessness. Therefore, we accepted all intermove times ≥ 1 s as part of the continuous process of moving the mouse to a new position and all intermove times > 1 s as indicating the initiation of a move to a new position. We then calculated the time between the end of a continuous move and the end of the succeeding continuous move and considered such an event as a dyspnea change over time.

The absolute threshold was taken as a correlate of the first dyspnea change over time that resulted in the mouse being moved so that the visible black bar on the screen matched or surpassed the number 0.5 on the response scale. This measure had the accompanying verbal descriptor "very, very slight (just noticeable)" on the CR-10 scale (see Fig. 1).

The difference between breathlessness ratings on the CR-10 scale defining a dyspnea change over time was the JND. The corresponding JNDs for work, $V_{O2}$, and $V_{E}$ were calculated by determining the appropriate value associated with the breathlessness JND. A Weber fraction was then calculated as the ratio of the JND to the previous physiological measure (or work) associated with that previous breathlessness rating (3). An Ekman fraction was also calculated as the ratio of the breathlessness JND to the previous breathlessness rating (1, 24). The present analysis of the JND is a departure from the conventional calculation (3) because in the present instance the stimulus is constantly changing. This could make the JNDs more dependent on the subjects' attention and decision times.

Study 2

Subjects. Fourteen undergraduate men enrolled in an introductory psychology course at Dartmouth College participated and received nominal course credit. Except for the different gender, inclusion criteria were the same as in study 1. Anthropometric characteristics of the subjects were age = 20.8 ± 6.5 yr, height = 1.8 ± 0.50 m, and weight = 77.9 ± 23.9 kg. Each of the subjects stated that he was in excellent physical health.

Apparatus. Breathlessness ratings for the discrete and continuous methods were obtained using the same computer format and displays employed in study 1 (Fig. 1) except that a larger computer screen (21 in.) and font size (no. 18) were employed.

Procedure. After a familiarization session was performed (as in study 1), subjects exercised on a cycle ergometer on two successive visits to the pulmonary laboratory. In the initial experimental session, subjects used either the discrete or continuous method (7 subjects in each condition) to rate their breathlessness during an incremental test in which the workload was increased 25 W/min using a ramp protocol until the subject reached exhaustion or stopped because of symptom limitation. A higher workload was used for the male subjects compared with the female subjects (15 W/min) because of a greater body mass. Levels of work, $V_{O2}$, and $V_{E}$ were recorded throughout the course of exercise. After a 30-min rest period, subjects exercised for 10 min at 60% of maximal $V_{O2}$ achieved during the incremental test. At two points in time (start of minutes 6 and 9) during this steady-state exercise, a respiratory load (15 cmH2O·1·s) was added to inspiration for 1 min. Although the subjects were informed at visit 1 that a "breathing load" would be added at visits 2 and 3, the subjects were naïve as to when the load was added. In a second visit to the laboratory, subjects repeated the procedure using the other judgment method (discrete or continuous). Other details of the procedure were identical to those of study 1.

Statistical Analysis. Details of the data analysis closely followed that employed in study 1 for the initial incremental exercise test. Additional analyses were performed for the continuous method to determine responsiveness to the onset and offset of the respiratory load during steady-state exercise. The responsiveness of the subject to changes in respiratory load was quantified for 11 (of the 14) subjects who showed clear changes in ratings on addition and removal of the respiratory load.

A baseline was determined for each subject by fitting a linear regression equation to the relationship between breathlessness ratings and time for the first 5 min of exercise. The predicted baseline value was then subtracted from each of the subsequent ratings (time > 5 min and ≤ 10 min). A correction to baseline was necessary because breathlessness ratings typically increase over time, even in the absence of an added respiratory load. A linear regression was then fit to the time-breathlessness data for successive judgments.
Table 1. Baseline and peak exercise and breathlessness characteristics in 14 female subjects (study 1)

<table>
<thead>
<tr>
<th></th>
<th>Visit 2</th>
<th>Visit 3</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lung function</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FVC, l/min</td>
<td>4.2 ± 0.9 (110 ± 14)</td>
<td>4.2 ± 0.9 (110 ± 13)</td>
<td>NS</td>
</tr>
<tr>
<td>FEV1, l/min</td>
<td>3.5 ± 0.6 (98 ± 8)</td>
<td>3.5 ± 0.5 (100 ± 10)</td>
<td>NS</td>
</tr>
<tr>
<td><strong>Peak exercise</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work, W</td>
<td>167 ± 30 (97 ± 14)</td>
<td>167 ± 31 (97 ± 15)</td>
<td>NS</td>
</tr>
<tr>
<td>VO2, l/min</td>
<td>2.22 ± 0.5 (95 ± 21)</td>
<td>2.26 ± 0.5 (97 ± 22)</td>
<td>NS</td>
</tr>
<tr>
<td>VO2, ml/kg·s−1</td>
<td>35 ± 5 (96 ± 14)</td>
<td>35 ± 6 (97 ± 16)</td>
<td>NS</td>
</tr>
<tr>
<td>HR, beats/min</td>
<td>177 ± 12 (95 ± 6)</td>
<td>175 ± 12 (94 ± 6)</td>
<td>NS</td>
</tr>
<tr>
<td>VE, l/min</td>
<td>67 ± 13 (54 ± 11)</td>
<td>70 ± 17 (57 ± 13)</td>
<td>NS</td>
</tr>
<tr>
<td><strong>Peak breathlessness (category-ratio scale)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discrete method</td>
<td>7.1 ± 2.6</td>
<td>7.1 ± 2.8</td>
<td>NS</td>
</tr>
<tr>
<td>Continuous method</td>
<td>6.7 ± 2.7</td>
<td>6.8 ± 2.7</td>
<td></td>
</tr>
</tbody>
</table>

Values are means ± SD; nos. in parentheses are percent of the predicted value. Peak exercise and breathlessness values represent first incremental exercise test at the visit. FVC, forced vital capacity; FEV1, forced expiratory volume in 1 s; VO2, oxygen consumption; HR, heart rate; VE, minute ventilation; NS, not significant (determined by paired t-test).

(calibrated to baseline) beginning with the second judgment after load onset and ending at the time of peak breathlessness. All regressions yielded a slope greater than zero. The distance on the x-axis (time) between load onset and the first point after onset was taken as responsiveness to load onset. A similar procedure was used to calculate the subjects’ responsiveness to the removal of the respiratory load. In this instance, the regression began with the point in time yielding a peak breathlessness rating following load onset and continued for points spanning the ensuing 60 s. The difference in time between the first point after the peak and time of load offset was taken as responsiveness to load offset.

**Study 3**

**Subjects.** Six patients (3 men and 3 women) with COPD participated in this study to explore the clinical application of the continuous method in individuals with chronic and symptomatic respiratory disease. Anthropometric characteristics of the subjects were age = 72.3 ± 9.4 yr, height = 1.65 ± 0.07 m, and weight = 74.5 ± 18.2 kg.

**Apparatus.** Breathlessness ratings for the discrete and continuous methods were obtained with the same computer format and displays employed in study 2.

**Procedure.** After a familiarization and practice session (visit 1) patients returned 2–3 days later for incremental exercise testing on the cycle ergometer. For rating of dyspnea, three subjects used the discrete method first, followed by a 30-min rest period, and then the continuous method. The other three subjects were tested in the opposite order. All measurements of breathlessness were obtained during an incremental test where the workload was increased 10 W/min until the subject reached exhaustion or symptom limitation. Levels of work, VO2, and VE were recorded throughout the exercise test. Other details of the procedure were identical to those of study 1.

**Statistical analysis.** Linear regressions (Eq. 1) were fit to the relationship between breathlessness ratings and VO2 for each of the six COPD patients. A two-tailed t-test was performed to determine whether the slope of each regression line was significantly greater than zero.

**RESULTS**

**Study 1**

The total exercise time was 11.6 ± 2.3 min (range of 7.1–16.1 min).

Values for lung function and peak exercise responses (based on the highest VO2 value at visits 2 and 3) are shown in Table 1. There were no significant differences for lung function or exercise performance including peak ratings of breathlessness between visits 2 and 3.

Values for Pearson correlation coefficients and the slopes and intercepts of the regression equation are shown in Table 2. The overall correlation between breathlessness and work, VO2, and VE, respectively, were high for both the discrete ($r = 0.97$, 0.94, and 0.94) and continuous ($r = 0.97$, 0.94, and 0.93) methods. There were no statistically significant differences for the slopes and y-intercepts of the X variable and breathlessness when comparing the discrete and continuous methods of measurement. Comparison of first and second exercise tests showed that the only significant difference was for the y-intercept of VO2 and breathlessness (lower for the second session compared with the first session on the same visit; $P < 0.05$). There were no significant differences in slopes or y-intercepts for the X variable and breathlessness between visits 2 and 3.

Because each subject participated in four exercise tests, there were a total of 12 regression lines per subject (based on 3 different X variables). To demonstrate variability among subjects, the 12 correlation coefficients for each subject were averaged, and the subjects yielding the highest ($r = 0.98$) and lowest ($r =$...
0.94) averages were identified. The individual regression plots for work-breathlessness for these two individuals at visit 2 are shown in Figs. 2 (best subject) and 3 (worst subject). Data from visit 3 were similar for these two subjects.

The correlations of the slopes for work-breathlessness for all subjects at visits 2 and 3 were 0.88 for the discrete method and 0.77 for the continuous method. Comparable values were obtained for \( \dot{V}O_2 \)-breathlessness (0.72 and 0.80) and \( \dot{V}E \) (0.79 and 0.66). All correlation coefficients were significant \((P < 0.05)\).

On the basis of data from the continuous method, the mean absolute threshold for the onset of breathlessness occurred at a workload of 37 ± 18 (range of 2–84) W, \( \dot{V}O_2 \) of 0.68 ± 0.24 (range of 0.20–1.16) l/min, and \( \dot{V}E \) of 18.6 ± 5.0 (range of 10.3–27.5) l/min. The mean Ekman fraction (1, 24) for ratings of breathlessness was 0.23 ± 0.1, indicating that subjects changed the length of the vertical bar (as shown in Fig. 1) by ~23% on each successive move to represent a change in perceived breathlessness. An example of the Weber fraction as a function of work for the “best subject” is shown in Fig. 4. Corresponding Weber fractions were 0.19 ± 0.09 for work, 0.15 ± 0.07 for \( \dot{V}O_2 \), and 0.15 ± 0.07 for \( \dot{V}E \).

**Study 2**

The total exercise time was 8.7 ± 1.3 min (range of 6.0–11.4 min).

Values for lung function and peak exercise responses (based on the highest \( \dot{V}O_2 \) value at visits 2 and 3) are shown in Table 3. There were no significant differences for lung function or exercise performance including peak ratings of breathlessness between visits 2 and 3. Thus there were no differences with regard to whether the discrete or continuous method was employed on each occasion.

### Table 3. Baseline and peak exercise and breathlessness characteristics in 14 male subjects (study 2)

<table>
<thead>
<tr>
<th></th>
<th>Visit 2</th>
<th>Visit 3</th>
<th>( P ) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lung function</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FVC, l/min</td>
<td>5.7±0.8(100±9.8)</td>
<td>5.7±0.8(99±10)</td>
<td>NS</td>
</tr>
<tr>
<td>FEV₁, l/min</td>
<td>4.8±0.6(102±11)</td>
<td>4.8±0.7(101±12)</td>
<td>NS</td>
</tr>
<tr>
<td><strong>Peak exercise</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work, W</td>
<td>265±32(103±9.8)</td>
<td>270±36(104±10)</td>
<td>NS</td>
</tr>
<tr>
<td>( \dot{V}O_2 ), l/min</td>
<td>3.39±0.6(96±16)</td>
<td>3.44±0.6(98±15)</td>
<td>NS</td>
</tr>
<tr>
<td>( \dot{V}O_2 ), ml·kg⁻¹·min⁻¹</td>
<td>44±7(96±14)</td>
<td>44±7(97±13)</td>
<td>NS</td>
</tr>
<tr>
<td>HR, beats/min</td>
<td>181±11(92±5.6)</td>
<td>182±11(92±5.4)</td>
<td>NS</td>
</tr>
<tr>
<td>( \dot{V}E ), l/min</td>
<td>107±29(72±13.7)</td>
<td>111±25(75±16.6)</td>
<td>NS</td>
</tr>
<tr>
<td><strong>Peak breathlessness</strong> (category-ratio scale)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discrete method</td>
<td>6.7±2.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous method</td>
<td>7.2±1.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discrete vs.</td>
<td>6.7±2.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>continuous (NS, paired ( t )-test)</td>
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</tbody>
</table>

Values are means ± SD; nos. in parentheses are percent of the predicted value. Peak exercise and breathlessness values represent first incremental exercise test at the visit. \( P \) values determined with paired \( t \)-test.
Values for Pearson correlation coefficients, slopes, and intercepts of the regression equation for the incremental exercise test are shown in Table 4. As observed in study 1, the overall correlation between breathlessness and work, $V_{O2}$, and $V_{E}$, respectively, were high for both the discrete ($r = 0.94, 0.90$, and $0.93$) and continuous ($r = 0.88, 0.91$, and $0.94$) methods. Replicating the findings in study 1, there were no statistically significant differences for the slopes and $y$-intercepts of the $X$ variable and breathlessness when comparing the discrete and continuous methods.

The mean Weber fraction for ratings of breathlessness was $0.18 \pm 0.10$. Corresponding Weber fractions were $0.10 \pm 0.06$ for work, $0.09 \pm 0.06$ for $V_{O2}$, and $0.11 \pm 0.06$ for $V_{E}$.

Representative results are presented in Fig. 5 for a single subject exercising in the steady-state condition during which an inspiratory load was added at minutes 6 and 9. For the discrete method (Fig. 5A), it was impossible to determine the responsiveness of subjects’ ratings of breathlessness to the onset and offset of the load because the single judgment depends on exactly when the experimenter asks a subject to give a rating. For the continuous method, three subjects did not exhibit the expected and consistent changes in breathlessness with addition or removal of the respiratory load. Therefore, these subjects were excluded from the analyses. Summary statistics for the 11 subjects who demonstrated responsiveness to loads are given in Table 5. Individual differences were large, as indicated by the SD values. The mean time to obtain an increase in breathlessness following the imposition of the initial respiratory load (at minute 6) was 7.4 s, whereas the mean response to onset for the second respiratory load (at minute 9) was slightly longer (8.6 s). On average, peak breathlessness occurred at 61 and 67 s, respectively, following load onset with corresponding mean breathlessness ratings of 5.1 and 5.6. Offset times, measured as the time at which ratings begin to decline following peak breathlessness, were 2.8 and 3.8 s, respectively. Comparison of data for the first (minute 6) and second (minute 9) respiratory load showed no significant differences by paired $t$-tests.

**Study 3**

The total exercise time was $4.8 \pm 1.1$ min (range of 3.8–8.1 min).

A statistical summary of the regression analyses relating breathlessness to $V_{O2}$ is presented in Table 6. The regression slopes (Eq. $I$) are approximately an order of magnitude greater than those obtained for $V_{O2}$ in healthy undergraduates (Tables 2 and 4). All slopes were significantly greater than zero for the continuous method. When work was the independent variable, the
slope of the regression for one subject was not significantly different from zero with the discrete method, and, when $V'\dot{E}$ was the independent variable, the slopes for three subjects failed to reach significance with the discrete method. The equations used to calculate $t$-values in such cases depend critically on the number of data points as well as the range of $X$ and $Y$ values. The small number of data points obtained with the discrete method ($4.8 \pm 1.0$) makes it difficult to accurately assess the regression parameters used to describe the relationship between breathlessness and the physiological variables.

Figure 6 shows breathlessness ratings plotted as a function of $\dot{V}O_2$ in a single patient with COPD. Although the relationship for the discrete method (4 ratings) appears to have a positive slope, it was not significantly greater than zero. In contrast, the relationship for the continuous method (233 ratings) yielded a slope that was statistically greater than zero ($P < 0.05$).

**DISCUSSION**

The results of this study demonstrate the validity, reliability, and responsiveness of the continuous method for individuals to rate their intensity of breathlessness during exercise. None of our subjects reported any difficulty using the mouse, monitor screen, and scale to provide spontaneous ratings “when you experience a change in your breathlessness” during incremental or steady-state exercise.

To test the validity of this methodology, we examined the results obtained with the continuous measure of breathlessness both with the discrete method and based on correlations with physiological variables. The relationships between breathlessness ratings measured by each technique and the independent variables of work, $\dot{V}O_2$, and $\dot{V}E$ were linear throughout exercise, and each method had relatively small variation in our population. The regression analyses (Table 2) as well as the plots (Figs. 2 and 3 for the “best” and “worst” subjects) indicated that there were no significant differences between continuous and discrete methods in the measurement of dyspnea. Harty et al. (11) also reported that the continuous method “compared favorably with...”

### Table 5. Summary statistics of responsiveness to the onset and offset of a respiratory load, as well as peak dyspnea (peak time – onset time) for the continuous method in study 2

<table>
<thead>
<tr>
<th></th>
<th>First load (at minute 6)</th>
<th>Second load (at minute 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onset</td>
<td>7.4 ± 6.6</td>
<td>8.6 ± 8.9</td>
</tr>
<tr>
<td>Peak dyspnea</td>
<td>60.5 ± 26.5</td>
<td>67.1 ± 21.1</td>
</tr>
<tr>
<td>Offset</td>
<td>2.8 ± 16.3</td>
<td>3.8 ± 17.5</td>
</tr>
</tbody>
</table>

All values are in s. There were no significant differences for time at onset, peak dyspnea rating, and offset between the first and second loads ($P > 0.05$).

### Table 6. Regression analyses relating breathlessness to $\dot{V}O_2$ for 6 patients with COPD during incremental exercise (study 3)

<table>
<thead>
<tr>
<th>Subject</th>
<th>Discrete Method</th>
<th>Continuous Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slope</td>
<td>Int</td>
</tr>
<tr>
<td>RS</td>
<td>13.6</td>
<td>-6.1</td>
</tr>
<tr>
<td>EK</td>
<td>25.0</td>
<td>-11.4</td>
</tr>
<tr>
<td>WF</td>
<td>21.3</td>
<td>-10.5</td>
</tr>
<tr>
<td>BH</td>
<td>7.8</td>
<td>-3.8</td>
</tr>
<tr>
<td>JJ</td>
<td>6.6</td>
<td>-4.2</td>
</tr>
<tr>
<td>WD</td>
<td>32.4</td>
<td>-14.3</td>
</tr>
<tr>
<td>Mean</td>
<td>17.8</td>
<td>-8.4</td>
</tr>
<tr>
<td>SD</td>
<td>10.2</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Subjects listed by their initials. Int, intercept on the y-axis; $n$, no. of ratings of breathlessness during exercise; COPD, chronic obstructive pulmonary disease.
ably with that of the more established discrete method” in six subjects 19–32 yr of age. For both female (study 1) and male (study 2) subjects, continuous (as well as discrete) ratings of breathlessness were highly correlated with standard physiological exercise variables. Despite these high correlations, the precise stimulus or combination of stimuli for the sensation of breathlessness remains unknown. In addition, we found that both methods were highly reliable across test sessions. Previous studies have also shown good reliability using the discrete method for measuring dyspnea during exercise (16, 20, 25).

To assess responsiveness of the two methods, we added an inspiratory load twice for 1 min each during steady-state exercise in study 2. We selected a load (15 cmH$_2$O·l$^{-1}$·s$^{-1}$) that was detectable to the investigators during practice sessions and substantially higher than a low-level resistive load (2.7 cmH$_2$O·l$^{-1}$·s$^{-1}$) used by Lane et al. (15) that did not result in an increase in breathlessness in normal subjects. Eleven of our 14 subjects provided consistent and expected increases (with the onset of the load) and decreases (with the removal of the load) in breathlessness, as depicted in Fig. 5. The fact that three subjects were unable to demonstrate the appropriate changes in breathlessness ratings was not surprising as some healthy adults, ~5–10%, have difficulty in providing ratings (4) and some patients with respiratory disease are considered “poor perceivers” (22, 23). As represented in Fig. 5, our subjects provided substantially more ratings of breathlessness with the continuous method as opposed to the discrete method during the steady-state exercise with and without the inspiratory load. Thus the continuous method proved more responsive to changes in dyspnea as induced by a respiratory load compared with the discrete method. These observations were not surprising as subjects signaled spontaneously when they experienced a change in breathlessness, whereas subjects had to wait for a cue each minute before giving a rating with the discrete method. Harty et al. (11) examined the responsiveness of the continuous method by producing brief episodes of hypoxia and hypercapnia during exercise. They found that transient changes in breathlessness were identified with the continuous scaling method but not the discrete approach (11).

We believe there are notable advantages of a continuous method for measuring dyspnea during exercise. First, the subject can provide spontaneous ratings of breathlessness rather than “on cue” at an arbitrary period of each minute. Second, a large number of data points can be collected because the subject’s judgments are recorded over the entire period of exercise. This is an important practical advantage because patients with severe respiratory disease may only exercise for a few minutes and therefore may only provide a limited number of ratings of breathlessness using the discrete method. In fact, six patients with COPD (study 3) gave only 4–6 ratings during an incremental exercise test, whereas the same individuals provided 34–435 ratings during the same exercise time (4.8 ± 1.1 min) using the continuous method. From a statistical perspective, it is hazardous to perform regression analysis with only a small number of data points. A larger number of breathlessness ratings obtained with the continuous method would overcome this limitation. Third, the breathlessness ratings are stored in the computer and can be merged with physiological data for subsequent analyses. Fourth, an absolute threshold and a series of JNDS can be computed throughout the course of exercise with the continuous but not the discrete method of measurement. It is also possible to use a continuous method to measure respiratory sensation in response to nonexercise stimuli. For example, Flume et al. (9) demonstrated the utility of a continuous rating (subjects manipulated a potentiometer to adjust lights on a VAS) of “respiratory distress” during breath holding.

Previous studies of measuring breathlessness during exercise have focused on peak values as well as the response throughout the exercise test (10, 14, 16, 18, 20, 21). However, additional information can be calculated using the continuous measurement of breathlessness methodology. For example, the subjects in studies 1 and 2 experienced “just noticeable” breathlessness (0.5 on the CR-10 scale) at specific physiological thresholds. Weber’s law states that a JND in the perception of breathlessness must be increased by a constant fraction of its original or background value to produce a minimum or perceived change (3). The values for the Weber fraction in our investigation in both men and women were comparable with those reported in previous studies for detection of changes in added respiratory loads in healthy subjects and in patients with respiratory disease at rest (2, 6, 7). Based on various studies, Katz-Salamon (13) reported that the Weber fraction ranged from 10 to 30% for discrimination of changes in lung volume and added respiratory load. In general, the Weber fractions for the healthy subjects (studies 1 and 2) were higher for the women than observed for the men. However, it is not appropriate to consider these results according to gender because the conditions of the stimulus (i.e., workload and exercise duration) were different.

We also observed that the Weber fraction tended to be larger near the lower end of the scale, which is in agreement with previous reports evaluating respiratory loads (12) as well as with data for other sensory modalities (1, 3). To the best of our knowledge, this is the first investigation to calculate and report Weber fractions for breathlessness and corresponding physiological variables during exercise. We believe that this information may have potential application for understanding the relationship between the threshold for breathlessness and the ability of patients with respiratory disease to perform certain physical activities. It is possible, although unproven, that various interventions, such as exercise training or pharmaceutical therapy, might alter the onset of breathlessness or the JND rather than peak responses.

In summary, this report describes our initial findings evaluating the continuous measurement of breathlessness during exercise using a standard (CR-10) scale connected to a computerized recording system. These
results expand the previous work of Harty et al. (11) who first described a method for continuous measurement of breathlessness during exercise in six healthy subjects. Our data demonstrate that the analyses of the continuous measurement were nearly identical to those obtained with the discrete method, which is the standard approach currently used for research and clinical purposes. Reliability of testing over a 2-day period was quite satisfactory. The ability of subjects to continuously rate breathlessness during exercise provides additional advantages over the standard discrete method of rating breathlessness each minute on cue. Use of a computer system for recording and analyzing the data and merging with physiological information provides an opportunity to explore various psychophysical relationships in more quantitative detail. Additional testing will be required to examine whether the additional calculations of absolute thresholds and Weber fractions available with the continuous method may be useful to investigate possible clinical benefits of a specific intervention.

REFERENCES