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A Multidimensional Computer Adaptive Test Approach to Dyspnea Assessment

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Abstract

Objective—To develop and test a prototype dyspnea computer adaptive test.

Design—Prospective study.

Setting—Two outpatient medical facilities.

Participants—A convenience sample of 292 adults with COPD.

Interventions—Not applicable

Main Outcome Measure—We developed a modified and expanded item bank and computer adaptive test (CAT) for the Dyspnea Management Questionnaire (DMQ), an outcome measure consisting of four dyspnea dimensions: dyspnea intensity, dyspnea anxiety, activity avoidance, and activity self-efficacy.

Results—Factor analyses supported a four-dimensional model underlying the 71 DMQ items. The DMQ item bank achieved acceptable Rasch model fit statistics, good measurement breadth with minimal floor and ceiling effects, and evidence of high internal consistency reliability ($\alpha = 0.92$ to 0.98). Using CAT simulation analyses, the DMQ-CAT showed high measurement accuracy compared to the total item pool ($r = .83$ to $.97$, $p < .0001$) and evidence of good to excellent concurrent ($r = -.61$ to $-.80$, $p < .0001$) validity. All DMQ-CAT domains showed evidence for known-groups validity ($p < .0001$).

Conclusions—The DMQ-CAT reliably and validly captured four distinct dyspnea domains. Multidimensional dyspnea assessment in COPD is needed to better measure the effectiveness of pharmacologic, pulmonary rehabilitation, and psychosocial interventions in not only alleviating the somatic sensation of dyspnea but also reducing dysfunctional emotions, cognitions, and behaviors associated with dyspnea, especially for anxious patients.

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⁴The DMQ-CAT is available in both PC and internet versions upon request from the first author.

Keywords

Dyspnea; COPD; Outcomes assessment; Reliability; Validity

Dyspnea is a complex, multidimensional symptom with sensory, emotional, cognitive, and behavioral components.^{1–5} The sensory component is the intensity and quality of the somatic sensation of labored, uncomfortable breathing.³ The emotional dimension is the affective response to dyspnea, including such emotions as fear, distress, and anxiety.^{4–8} The cognitive dimension includes perceptions and interpretations of dyspnea, which may be negative or catastrophic, and coping appraisal such as self-efficacy.^{9–10} The behavioral dimension involves the avoidance of activities and hypervigilance behaviors related to dyspnea.^{7,11} Because dyspnea is a prevalent yet a modifiable symptom of chronic obstructive pulmonary disease (COPD), it is an important symptom to measure and target in healthcare settings.¹²

COPD research and practice has focused predominately on evaluating and treating the sensory component of dyspnea.^{13,14} Scientists have only recently begun to develop multidimensional theoretical models of dyspnea and empirically test them.^{13,15} For example, Lansing et al.'s¹³ multidimensional theoretical model of dyspnea describes dyspnea as consisting of sensory and affective dimensions (immediate unpleasantness and cognitive evaluation / emotional responses). Initial evidence exists that sensory and affective dyspnea dimensions respond differently to treatment.¹⁶

Given the wide variation in dyspnea experiences³ and high prevalence of anxiety in COPD¹², a multidimensional approach to dyspnea assessment is needed to more adequately characterize dyspnea for each individual with COPD.¹³ Multidimensional assessment can identify patients with COPD who experience greater distress and anxiety associated with dyspnea, and therefore, improve therapeutic efficacy by optimizing the match and tailoring of treatment components specifically for these patients.^{13,17} A multidimensional assessment approach in COPD could also increase and strengthen the available evidence of how to best minimize the disabling and distressing effects of dyspnea and promote dyspnea self-management¹⁸ and adaptive coping.

Current dyspnea measures tend to focus too narrowly on measuring the sensory dimension of dyspnea, with inadequate measurement of its psychological and behavioral aspects. For example, the University of Cincinnati Dyspnea Questionnaire (UCDQ),¹⁹ the University of California, San Diego Shortness of Breath Questionnaire,²⁰ and the Chronic Respiratory Disease Questionnaire (CRQ)²¹ dyspnea scale all focus on measuring the sensory component of dyspnea. Single, discrete (categorical) dyspnea scales, such as the VAS⁶, and the British Medical Research Council (MRC) scale²², while efficient, are not multidimensional and have high measurement error for comparing dyspnea change following treatment.^{13,23} With a single categorical dyspnea scale, the rater cannot be certain of which characteristic of dyspnea is being measured: the sensory, psychological, or behavioral component of dyspnea.¹³ While COPD quality of life questionnaires are multidimensional, such as the St. George's Respiratory Questionnaire (SGRQ)²⁴ and the Seattle Obstructive Lung Disease Questionnaire²⁵ (SOLQ), they do not separate dyspnea from other symptoms³, and are therefore, less sensitive in measuring dyspnea change following treatment.

One challenge to implementing a multidimensional dyspnea approach is administrative and patient burden. To include a sufficient number of items to adequately measure each dimension of dyspnea and to cover the wide spectrum of disability levels among adults with

COPD, a traditional fixed-format multidimensional dyspnea instrument would be too long and time consuming to administer and score. Computer adaptive test (CAT) and item-response theory (IRT) techniques are currently being used to develop a new generation of health outcome instruments that enhance usability in a busy clinical or research setting.^{26–29} CAT technology uses a simple form of artificial intelligence that selects questions based on a respondent's pattern of responses to previous questions.

This study applied IRT and CAT measurement methods to develop and test a prototype multidimensional dyspnea outcome measure for adults with COPD, the Dyspnea Management Questionnaire (DMQ).^{30–31} The fixed-form DMQ consists of five theoretically-derived dyspnea dimensions: dyspnea intensity, dyspnea anxiety, activity avoidance, activity self-efficacy, and satisfaction with strategy use. The DMQ was developed to measure patient-reported COPD treatment outcomes. Our specific aims were to: (1) Develop additional items to create an expanded calibrated item pool for the DMQ to improve upon its breadth, precision, and conceptual clarity; (2) Field test the expanded DMQ item bank to evaluate its dimensionality, scale properties, internal consistency reliability, and validity; (3) Develop a prototype DMQ-CAT instrument; and (4) Conduct preliminary testing of the DMQ-CAT's accuracy, precision and validity compared to the full item pool.

METHODS

Instrument

DMQ item bank development—The item pool of the original DMQ³¹ (consisting of 56 items) was revised and expanded to a core set of 121 items based on four focus groups with multi-disciplinary clinicians specializing in pulmonary medicine and people with COPD; two cognitive testing groups with adults with COPD; and a comprehensive review of the literature. We applied item response theory to develop new and revised DMQ items. The dyspnea intensity items asked patients to rate how much dyspnea they had performing activities. The dyspnea anxiety items asked about emotions, autonomic arousal, and perceptions during breathing difficulty. The wording of the activity avoidance and self-efficacy item stems were changed (see Appendix). The DMQ response scales were changed from 7-point to 6-point Likert-type scales. The response choices for the activity avoidance scale, for example, ranged from “did not avoid it at all” (scored as 6) to “completely avoided it” (scored as 1). The satisfaction with strategy use domain included in the original DMQ^{30–31} was not retained for the revised DMQ item pool.

Sample

The sample consisted of 292 adults with COPD from two medical centers. Patients were eligible if they had dyspnea with activities, physician-diagnosed COPD, a FEV₁/FVC ratio of < 0.70 (based on post-bronchodilator FEV₁), were English speaking, and aged 40 years or older. Individuals with a neurological disorder that affected their ability to move or perform daily activities were excluded. This study was approved by the institutional review boards of both cooperating facilities.

Data Collection

We mailed 945 recruitment letters and followed-up by a phone call to potential participants to check their interest and to conduct a screening assessment. Participants were interviewed in-person by a trained interviewer in their home or in the clinic. A total of 292 interviews with usable data were conducted and included the DMQ item pool, the CSES³², HADS-Anxiety³³, CRQ²¹, and UCSD SOBQ²⁰.

DMQ structure and dimensionality

To test the dimensionality of the DMQ, we first employed exploratory factor analysis (EFA) with all 121 items using unweighted least squares estimates based on the polychoric correlation matrix. We then implemented separate confirmatory factor analysis (CFA) in each hypothesized subscale, and trimmed the item pool by removing the high residual correlation items and attempting to satisfy the fit indices. Third, we did the EFA on the remaining 71 items to check that the hypothesized structure was maintained. We then compared three different IRT models with the 71 items: (1) one-factor unidimensional, (2) four-factor multidimensional (MIRT), and (3) bi-factor (orthogonal) MIRT using both fit indices and the likelihood ratio test.³⁴ The goodness-of-fit indices used to evaluate model fit were: the chi-square to degrees of freedom ratio³⁵, the comparative fit index (CFI),³⁶ the Tucker-Lewis index (TLI), and the root mean square error of approximation (RMSEA).³⁷ All the analyses were conducted using MPlus software [Muthén & Muthén, Los Angeles, CA].

Item Calibrations

We then calibrated the items based on the multidimensional Rasch model and differential item functioning (DIF) analysis^{38–41} using Conquest computer software.⁴² Item calibrations using a Rasch partial credit model estimated the level of difficulty of each item based on the sample's response pattern.

Differential item functioning

DIF analysis using logistic regression was completed to evaluate the conditional independence of item calibrations across several variables: age, COPD severity,⁴³ gender, whether any supplemental oxygen at home was required, marital status, and current smoking status.^{44–45} DIF analysis ensures that item calibrations are sample independent and that a participant's score on any item depends on the latent variable being measured rather than extraneous factors such as a person's age or gender.⁴⁴

Internal consistency reliability

Item internal consistency reliability was examined using item-to-scale correlation ranges. Subscale internal consistency reliability was measured using Cronbach's alpha.⁴⁶

Development of the DMQ-CAT

We then applied the final 71-item DMQ pool and item calibrations to construct the DMQ-CAT using an internally developed CAT program and a multidimensional partial credit model. Bayesian model estimations were used for the score estimation algorithms. The CAT first collected background information on respondents including their age, gender, and supplemental oxygen use at home to estimate the initial person scores. An initial dyspnea global question was then administered to all respondents, “how short of breath were you while showering”. Subsequent items chosen by the CAT algorithms, sampled across the 4 domains, were those that yielded the most information at particular score levels. With the administration of additional items, the CAT re-estimated the subscale scores and confidence intervals (CI). Additional items were administered until a pre-defined maximum number of items were administered.

Psychometric testing of the DMQ-CAT

CAT real data simulations were subsequently conducted to estimate the CAT's accuracy, precision, and validity. For the simulation DMQ-CAT testing, we used four pre-determined maximum number of items, which were 5, 10, 15, and 20 items, to compare the accuracy of scoring. Participants' actual responses, to items selected by the CAT, were fed to the

computer to simulate the conditions of a CAT assessment. The scores estimated by the CAT were compared with the scores obtained from administering the full DMQ pool of 71 items.

To assess the precision of CAT scores compared to scores obtained from the full-item pool, we used scatter plots of the standard errors. For concurrent validity testing of the DMQ-CAT, we used Pearson correlations to compare DMQ-CAT scores with those of the UCSD SOBQ, CRQ, CSES, and HADS. We assessed known-groups validity of the DMQ-CAT using ANOVA.

RESULTS

Of the 945 people contacted, 119 people were ineligible for the study. The survey response rate was 35.4 percent. The study sample of 292 adults with COPD had a mean age of 68.4 years, an age range of 40 – 92 years, a mean FEV₁/FVC of 0.5 (SD = 0.1), and an FEV₁% predicted of 50.9 (SD = 17.9), and consisted of 72% males (see Table 1). A statistically significant difference was found for gender between responders and non-responders ($\chi^2 = 7.02$, $p = .008$) with a higher percentage of females in the sample pool being interviewed. There were no other statistically significant differences between responders and non-responders.

The EFA results with 121 items showed that a 4-factor solution had a good fit and represented our conceptual framework. The item factor loading pattern was consistent with our hypothesis of 4 distinct factors: dyspnea intensity, dyspnea anxiety, activity avoidance, and activity self-efficacy. Dyspnea intensity was the degree of sensory dyspnea experienced with performing daily activities. Dyspnea anxiety was the degree of anxiety symptoms associated with dyspnea. Activity avoidance was the extent to which dyspnea contributed to activity avoidance. Activity self-efficacy was a person's perceived confidence in managing dyspnea during activities.

Several items were subsequently removed from the item pool based on examination of CFA goodness-of-fit indices and Rasch Infit and Outfit statistics for each of the four scales (see Table 2). The dyspnea intensity scale was reduced (from 26) to 11 items. The dyspnea anxiety scale went from 20 to 12 items. The activity avoidance scale was reduced (from 39) to 30 items and the self-efficacy scale went from 36 to 18 items. The final set of 71 items was used for all the remaining analyses. The EFA results with 71 items showed that a 4-factor solution continued to have a good fit and represent our conceptual framework, explaining a shared variance of 63.06%.

The model that fit the data the best was a multidimensional non-hierarchical model with four factors. The likelihood ratio test results clearly supported the multidimensional model over the bi-factor model (chi-square = 57.56, $df = 5$, $p < 0.0001$) and the unidimensional model (chi-square = 2177.977, $df = 9$, $p < 0.0001$). The fit indices were also within acceptable ranges for the 4-factor multidimensional (MIRT) model (CFI & TLI = .94 – 1; RMSEA = .08 – .09).

The distribution of the item calibrations of the four domains of the DMQ and response categories of the sample are shown in Figure 1. IRT analyses showed excellent DMQ breadth and match of item difficulty compared to sample distributions and minimal (0 – 5%) floor and ceiling effects.

There were only two items that displayed DIF. One item in the Dyspnea Intensity domain (lifting and carrying furniture) displayed gender and marriage DIF. A second item in the Activity Avoidance domain (engaging in sexual activities) displayed marriage DIF.

However, because these items displayed only moderate DIF (an R-square change of 0.0375) and because of their content value, we retained them in the questionnaire.

Cronbach α ranged between 0.92 and 0.98 for the four scales indicating high internal consistency reliability.⁴⁶ All items correlated above 0.50 within their hypothesized scale, which was above the minimum standard of 0.40.⁴⁷ Inter-scale correlations were moderate to high, ranging between 0.58 and 0.82.

Table 3 shows the level of agreement between the simulated CAT scores and the scores from the full item set. Correlations ranged from .83 to .97, $p < .0001$.

The standard errors of different CAT versions are shown in Figures 2 and 3. The 5-item and 10-item CAT versions were less precise (with higher SE) than the 15- and 20-item CATs as fewer items were used for score estimates. For the 20-item CAT, the average number of items used from each scale was 5; for the 5-item CAT, the average number of items used was 1 to 2 per scale.

The DMQ-CAT demonstrated good to high concurrent validity with the comparative questionnaires as hypothesized ($r = -.61$ to $-.80$, $p < .0001$; see Table 4). Evidence for criterion-related or known-groups validity was demonstrated for all DMQ-CAT domains on the basis of supplemental oxygen use, COPD severity, and smoking status. Dyspnea intensity and activity avoidance were greater and activity self-efficacy was lower for the group requiring supplemental oxygen (see Table 5). The dyspnea intensity and activity avoidance domains discriminated between COPD severity groups with scores significantly worse for adults with more severe COPD compared to those categorized with less severe COPD (Table 6). Also, current smokers with COPD showed more dyspnea-related anxiety ($M = 0.19$ for smokers; $M = 0.74$ for non-smokers; CAT-20: $F = 14.2$, $p = .0002$).

DISCUSSION

This study supported the DMQ's four distinct dyspnea dimensions for COPD patients and the DMQ 71-item pool fit a multidimensional model best. The DMQ-CAT provided valid, accurate, and precise estimates of dyspnea function in a sample of adults with COPD while saving on administration time, as a maximum of 28% of the items of the full-length DMQ were required to obtain the four subscale scores. The CAT simulations revealed accurate estimates of dyspnea function by closely matching those of the full-item pool, especially for the 15- and 20-item versions.

DMQ item calibrations showed a good match between the sample distributions of ability levels and item difficulty estimates (as evident in figure 1), and reflected meaningful continuums of function within each domain. With the current trend to offer pulmonary rehabilitation and other treatments earlier for adults with COPD, there is a greater need for dyspnea assessment which adequately captures the spectrum of dyspnea functional levels (including the mild stage to avoid ceiling effects).

All DMQ domains displayed evidence of good to excellent concurrent validity. The DMQ-CAT mean scores also differentiated significantly between COPD patients based on their disease severity levels, current smoking status, and need for any supplemental oxygen at home supporting its known-groups validity. The ability of the dyspnea anxiety scale to differentiate between groups based on current smoking status may have implications for smoking cessation programs. It appears that smoking cessation in adults with COPD, a very important treatment goal,⁴⁸ could be facilitated by reducing dyspnea anxiety.

The results add further support for the reliability and validity of the DMQ. Previous research tested the reliability, validity, and dimensionality of fixed-format DMQ versions (with 30 and 56 items respectively and 5 domains). In contrast, the present study used a new sample of patients with COPD to develop and psychometrically test a DMQ-CAT (with an item pool of 71 items and 4 domains).

The differentiation between different constructs of pain (a complex symptom that is very similar to dyspnea) led to significant advances in pain assessment and treatment.^{13,49} A dyspnea scale that distinctly separates sensory, psychological, and behavioral dimensions of dyspnea offers similar promise in advancing dyspnea assessment and treatment.⁴⁹ Multidimensional dyspnea assessment promotes a better linking of the mechanisms underlying dyspnea and the dyspnea treatment components as an important avenue for future research.¹³

A limitation of dyspnea COPD outcome scales is that a patient's effort is not considered.³ Patients can minimize their dyspnea intensity or distress by reducing their level of activity. For example, a patient can minimize his dyspnea intensity or emotional distress by using an elevator instead of climbing two flights of steps.³ The DMQ activity avoidance subscale measures how much patients limit their daily activities, thereby, making it possible to separate activity level from dyspnea intensity and anxiety. The activity avoidance subscale also enables the potential treatment effects of an increased number and the adoption of new activities into a patient's daily life to be identified even when a patient's dyspnea intensity doesn't meaningfully change following an intervention.

The lack of measurement of change in the affective component of dyspnea following treatment has impeded the development of dyspnea practice guidelines that adequately address how to best alleviate and manage the psychological and behavioral components of dyspnea in COPD.¹³ For example, the ACCP/AACVPR's pulmonary rehabilitation guidelines do not specifically address how to relieve dyspnea-related anxiety.⁵⁰ Treatment strategies such as psychosocial interventions⁵¹, cognitive-behavioral techniques^{52–53}, self-management education^{17,18,54}, and pharmacologic therapy offer promise in alleviating dyspnea. But research into their effectiveness has been limited by current COPD dyspnea assessments, which do not distinctly measure the affective and behavioral components of dyspnea.^{13,14}

By offering a multidimensional dyspnea assessment approach, the DMQ-CAT can be used to measure the psychosocial benefits of and build needed evidence for the value of pharmacologic, pulmonary rehabilitation, and psychosocial interventions especially for anxious patients with COPD. Such dyspnea research could help to optimize the effectiveness of dyspnea treatments by better individualizing the non-exercise components based on their psychosocial effects and benefits.⁵⁵ The DMQ-CAT is intended for use as both a clinical and research outcome instrument to compare individual patient's and groups of patients' dyspnea scores obtained before and after treatment. In addition to primarily evaluating treatment effectiveness, the DMQ-CAT can help to guide patient selection and plan individualized COPD treatment.

Study Limitations

There were some limitations of our study. Simulation analyses were used to evaluate the newly constructed DMQ-CAT. CAT simulation analyses are close but not exact approximations of actual CAT administrations. A follow-up study is needed to compare actual DMQ-CAT scores in real time with the full item DMQ pool. The statistically significant difference found for gender between responders and non-responders can be explained by our intentional recruitment efforts to target females from a sample pool with a

male majority. It should be noted that the same sample was used to conduct both EFA and CFA. Also, since a majority of the sample was Caucasian, further testing of the DMQ-CAT with larger and more culturally diverse samples of adults with COPD would be beneficial to confirm the results, including the stability of the item calibrations of each dyspnea construct. It will also be important to test the DMQ-CAT's responsiveness to detecting dyspnea change following COPD treatment.

CONCLUSION

The multidimensional assessment approach afforded by the DMQ-CAT can potentially advance the measurement of patient-reported changes in dyspnea following treatment. It appears that the DMQ-CAT can reliably, validly, and efficiently differentiate distinct sensory, psychological and behavioral domains of dyspnea to improve the measurement of psychosocial, pharmacologic, and pulmonary rehabilitation treatment effects in adults with COPD. An advantage of the DMQ-CAT is that it reduces respondent burden by minimizing the number and tailoring the content of dyspnea items to ensure that only the most relevant and informative items are administered, thereby increasing its usability in busy clinical and research settings.

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Appendix

DMQ-CAT Items

This questionnaire asks about your breathing and how it has affected your life during the past 2 weeks. We are interested to know how short of breath you have been, how you have been feeling, what activities you may have avoided, and your confidence with managing your breathing difficulty. We will start by asking you 4 background questions about your gender, use of supplemental oxygen, age, and feelings when short of breath. We will then ask you a few questions about your shortness of breath. If you have not performed a particular activity in the last 2 weeks, give your best estimate of how much shortness of breath you would have had if you had performed the activity. If you have never done a certain activity in your life, rate the question as “not relevant”.

I. Dyspnea Intensity

How short of breath were you in the last 2 weeks while?

1. Showering
2. Bending down (for example, picking items up off the floor)
3. Walking outdoors for 1 block (1/20 mile) on level ground
4. Taking out the garbage
5. Carrying something weighing 10 pounds a distance of 40 feet (such as 2 bags of potatoes or a can of paint)
6. Climbing 1 flight of stairs (about 12 steps) without stopping
7. Carrying a load of wash up a flight of stairs (about 12 steps)

8. Playing moderate sports such as golf or bowling
 9. Walking 5 miles on level ground
 10. Lifting and carrying furniture such as a 20 pound dining chair 10 feet
 11. Talking and walking with another person
- Not at all short of breath (6)
- Very slightly short of breath (5)
- A little short of breath (4)
- Quite a bit short of breath (3)
- Very much short of breath (2)
- Extremely short of breath (1)
- Not relevant (9)

II. Dyspnea Anxiety

- a)
 1. How upset did you feel during breathing difficulty in the last 2 weeks?
 2. How concerned did you feel during breathing difficulty in the last 2 weeks?
 3. How much did your breathing difficulty cause you to feel tense in the last 2 weeks?

Not at all (6)

Very slightly (5)

A little (4)

Quite a bit (3)

Very (2)

Extremely (1)
- b) How often did you feel during breathing difficulty in the last 2 weeks?
 4. Afraid that you were dying
 5. Worried that something was seriously wrong with you
 6. Afraid of not being able to breathe at all
 7. Your heart was suddenly pounding or racing
 8. Sweaty

Never (6)

Very rarely (5)

Occasionally (4)

Frequently (3)

Almost all the time (2)

All the time (1)
- c) How often in the last 2 weeks did you feel ?

9. Worried about a future breathing attack
10. Bothered by unwanted or distressing thoughts about your breathing difficulty
11. Your breathing difficulty was out of control
12. It was hard to concentrate because of your breathing difficulty

III. Activity Avoidance (Example items)

How much did you avoid because of breathing difficulty in the last 2 weeks?

1. Walking uphill for 1 block (1/20 mile)
2. Climbing stairs
3. Visiting friends or family in their home
4. Doing yard work
5. Engaging in sexual activities
6. Doing grocery shopping in a supermarket
7. Running for short distances
8. Using public transportation (for example, a bus or train)

Did not avoid it at all (6)

Very slightly avoided it (5)

Avoided it a little (4)

Avoided it quite a bit (3)

Avoided it a lot (2)

Completely avoided it (1)

Not relevant (9)

IV. Activity Self-Efficacy (Example items)

How confident are you to manage breathing difficulty when ?

1. Getting dressed
2. Reaching into cabinets and closets above your head
3. Taking out the garbage
4. Climbing one flight of stairs (about 12 steps)
5. Walking inside a mall
6. Sleeping at night
7. Walking for exercise
8. Having a disagreement that upsets you

Extremely confident (6)

Very confident (5)

Quite a bit confident (4)

A little confident (3)
 Hardly at all confident (2)
 Not at all confident (1)
 Not relevant (9)

List of Abbreviations

COPD	Chronic obstructive pulmonary disease
DMQ	Dyspnea management questionnaire
CAT	Computer adaptive test
UCSD SOBQ	University of California, San Diego shortness of breath questionnaire
CRQ	Chronic respiratory disease questionnaire
SOLQ	Seattle obstructive lung disease questionnaire
IRT	Item-response theory
FEV₁	Forced expiratory volume in one second
FVC	Forced vital capacity
CSES	COPD self-efficacy scale
HADS	Hospital anxiety and depression scale
EFA	Exploratory factor analysis
CFA	Confirmatory factor analysis
DIF	Differential item functioning
MIRT	Multidimensional item response theory model
CFI	Comparative fit index
TLI	Tucker-Lewis index
RMSEA	Root mean square error of approximation
SE	Standard error
ACCP	American College of Chest Physicians
AACVPR	American Association of Cardiovascular and Pulmonary Rehabilitation

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Figure 1.
Sample and item bank distributions for the dyspnea domains

Figure 2.
Scatterplots of standard error of participant score estimates for Dyspnea Intensity and Dyspnea Anxiety CAT Scales; TOT = Full-item bank

Figure 3. Scatterplots of standard error of participant score estimates for Activity Avoidance and Activity Self-Efficacy CAT Scales; TOT = Full-item bank

Table 1

Demographics for Adults with COPD (N = 292)

Variable	n (%)
Gender	
Male	209 (71.58)
Clinic Location	
BUMC	145 (49.66)
VAHC	147 (50.34)
Age (mean) (SD)	68.4 (11)
Age groups n	
40 – 54	36 (12.33)
55 – 75	170 (58.22)
76	86 (29.45)
Diagnoses	
Emphysema	198 (67.81)
Bronchitis	148 (50.68)
Asthma	119 (40.75)
Supplemental Oxygen Use	
Yes	104 (35.62)
FEV1/FVC (mean) (SD)	0.5 (0.1)
FEV1 % predicted (mean) (SD)	50.9 (17.9)
COPD severity *	
Mild (I)	16 (5.48)
Moderate (II)	127 (43.49)
Severe (III)	114 (39.04)
Very Severe (IV)	35 (11.99)
Smoked ever	
Yes	290 (99.32)
Smoke now	
Yes	90 (31.03)
Marital Status	
Single	67 (22.95)
Married	85 (29.11)
Widowed	48 (16.44)
Separated/Divorced	92 (31.51)
Ethnicity	
Hispanic or Latino	5 (1.71%)
Race	
African American	58 (19.86%)
Hispanic	3 (1.03%)

Variable	n (%)
White	218 (74.66%)
Combination	11 (3.77%)
Education	
< High School	68 (23.28)
High school	186 (63.7)
Associate degree or Higher	38 (13.01)
Employment	
Retired	179 (61.3)
Working	26 (8.9)
Unemployed	26 (8.9)
Not relevant	61 (20.9)

Notes.

* BUMC = Boston University Medical Center, GOLD = Global Initiative for Chronic Obstructive Lung Disease, 2006, VAHC = Veterans Affairs Boston Healthcare System

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Table 2
Overall Model Fit Indices for a 4-Domain DMQ Item Pool using Confirmatory Factor Analysis (N = 292)

Scale	No. Items	Chi-square (DF)	Ratio	P	CFI	TLI	RMSEA
Dyspnea Intensity	11	102.92 (30)	3.43	.0000	0.957	0.989	0.091
Dyspnea Anxiety	12	100.59 (33)	3.05	.0000	0.969	0.992	0.084
Activity Avoidance	30	283.62 (91)	3.12	.0000	0.959	0.991	0.085
Activity Self-Efficacy	18	195.65 (57)	3.43	.0000	0.944	0.99	0.091

Notes.

CFI = comparative fit index, TLI = Tucker–Lewis index, RMSEA = Root Mean Square error of approximation

Table 3

Pearson Correlations of CAT Simulated Score Estimates compared to the Full Item Pool (N = 292)

Multidimensional CAT	Dyspnea Intensity	Dyspnea Anxiety	Activity Avoidance	Activity Self-Efficacy
5-item stopping rule	0.83	0.84	0.87	0.79
10-item stopping rule	0.91	0.93	0.90	0.88
15-item stopping rule	0.95	0.94	0.92	0.94
20-item stopping rule	0.97	0.96	0.94	0.96

Note.

CAT = computer adaptive test;

p < .0001 for all correlations

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Table 4

Concurrent Validity of the Dyspnea Management Questionnaire

DMQ Scale		HADS-Anxiety	CSES	USCD	CRQ-dyspnea	CRQ-emotional	CRQ-mastery
Dyspnea Intensity	CAT - 20	-0.31	0.51	-0.80	0.47	0.41	0.53
	Full-item Bank	-0.32	0.51	-0.80	0.50	0.41	0.53
Dyspnea Anxiety	CAT - 20	-0.61	0.66	-0.59	0.45	0.62	0.75
	Full-item Bank	-0.62	0.65	-0.6	0.48	0.65	0.77
Activity Avoidance	CAT - 20	-0.36	0.47	-0.72	0.37	0.45	0.58
	Full-item Bank	-0.38	0.49	-0.76	0.38	0.47	0.58
Activity Self-efficacy	CAT - 20	-0.42	0.71	-0.69	0.36	0.48	0.64
	Full-item Bank	-0.45	0.71	-0.71	0.37	0.5	0.64

Notes.

p < .0001;

total = fixed-form with 71 items; HADS-Anxiety = Hospital Anxiety and Depression Scale – anxiety subscale; CSES = COPD Self-Efficacy Scale; USCD = University of California, San Diego Shortness of Breath Questionnaire; CRQ = Chronic Respiratory Disease Questionnaire; CAT-20 = CAT with 20 items

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Table 5
Known Groups Validation of the DMQ-CAT Scales Using Supplemental Oxygen Use (N = 292)

	Supplemental O ₂		No Supplemental O ₂		F	p
	M	SD	M	SD		
Dyspnea Intensity						
CAT-20	-0.64	1.16	0.19	1.14	35.21	<0.001
Full-item Bank	-0.65	1.2	0.18	1.16	34.11	<0.001
Activity Avoidance						
CAT-20	-0.31	0.83	0.17	0.86	21.77	<0.001
Full-item Bank	-0.29	0.8	0.22	0.86	24.78	<0.001
Activity Self-Efficacy						
CAT-20	0.06	1.23	0.52	1.13	10.45	0.001
Full-item Bank	0.07	1.24	0.57	1.2	11.55	0.001

Notes.
CAT = computer adaptive testing; M = mean logit units; SD = standard deviation; CAT-20 = CAT with 20 items

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Table 6
Known Groups Validation of the DMQ-CAT Scales using COPD Severity (N = 292)

	Mild (I)		Moderate (II)		Severe (III)		Very Severe (IV)		F	p
	M	SD	M	SD	M	SD	M	SD		
Dyspnea Intensity										
CAT-20	0.39	0.96	0.04	1.2	-0.2	1.19	-0.56	1.25	3.43	0.018
Full-item Bank	0.28	0.91	0.04	1.2	-0.21	1.23	-0.58	1.39	3.14	0.026
Activity Avoidance										
CAT-20	0.38	0.75	0.1	0.78	-0.06	0.94	-0.36	0.95	3.93	0.009
Full-item Bank	0.36	0.69	0.15	0.79	-0.03	0.93	-0.25	0.95	2.97	0.032

Notes.

CAT = computer adaptive testing; M = mean logit units; SD = standard deviation, Fixed-Form = 71 items; CAT-20 = CAT with 20 items; COPD severity categorized by the GOLD stages⁴³