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ORIGINAL ARTICLE

Asthma Numeracy Skill and Health Literacy

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To assess understanding of numerical concepts in asthma self-management instructions, a 4-item Asthma Numeracy Questionnaire (ANQ) was developed and read to 73 adults with persistent asthma. Participants completed the Short Test of Functional Health Literacy in Adults (STOFHLA), 12(16%) answered all 4 numeracy items correctly; 6(8%) answered none correctly. Participants were least likely to understand items involving risk and percentages. Low numeracy but not STOFHLA score was associated with a history of hospitalization for asthma. At higher STOFHLA levels there was a wide range of the total number of correct numeracy responses. Numeracy is a unique and important component of health literacy.

Keywords numeracy, health literacy, asthma, patient education, communication

INTRODUCTION

The National Asthma Education and Prevention Program (NAEPP) guidelines call for patients with moderate or severe persistent asthma to master considerable self-management skills (1, 2). These skills require health literacy, defined by the Surgeon General's Healthy People 2010 Program as "the degree to which individuals have the capacity to obtain, process, and understand basic health information and services needed to make appropriate health decisions" (3). Suboptimal health literacy is widespread, affecting up to one quarter of the general adult population, with increased prevalence among the elderly and the poor, the same groups where asthma morbidity is excessive (3–7). Inattention by health providers to the health literacy of patients may result in poor communication between patient and provider and, as a result, to poor patient self-care (4, 6, 7).

Numeracy is an aspect of health literacy that includes the quantitative skills necessary to understand and act on numerical directions given by the health care provider (8, 9). Patients encounter numeracy items, which may demand computing and mathematical problem solving, when they receive health care services, follow medical advice, and pay for medications. Such skills include arithmetic computation and use of percentages, but also more complex tasks such as estimation, probability, risk assessment, and problem solving. For example, when a patient is asked to use a peak flow meter, an understanding of percentage may be required to understand the results, or in asking a patient to take oral steroids, arithmetic and an assessment of risk may be needed (10, 11). Few studies have examined numeracy in the health care setting. Low numeracy has been associated with poor anticoagulation control (12), and with less accurate appraisal of the benefits of mammography (13).

Low literacy as estimated by currently available instruments designed for the health care setting is associated with poorer knowledge of asthma and improper inhaler use (7). We are unaware of any research assessing either simple numeracy skills such as arithmetic computations or more complex skills such as risk assessment in the context of asthma care. We developed a measure of patients' ability to use mathematical principles to carry out asthma self-care activities adapted from instructions commonly given to asthma patients (1, 2). We reasoned that a context-specific measure would more directly aid and complement the asthma-specific instructional goals than a general literacy assessment and would be more useful in overcoming obstacles created by low health literacy in the asthma care setting.

The goals of this project were to pilot and validate an asthma numeracy instrument and compare it to standard measures of general literacy. More importantly, we wanted to develop an instrument that could allow practitioners to test patients' abilities to interpret specific standard asthma self-management instructions and provide information for adjusting instructions appropriately for individual patients.

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METHODS

Questionnaire Development

Asthma specialist clinicians developed a series of potential survey items from common recommendations made to patients with moderate or severe asthma adapted from current national guidelines (1, 2). Items were discussed with other clinicians and piloted on a small number of patients to assess their clarity. A native speaker carried out Spanish translation and another bilingual speaker back-translated the instrument.

Participants

The protocol was approved by the Institutional Review Board of the University of Pennsylvania. Eligible subjects were at least 18 years of age and used prescribed inhaled steroids for treatment of asthma. Eligible asthma patients presenting for an evaluation at urban clinics of the University of Pennsylvania Health System, General Medicine Clinic of Pennsylvania Hospital, Woodland Avenue Health Center, and the Primary Care Center of Episcopal Hospital were approached for a brief face-to-face interview.

Interview

Participants provided sociodemographic and asthma history information. The 4-item asthma numeracy questionnaire (ANQ) was read aloud while participants viewed a printed version. Two standard screening instruments of reading skill in the health setting, which test reading comprehension, were used: the Short Test of Functional Health Literacy (STOFHLA) and the Rapid Estimate of Adult Literacy in Medicine (REALM) (14, 15). The STOFHLA has both an English and Spanish version; the choice of language was selected by the participant. It uses a Cloze method: Subjects read passages in which words are deleted and the correct missing word is selected from four choices. While the full length TOFHLA includes a general numeracy assessment, we did not make use of this measure because of its prohibitive length and our goal of developing an asthma care specific measure (14). The REALM, a word recognition assessment, has no Spanish translation or equivalent. It was administered to English-speaking participants only (15). Both the STOFHLA and REALM correlate with other general literacy tests (15).

ANQ Validation

Convergent validity was examined by comparing scores with the REALM and the STOFHLA. If the ANQ is a valid test of numeracy, we expect to see at least a moderate association between numeracy scores and the REALM/STOFHLA scores because such an association previously has been reported between reading and numeracy skills (6, 16, 17). Therefore, to examine the convergent validity of the ANQ, pairwise correlation of the participant's score on the ANQ and the 36 reading comprehension items on the STOFHLA was computed. This correlation is not straightforward to interpret because it is influenced by both (1) the correlation between the constructs measured by the ANQ and the STOFHLA and (2) the reliability of the ANQ and of the STOFHLA (18). To obtain a better understanding of the association between the constructs measured by the two tests that is not influenced by the reliability of the tests, we fit Rasch models with normally distributed latent traits to both tests and then examined the correlation between the ANQ and STOFHLA latent traits

The discriminatory power of each item was examined by looking at the point biserial correlation between the item score and the total numeracy score, excluding the item under consideration (19). The internal consistency and reliability of the ANQ was measured using Cronbach's alpha. The Rasch model, a widely used model for questionnaires (20), was fit to the ANQ data and goodness of fit was examined.

Association Between ANQ and Demographic/ Socioeconomic Variables

The demographic/socioeconomic variables we considered included age, sex, race, education, and household income. Race in the multiple regression analyses was categorized as minority (non-Caucasian) versus non-minority (Caucasian). Education level was categorized into five levels based on the highest level of educational attainment: at most 8th grade, some high school, high school graduate, some college, and college graduate. To understand the association between numeracy score and demographic/socioeconomic variables, proportional odds ordinal logistic regression analysis was performed (21). An approximate likelihood-ratio test was performed to test proportionality of odds across response categories.

Association Between ANQ and STOFHLA and asthma severity variables

Asthma severity variables measured include lifetime hospitalizations and emergency department (ED) visits for asthma. Both hospitalizations and ED visits for asthma were categorized into four categories: 0, 1, 2, and 3 or greater hospitalizations or ED visits, respectively. Proportional odds ordinal logistic regression analyses were performed to test the associations of ANQ and STOFHLA scores with asthma severity variables controlling for age, sex, educational attainment, and household income. The model assumption of proportional odds across response categories was tested by an approximate likelihood-ratio test.

RESULTS

Participants

Seventy-three subjects participated in this study. Table 1 describes their sociodemographics. Thirty-three (45%) had

TABLE 1.—Demographics of 73 participants.

	$n = 73$
Age	47 ± 14
Sex	62 female
Race	16 Caucasian
	42 African American
	1 Asian
	5 other
Ethnicity	15 Hispanic
Primary language	59 English
	14 Spanish
Education*	8 ≤8th grade
	15 Some high school
	22 High school graduate
	10 Some college
	18 College graduate

*Highest level of educational attainment.

had at least one ED visit for asthma and 17 (23%) reported a past hospitalization for asthma.

Asthma Numeracy Questionnaire and its Psychometric Properties

The numeracy instrument was completed by 73 adult asthma patients. The instrument was well accepted by patients and providers without any reports of undue burden on the visit.

The questionnaire is presented in Table 2. Content validity was established from the NAEPP guidelines for asthma management. The number of participants answering each item correctly is shown in the right column of Table 2. Total scores on the test were distributed as follows: 12 participants answered all 4 numeracy items correctly; 18 answered 3 items correctly; 23 answered 2 items correctly; 14 answered 1 item correctly; and 6 answered no items correctly. The point biserial correlation between performance on an item (1 if correct, 0 if incorrect) and total numeracy score, excluding the item being considered, was 0.24, 0.40, 0.38, and 0.41 for items 1, 2, 3, and 4, respectively. These point biserial correlations indicate that all 4 items have moderate power to discriminate among the numeracy of participants (22). The first item, which is the least discriminating, is the easiest item. Cronbach's alpha, a measure of the internal consistency of the items and the reliability of the test, was 0.57 for the ANQ. This is a moderate value of alpha with 4 items. Kehoe (22) gives the guideline that for a test with less than 10 items, an alpha value greater than 0.50 indicates a test of satisfactory reliability.

TABLE 2.—4-Item Asthma Numeracy Questionnaire

	No. of participants with correct response ($n = 73$)
Here are some examples of statements or questions that patients might hear in a doctor's office:	
1. Your doctor asks you to take 30 mg of prednisone every day for a week. The pharmacist gives you a bottle of 5 mg tablets. How many pills should you take each day?	61
2. If a patient has a 1% chance of developing osteoporosis or bone loss: that means a. out of 1,000 patients, one will develop bone loss b. out of 100 patients, one will develop bone loss c. out of 10 patients, one will develop bone loss d. out of 5 patients, one will develop bone loss e. the patient will develop bone loss f. the patient will never develop bone loss	28
3. You have a peak flow meter. Your Danger or Red Zone is 50% of your best reading. Your best reading is 400 L/min. What is your Danger Zone? □□□ L/min or less	52
4. You are told the Green Zone (the OK zone) is a reading between 80% and 100% of your best reading. Your Worry Zone is between 50% and 80% of your best reading. Your best reading is 400 L/min. When are your readings in the Worry Zone? a. Between 300 and 400 L/min b. Between 200 and 320 L/min c. Between 200 and 300 L/min d. Between 240 and 320 L/min e. Between 100 and 300 L/min	21

TABLE 3.—Health literacy levels of 73 participants who took the STOFHLA and 63 participants who took the REALM.

STOFHLA ($n = 73$)*	27.5 ± 8.6
Inadequate functional health literacy (0–16)	8
Marginal functional health literacy (17–22)	10
Adequate functional health literacy (23–36)	55
REALM ($n = 63$)*	55.9 ± 12.9
3rd grade and below	2
4th–6th grade	8
7th–8th grade	19
High school	34

STOFHLA = Short Test of Functional Health Literacy in Adults; REALM = Rapid Estimate of Adult Literacy in Medicine.
* Mean score ± standard deviation.

Dimensionality and fit to the Rasch model. A test that follows the Rasch model is unidimensional, meaning that a single latent trait underlies performance on the test. Furthermore, for a test that follows the Rasch model, the total score on the test is an appropriate summary of a subject's performance on the test (20, 23). We fit the Rasch model to the ANQ data and performed several goodness-of-fit tests (23).

With the overall goodness-of-fit test of the Rasch model versus a general log-linear model alternative, we found no evidence that the Rasch model does not hold ($p = 0.74$). We also carried out tests of the Rasch model designed to have power against specific alternatives. We found no evidence of a violation of unidimensionality when the Rasch model was tested against an alternative allowing violations of quasi-independence between responses ($p = 0.44$). We also found no evidence of a violation of the Rasch model assumption that item responses are parallel and monotone increasing when the Rasch model was tested against an alternative allowing violations of quasi-independence between item responses and total score ($p = 0.69$) (23). Overall, our goodness-of-fit tests provide no evidence against the Rasch model. Consequently, a viable description of the ANQ is that it measures a single trait of numeracy and the total score on the test is an appropriate summary of a patient's numeracy.

The relationship between asthma numeracy and general literacy. Table 3 shows the results of the two health literacy tests administered, the STOFHLA and the REALM. Figure 1 is a scatterplot of the STOFHLA score versus the ANQ score. The correlation between a patient's score on the numeracy test and the 36 reading comprehension items on the STOFHLA was 0.47. The correlation between the numeracy score and REALM score was 0.41.

To examine the association between the numeracy construct measured by the ANQ and the literacy construct measured by the STOFHLA, we fit Rasch models with normally distributed latent traits for patients. We obtained an estimated correlation between the latent traits of $\hat{r} = 0.6172$, and a 95% confidence interval for r of (0.4470, 0.7442). Thus, there is evidence that the numeracy construct measured by the ANQ and the literacy construct measured by the reading comprehension questions in the STOFHLA are moderately but not strongly correlated.

Association Between Numeracy Score and Demographic/Socioeconomic Variables

Table 4 shows the results of six sets of proportional odds ordinal logistic regressions of ANQ numeracy score on

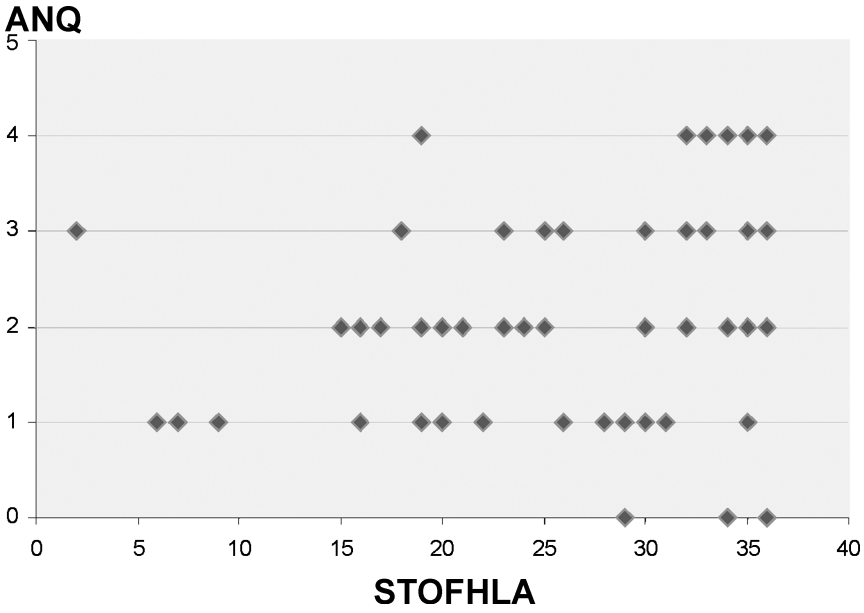

FIGURE 1.—Number of asthma numeracy questionnaire items correct compared with STOFHLA score. ANQ = Asthma Numeracy Questionnaire; STOFHLA = Short Test of Functional Health Literacy in Adults.

different combinations of the predictors minority, educational attainment, and household income, always controlling for age and sex. Models 1 through 3 use as predictors one of minority, educational attainment, and household income in addition to age and sex. After controlling for age and sex, model 1 shows that minority is significantly and negatively associated with numeracy score (estimated odds ratio 0.127; $p < 0.001$); model 2 shows that education is significantly and positively associated with numeracy score (estimated odds ratio 2.246; $p < 0.001$); and model 3 shows that household income is significantly and positively associated with numeracy score (estimated odds ratio is 1.768; $p < 0.001$). Model 4 includes all of the predictors minority, educational attainment, and household income in addition to age and sex. Among these five variables, only educational attainment is strongly associated with numeracy score controlling for the other four variables ($p = 0.005$). The estimated odds ratio for education after controlling for all other four demographic/socioeconomic variables is decreased to 1.791 compared to 2.246 in model 2 that only controlled for age and sex, but the decrease is not significant. Model 5, which drops household income from model 4, shows that educational attainment is significantly and positively associated with numeracy score controlling for age, sex, and minority (estimated odds ratio, 1.932; $p = 0.001$), and minority is marginally significantly and negatively associated with numeracy score controlling for age, sex, and education (estimated odds ratio, 0.322; $p = 0.070$). Model 6, which drops minority status from model 4, demonstrates that educational attainment is significantly and positively associated with numeracy score controlling for age, sex, and household income (estimated odds ratio, 1.854; $p = 0.002$), and household income is significantly and positively associated with numeracy score controlling for age, sex, and education (estimated odds ratio, 1.397; $p = 0.039$). An approximate likelihood-ratio test of proportionality of odds across response categories was performed for each model. These tests show that there is no evidence to reject the assumption of proportional odds for each model (p values are between 0.216 and 0.799). Thus, the proportional odds model appears reasonable.

To investigate whether there is multicollinearity among the predictors, that is, a high magnitude of correlation between the predictors, we examined the pairwise correlations between educational attainment, minority, and household income. We found moderately strong correlations: educational attainment and minority, -0.49, $p < 0.0001$; educational attainment and household income, 0.51, $p < 0.0001$; and minority and household income, -0.56, $p < 0.0001$. Overall, models 1 through 6 and the correlations between the predictors suggest that (a) educational attainment is positively associated with numeracy score controlling for minority, household income, age, and sex and (b) the composite of household income and minority is associated with numeracy score controlling for educational attainment, age, and sex but it is difficult to separate the effects of household income and minority owing to the correlation between these variables.

To illustrate the meaning of the odds ratios in the proportional odds ordinal logistic regression models 1 to 6, we use model 4 as an example. The odds that a person with a given education level obtains a numeracy score greater than or equal to a given score as opposed to less than that score is estimated to be 1.791 times the odds that a person with one lower education level obtains a numeracy score greater than or equal to a given score as opposed to less than that score. That is, the odds that a person whose education level is high school obtains a numeracy score greater than or equal to 2 as opposed to less than 2 is estimated to be 1.791 times the odds that a person with an education level of some high school obtains a numeracy score greater than or equal to 2 as opposed to less than 2. To illustrate the meaning of the odds ratios in the proportional odds ordinal logistic regression models 1 through 6, we use model 4 as an example. An

TABLE 4.—Association between numeracy score and demographic/socieconomic variables. Presented are regressions of ANQ numeracy score on different combinations of the predictors minority, educational attainment, and household income, always controlling for age and sex. In each cell the first line represents the point estimate of the odds ratio (OR), the second the 95% confidence interval of the odds ratio (95% CI), and the third the p-value for the association.

Variable	Model 1 OR 95% CI *p* value	Model 2 OR 95% CI *p* value	Model 3 OR 95% CI *p* value
Age	0.966 (0.935, 0.997) 0.034	0.969 (0.940, 0.999) 0.044	0.961 (0.930, 0.992) 0.015
Sex	0.537 (0.163, 1.776) 0.309	0.568 (0.183, 1.766) 0.328	0.452 (0.135, 1.519) 0.199
Minority	0.127 (0.040, 0.397) 0.000		
Education		2.246 (1.570, 3.213) 0.000	
Household income			1.768 (1.328, 2.354) 0.000

Variable	Model 4 OR 95% CI *p* value	Model 5 OR 95% CI *p* value	Model 6 OR 95% CI *p* value
Age	0.963 (0.933, 0.995) 0.023	0.967 (0.937, 0.998) 0.038	0.963 (0.933, 0.994) 0.021
Sex	0.528 (0.164, 1.702) 0.285	0.577 (0.181, 1.839) 0.352	0.510 (0.158, 1.645) 0.259
Minority	0.542 (0.128, 2.301) 0.407	0.322 (0.094, 1.099) 0.070	
Education	1.791 (1.191, 2.694) 0.005	1.932 (1.307, 2.856) 0.001	1.854 (1.243, 2.765) 0.002
Household income	1.282 (0.881, 1.866) 0.194		1.397 (1.016, 1.919) 0.039

*Education is highest level of educational attainment treated as an ordinal variable: 8th grade or less, some high school, high school graduate or GED, some college or trade school, college graduate.

**Minority is a dichotomous variable: minority or non-minority, with non-minority defined as white, non-Hispanic.

approximate likelihood-ratio test of proportionality of odds across response categories was performed for each model. These tests show that there is no evidence to reject the assumption of proportional odds for each model (p values are between 0.2162 and 0.7986). Thus, the proportional odds model appears reasonable.

Association Between Numeracy Score and Asthma Severity Variables

Both a history of hospitalizations and ED visits for asthma are significantly and negatively associated with the numeracy score controlling for age, sex, educational attainment, and household income (estimated odds ratios and 95% CIs are 0.546 [0.338, 0.879] and 0.563 [0.380, 0.835], respectively; $p = 0.012$ and 0.004, respectively). There was not a significant association between the STOFHLA score and hospitalizations or ED visits. The approximate likelihood-ratio tests of proportionality of odds across response categories show that there is no evidence to reject the assumption of proportional odds for these proportional odds ordinal logistic regression models (p values are between 0.228 and 0.783).

DISCUSSION

There is little research on patients' understanding of numerical health concepts, although self-management directions such as those for asthma, diabetes, and other chronic diseases frequently use them. We examined participants' understanding of numerical concepts specifically incorporated into instructions for the self-management of asthma. To do this we developed and validated a simple questionnaire, the ANQ. We found that this tool is correlated with two standard reading comprehension tests of health literacy, the STOFHLA and the REALM. However, among participants with adequate literacy assessed by the STOFHLA, there was a wide range of scores on the ANQ, including some with no correct responses. Additionally, we found that lower ANQ scores were associated with a history of hospitalizations and ED visits for asthma. This relationship was not seen with STOFHLA scores. Our findings indicate that patients' understanding of numerical concepts should be considered separately from general literacy when providing asthma self-management education. That is, numeracy appears to be a unique literacy property related to asthma outcomes.

Risk and percentage concepts were particularly difficult for many participants. Sixty percent of participants answered question 2, which involves risk assessment, incorrectly. A recent study using general medicine, but not asthma-related content, showed that risk assessment is necessary for medical decision making (10, 11). We have shown that risk assessment is specifically important in asthma with our finding that adherence to inhaled steroid regimens is associated with the weighing of risks and benefits of the medication (24, 25).

More than 25% of the participants answered the simplest percent question incorrectly and 70% failed to answer the more complicated percentage item correctly. These concepts are at the foundation of peak flow meter instructions and the interpretations of spirometry. Even the first question was answered incorrectly by almost 9%. Taking and tapering prednisone doses is frequently part of instructions for the acute and chronic management of persistent asthma. Percentages are also part of risk assessment. Williams et al. showed that asthma knowledge and MDI use were related to performance on a measure of literacy skill that was not disease specific (7). Our finding expands on theirs, demonstrating that risk assessment and percentages directly tied to immediately relevant self-management skills are important aspects of medical instructions that may not be well understood by patients.

We found a wide range of ANQ scores for patients with the highest STOFHLA scores. Educational attainment was associated with ANQ scores, but we found a wide range of numeracy scores for patients with the highest STOFHLA scores. Furthermore, we found evidence that the numeracy construct measured by the ANQ and the literacy construct measured by the STOFHLA are moderately but not strongly correlated. A recent report by Weiss et al. (17) of the development and validation of a brief numeracy test based on nutrition label reading and largely assessing arithmetic skills had similar findings. Their test was more likely to identify marginal health literacy than the TOFHLA. These findings support our belief that understanding of numeracy concepts should be assessed and that patients with adequate literacy as determined by general literacy instruments may still have

trouble understanding quantitative aspects of health information. This belief was supported by our finding that ANQ scores but not STOFHLA scores were negatively associated with hospitalizations and ED visits for asthma.

Educational attainment was associated with ANQ scores. There is moderate evidence that minority status was negatively associated with ANQ scores controlling for educational attainment, age, and sex (95% CI: −2.36, 0.091). However, when we added household income, a measure of socioeconomic status, to the model, there was not strong evidence that minority status was associated with ANQ scores controlling for household income, educational attainment, age, and sex. Thus, although we found evidence of an association between ANQ scores and the combination of SES factors and minority status controlling for educational attainment, we were unable to isolate the relative effect of SES factors versus minority status due to the correlation between these variables in our data set.

Our study has several limitations. First, the questionnaire is brief and is not a comprehensive assessment of asthma numeracy but rather a targeted assessment of several common asthma self-management numeracy skills. Nevertheless, it assesses some of the most commonly used numerical concepts in asthma education and because of its brevity, it can easily be used in clinical care or added to a clinical research protocol. It can be used to assess "baseline skills" and judge effectiveness of teaching around these mathematical concepts. While the sample was a convenience sample, we attempted to recruit all eligible subjects presenting to clinics serving a diverse patient population during the time the research assistant was available. The current analysis is limited to initial validation and assessment of the instrument and does not evaluate its impact on asthma outcomes. Further study is needed to determine if use of the ANQ will result in improvements in relevant outcomes such as patient comprehension, asthma self-management skills, medication adherence, and rates of avoidable hospitalization. Future research that examines the association between the ANQ and other numeracy tests will further assess its construct validity. Finally, although we have shown that the ANQ is acceptable to both English- and Spanish-speaking patients, the small sample size limits our ability to analyze these groups separately.

In conclusion, many patients have difficulty with numerical concepts required for asthma self-management that are different from other health literacy skills. Widely used measures of health literacy do not identify many adults who lack numerical skills needed for asthma self-management. Because these instruments do not directly measure skills needed for asthma self-management, they are more burdensome to clinical care than an instrument that could be incorporated into asthma management instruction. The ANQ was well accepted by asthma patients and identified numeracy difficulties with asthma self-management that were immediately useful for clinicians delivering asthma care. Even without testing individual patients with the ANQ, our results indicate the importance of assessing, even informally, numeracy skills relevant to asthma self-management and adjusting patient education to the level of the patients' mastery of these skills.

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