The association of health literacy with adherence and outcomes in moderate-severe asthma

Andrea J. Apter, MD, MSc,[a,b,c] Fei Wan, MS,[c,d] Susan Reisine, PhD,[e] Bruce Bender, PhD,[f] Cynthia Rand, PhD,[g] Daniel K. Bogen, MD, PhD,[c,h] Ian M. Bennett, MD, PhD,[c,i] Tyra Bryant-Stephens, MD,[c,j] Jason Roy, PhD,[c,d] Rodalyn Gonzalez, BA,[a,b,c] Chantel Priolo, BA,[a,b,c] Thomas Ten Have, PhD, MPH,[c,d]† and Knashawn H. Morales, ScD[c,d] *Philadelphia, Pa, Farmington, Conn, Denver, Colo, and Baltimore, Md*

Background: Low health literacy is associated with poor outcomes in asthma and other diseases, but the mechanisms governing this relationship are not well defined.
Objective: We sought to assess whether literacy is related to subsequent asthma self-management, measured as adherence to inhaled steroids, and asthma outcomes.
Methods: In a prospective longitudinal cohort study, numeric (Asthma Numeracy Questionnaire) and print literacy (Short Test of Functional Health Literacy in Adults) were assessed at baseline in adults with moderate or severe asthma for their impact on subsequent electronically monitored adherence and asthma outcomes (asthma control, asthma-related quality of life, and FEV_1) over 26 weeks, using mixed-effects linear regression models.
Results: A total of 284 adults participated: age, 48 ± 14 years, 71% females, 70% African American, 6% Latino, mean FEV_1 66% ± 19%, 86 (30%) with hospitalizations, and 148 (52%) with emergency department visits for asthma in the prior year. Mean Asthma Numeracy Questionnaire score was 2.3 ± 1.2 (range, 0-4); mean Short Test of Functional Health Literacy in Adults score was 31 ± 8 (range, 0-36). In unadjusted analyses, numeric and print literacy were associated with better adherence ($P = .01$ and $P = .08$, respectively), asthma control ($P = .005$ and $P < .001$, respectively), and quality of life ($P < .001$ and $P < .001$, respectively). After controlling for age, sex, and race/ethnicity, the associations diminished and only quality of life (numeric $P = .03$, print $P = .006$) and asthma control (print $P = .005$) remained significantly associated with literacy. Race/ethnicity, income, and educational attainment were correlated ($P < .001$).
Conclusion: While the relationship between literacy and health is complex, interventions that account for and address the literacy needs of patients may improve asthma outcomes.
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Key words: *Health literacy, numeracy, print literacy, asthma, adherence, adults, inner-city asthma, inhaled corticosteroids, asthma-related quality of life, asthma control*

From [a]the Section of Allergy and Immunology, Division of Pulmonary, Allergy, and Critical Care Medicine, [b]the Department of Medicine, [d]the Department of Biostatistics and Epidemiology, [h]the Department of Bioengineering, and [i]the Department of Family Medicine and Community Health, [c]University of Pennsylvania, Philadelphia; [e]the Division of Behavioral Sciences and Community Health, Department of Oral Health and Diagnostic Sciences, University of Connecticut Health Center, Farmington; [f]National Jewish Health, Denver; [g]Johns Hopkins University, Baltimore; and [j]Children's Hospital of Philadelphia, Philadelphia.

†Deceased.

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Corresponding author: Andrea J. Apter, MD, MSc, 829 Gates Bldg, Hospital of the University of Pennsylvania, 3600 Spruce St, Philadelphia, PA 19104. E-mail: apter@mail.med.upenn.edu.

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About half of US adults have no more than basic reading and numerical skills, the primary components of literacy.[1] Lack of these skills in turn compromises health literacy, "the degree to which individuals have the capacity to obtain, process, and understand basic health information and services needed to make appropriate health decisions."[2] Low health literacy is associated with poorer health access and outcomes, higher health costs, and less patient satisfaction with health care providers.[2-5] Low health literacy is especially prevalent among those with low socioeconomic status, the elderly, and those whose primary language is not English, reflecting limited educational opportunities. In these same groups, the prevalence of asthma morbidity is high. Limited literacy is thought to contribute to poor health outcomes in part by making self-management difficult. This is pertinent in chronic diseases such as asthma that require relatively complicated self-management regimens and especially for patients with several medical problems. The complexity of insurance plans and health care systems also may pose particular difficulty for those with limited literacy to access health care.[6,7]

In asthma, cross-sectional studies have associated limited reading ability or low print literacy with improper use of inhalers and less disease knowledge.[8] Poor aural literacy skills have also been associated with poorer management.[9] We found that low numeric literacy or numeracy is associated with prior emergency department (ED) visits and hospitalizations for asthma.[10] We also found that adequate numerical skills attenuate the association of minority status with lower asthma-related quality of life

Abbreviations used
AE: Asthma education
ANQ: Asthma Numeracy Questionnaire
AQOL: Asthma-related quality of life
ED: Emergency department
ICS: Inhaled corticosteroid
PS: Problem-solving
S-TOFHLA: Short Test of Functional Health Literacy in Adults

(AQOL).[11] Together these studies suggest that health literacy influences self-management and subsequent outcomes, but longitudinal studies are needed to better assess potential causal pathways between health literacy and health outcomes.

An important marker of self-management ability for all but the mildest asthma may be adherence to inhaled corticosteroid (ICS) therapy,[12-14] which is universally difficult to achieve.[15-17] Adherence may also be a measure of patient satisfaction with care or trust in the provider[18,19] or the prescribed therapy.[20] Measuring adherence to ICS is difficult; serum levels cannot be measured, and canister weighing or patient and physician report are unreliable.[21-23] Counting prescribed or filled prescriptions does not ensure that medications are taken.[16,24] Although the act of monitoring adherence can change behavior, recording the date and time of use with an electronic monitor is the most accurate method of assessing adherence.[25,26]

This project explores the association of health literacy, measured by print literacy or reading comprehension and asthma-related numeracy, with electronically monitored ICS adherence and asthma outcomes in adults with moderate or severe asthma. We hypothesized that higher health literacy is associated with better adherence and better asthma outcomes.

METHODS

Study design

We conducted a prospective cohort study to examine the association between baseline health literacy skills and subsequent ICS adherence as a reflection of self-management within a large randomized controlled trial. The parent study, Individualized Interventions to Improve Adherence in Asthma (NCT00115323, R01 HL073932), compared an individualized problem-solving (PS) strategy to standard asthma education (AE) in adults with moderate or severe asthma.[27] Electronically monitored adherence was the primary outcome of this 26-week trial; asthma clinical outcomes were other end points. In the parent study, overall no difference emerged in outcomes between randomized groups.[27] About 6 months into recruitment, we added literacy questionnaires to the protocol for all participants for the secondary analysis reported here. Controlling for randomization assignment, we assessed whether adherence and asthma outcomes were associated with health literacy, measured by asthma-related numeracy and reading comprehension or print literacy. We evaluated whether participants would differentially benefit from the PS intervention by literacy level and whether the negative association between low literacy and adherence and asthma outcomes is diminished by the PS intervention. This study was approved by the institutional review boards of the University of Pennsylvania and the Philadelphia Veterans Affairs Medical Center.

Subjects

Participants were English- or Spanish-speaking adults with moderate or severe persistent asthma according to National Heart, Lung, and Blood Institute Expert Panel Report 3 guidelines.[28] Inclusion criteria were designed to identify patients with sufficiently severe and reversible asthma who were likely to benefit from ICS therapy. Specific criteria were (1) age 18 years or older; (2) physician's diagnosis of asthma; (3) prescription for an ICS-containing medication for asthma; and (4) evidence of reversible airflow obstruction defined as an increase of at least (i) 15% and 200 mL in FEV_1 with asthma treatment over the previous 3 years or (ii) 12% in FEV_1 or forced vital capacity and 200 mL in FEV_1 within 30 minutes of 2 to 4 puffs of albuterol by metered-dose inhaler or 2.5 mg by nebulizer. Smokers were included. Patients with severe psychiatric problems such as obvious mania or schizophrenia that would make it impossible to understand or carry out the protocol were excluded. Subjects were not selected by criteria related to literacy or adherence.

Subjects were recruited from practices serving low-income inner-city neighborhoods with high prevalence of asthma morbidity. These included outpatient primary care and asthma specialty practices of the University of Pennsylvania Health System; Woodland Avenue Health Center, a federally qualified health center; the Comprehensive Health Center at Episcopal Hospital; and Philadelphia Veterans Affairs Medical Center. Charts or electronic medical records of participating practices were prescreened for patients with a diagnosis of asthma who were prescribed an ICS. Potential subjects were then approached by telephone or at the time of a clinic visit and asked to sign consent for further screening, which included spirometry using standard procedures.[29] Those satisfying all enrollment criteria were then asked to sign a second informed consent to participate in the 26-week study.

Procedures

Upon enrollment, participants completed questionnaires about their sociodemographics, health literacy, present and past asthma status, and comorbidities. Spirometry was obtained.[29] An electronic monitor was attached to participants' ICS-containing inhaler.[25,30] Participants were informed that the monitor recorded the time and date of inhaler actuation and that data would be downloaded at each of the following study visits. Two weeks later, at visit 2, subjects were randomized according to a computer-generated algorithm in 1:1 ratio to either PS or AE. Subjects met with research coordinators monthly for 4 sessions (visits 2-5) of either PS or AE, which included assessment of asthma control, spirometry, and need for hospitalization or ED visits. Electronic monitor data were downloaded. Subjects then continued to meet monthly with research coordinators for 3 additional months (visits 6-8) so that the research coordinators could download monitor data, obtain spirometry, and collect information on medication use, ED visits, and hospitalizations. No PS or AE occurred at visits 6 to 8. Details of the PS and AE interventions have previously been reported.[27] Participants received $20 for the first visit, $15 for visits 2 to 5, $10 for short visits 6 to 7, and $50 for completing visit 8. The ICS was supplied for subjects without any insurance coverage for an ICS. For subjects with a co-payment, this sum was reimbursed if all visits were completed and medication receipts were submitted.

With the exception of the print literacy questionnaire, all questionnaires were administered by reading the items to the participant while the participant looked at the written questionnaire. For patients whose primary language was Spanish, bilingual research coordinators administered the questionnaires and PS or AE in Spanish. All validated questionnaires were available in English and Spanish; clinic scripts were translated into Spanish by native speakers, translated back into English, and compared with the original English version. In addition, both English and Spanish versions were reviewed independently by other bilingual speakers to be sure the Spanish scripts were equivalent to the English versions.

Outcomes

Adherence to ICS regimen prescribed by participant's physician. Electronic monitors recorded the time and date of ICS actuation.[25,31] Such monitors can record multiple actuations over a short time period and thus can detect medication "dumping."[31] This is in contrast to inhalers with built-in counters, which display doses but cannot capture deliberate multiple actuations of an ICS unaccompanied by inhalation.[31,32]

No commercial monitor was available for a dry powder inhaler containing fluticasone-salmeterol, the most frequently prescribed ICS to subjects during the study period. We used the Diskus Adherence Logger or DAL, the research

monitor developed by a team member (D.K.B.) and previously validated.[25,27] Fluticasone and beclomethasone in metered-dose inhalers were next most frequently prescribed; for these, we used a commercial monitor, MDILog (Life Link Monitoring, Inc, Kingston, NY). Approximately 90% of participants were prescribed an ICS monitorable with the DAL or MDILog. There were 14 patients who were initially prescribed inhaled mometasone via Veterans Affairs formulary, but they and their physician allowed a switch to a monitorable medication, fluticasone, during the study period.

ICS adherence was calculated from the date-time record of the ICS data downloaded from the monitors. Daily adherence was defined as (number of actuations recorded/number prescribed) × 100.[33,34] We truncated adherence at 100% for each monitoring period because it controls for multiple actuations over a very short period of time, and thus provides a better measure of adherence.[25,31,33-35] We then took the mean of recorded daily truncated adherence from the day after to the day before the next downloading visit. If the participant returned after 30 days from the last downloading visit, we counted only the first 30 days.

Asthma outcomes. *Asthma control* was assessed at each visit by using the 7-item version of the Asthma Control Questionnaire,[36-38] which asks about symptoms over the past week. The score is the mean of all responses (0 = total control, 6 = extremely uncontrolled). The minimal important clinical difference is 0.5, and a score of more than 1.5 is considered inadequate control, but we used the Asthma Control Questionnaire as a continuous variable in our analysis.[39] AQOL was measured with the Mini-Asthma Quality of Life Questionnaire.[40-42] This 15-item questionnaire, reflecting well-being over the past 2 weeks, has a 7-point response scale for each item ranging from 1 (maximum impairment) to 7 (no impairment) and the average of these provides a mean summary score. A 0.5-unit change is considered clinically meaningful within individuals.[42] The Mini-Asthma Quality of Life Questionnaire has been shown to be a useful indicator of AQOL in low-income adults.[43] Spirometry was obtained by using American Thoracic Society procedures for FEV_1 and forced vital capacity.[29]

Predictors: Health literacy variables

Two domains of health literacy were evaluated: (1) health-related print literacy was assessed with the Short Test of Functional Health Literacy in Adults (S-TOFHLA),[44] and (2) asthma-related numerical ability was measured by the Asthma Numeracy Questionnaire (ANQ).[10] Both have validated English and Spanish versions. The ANQ is a brief, verbally administered 4-item questionnaire of numerical concepts (arithmetic and percentage) adapted from standard AE.[10] The score is the number correct.[10] The S-TOFHLA consists of 36 modified Cloze procedure items.[44] The score is the number of items correct; however, the authors recommend treating it as a categorical variable that has functional relevance.[45,46] A S-TOFHLA score of less than 23 is considered low literacy[47] and corresponds to difficulty reading and interpreting health texts.[45]

Other independent variables

Demographic characteristics—age, race, ethnicity, educational attainment, and household income—were participant-reported. Household income (Table I) was ascertained in categories to make responses by participants more acceptable and feasible.

Statistical analysis

Descriptive statistics and data analyses were performed by using STATA 11.0 (STATA Corp, College Station, Tex) and SAS V9.2 (SAS Corp, Cary, NC).

Numeracy was analyzed as a continuous variable with range 0 to 4. S-TOFHLA was analyzed as a binary variable: adequate (raw score ≥23) or low (marginal or inadequate) literacy (raw score <23). We assessed for collinearity among race, household income, and educational attainment by using Spearman correlation coefficients.

The analysis of the 284 participant sample was based on an "as randomized" principle using all 284 participants. For longitudinal adherence and the asthma outcomes, we used mixed-effects linear regression with random intercepts and slopes to account for clustering by patient. We assessed 3 models. Model 1 was unadjusted. Model 2 was adjusted for age, sex, and randomization assignment to PS or AE. Model 3 included the adjustments of model 2 and also adjusted for race/ethnicity. Because race/ethnicity, income, and educational attainment individually were found to be collinear, these latter 2 variables were not included in model 3.

We examined whether the effect of literacy on outcomes (adherence, asthma control, asthma-related quality of life, and FEV_1) varied with time by entering a literacy-by-time interaction term in the model. We also examined whether the PS intervention modified the effect of literacy on adherence by testing the intervention by literacy interaction.

TABLE I. Baseline characteristics of 284 adults, 139 assigned to PS, 145 to AE, with moderate to severe asthma

Characteristic	Total (N = 284)
Sociodemographics	
Age (y)*	48 ± 14
Females, n (%)	202 (71)
Race, n (%)	
Black/African American	198 (70)
White	54 (19)
Other†	19 (7)
No response or declined to answer	13 (4)
Ethnicity: Hispanic/Latino, n (%)	18 (6)
Household income per year, n (%)	
<$30,000	184 (65)
$30,000-$49,999	36 (13)
$50,000-$99,999	38 (13)
$100,000 or more	16 (6)
No response or declined to answer	10 (4)
Educational attainment (highest level achieved), n (%)	
8th grade or less	6 (2)
Some high school	38 (13)
High school graduate	103 (36)
Some college or trade school	78 (27)
College graduate	59 (21)
Asthma severity at baseline	
FEV_1 (percent predicted)*	66 ± 19
No. with ≥1 ED visit for asthma in past year, n (%)	148 (52)
No. with ≥1 hospitalization for asthma in past year, n (%)	86 (30)
AQOL*	4.0 ± 1.4
Asthma control*	1.66 ± 1.07
Comorbidities	
Hypertension, n (%)	140 (49)
Diabetes, n (%)	59 (21)
BMI‡	33.2 ± 8.9

BMI, Body mass index.
*Mean ± SD.
†Other = American Indian/Alaskan Native, Asian, Native Hawaiian/Pacific Islander.
‡BMI ≥ 30 is classified as obese where 25-29 is considered overweight.

RESULTS

Recruitment

We prescreened more than 49,000 charts of patients scheduled to have a physician's appointment in participating general or specialty clinics within 2 weeks or were admitted to the ED for asthma. Charts were reviewed more than once if the patient had more than 1 appointment. This prescreening process identified approximately 7000 appointments for patients 18 years or older with a doctor's diagnosis of asthma and an ICS prescription. After

eliminating screening of patients with more than 1 appointment and screening for the other enrollment criteria, 585 patients were eligible. Of these, 397 completed the surveys for the parent study (visit 1). Of the 188 who declined, 70 stated that they were too busy, 57 did not come for appointments scheduled with researchers, 39 thought the travel time for appointments was too burdensome, and 18 did not consider the research likely to be beneficial to themselves or others. In addition, another 4 eligible patients declined, 1 each for the following reasons: concerns about research, questions about data privacy/protection of personal medical information, patient's doctors believed that the study was not likely to be beneficial, and patient was unable to switch to an inhaled steroid for which we had a monitor. A total of 333 returned for visit 2 and were randomized. Of 333 participants, 284 were enrolled after the literacy assessments were added to the protocol and are the subjects of this analysis. Of the 284 participants, 271 (95%) completed all visits.

Patient characteristics

The 284 subjects had baseline characteristics similar to the parent cohort[27] and were mostly female, African American, and from households earning less than $30,000 per year (Table I). Asthma morbidity was significant, with the cohort having a low mean FEV_1 (66% ± 19%). More than half had had an asthma-related ED visit in the year prior to enrollment and almost one-third had been hospitalized for asthma in that time interval. Comorbidities were prevalent. About half had hypertension, 1 out of 5 had diabetes, and mean body mass index was high (Table I).

Health literacy and outcomes

Both health literacy measures (ANQ and S-TOFHLA) revealed a range of values (Table II). On average, participants answered 2 to 3 ANQ items correctly. One participant declined to answer this questionnaire. Two did not answer S-TOFHLA because their vision did not allow them to read. Three who had adequate vision were unable to respond. The results of the 2 literacy measures were moderately correlated ($\rho = 0.37$, Table III).

We examined correlations of race, income, and educational attainment and their correlations with health literacy measures (Table III). In our study population, race/ethnicity was highly correlated with household income and educational attainment.

For 1734 possible downloads, adherence data were present for 1340 or 77%. Of the 394 missing values, 294 (75%) were missing because of monitor failure and 67 (17%) were missing because the monitor was not returned or returned so late that the monitor's battery was dead. Thirty-three patients (8%) did not provide their inhaled steroid to attach a monitor. Each patient had at least 1 download of adherence data.

Adherence declined over time, with mean baseline adherence of 62% ± 28%. Fig 1 describes adherence and the asthma outcomes over the study period, stratified by high versus low numeracy (Fig 1, *A*) and print literacy (Fig 1, *B*). For purposes of this graphical presentation, we dichotomized numeracy at its approximate median as high (ANQ score >2) versus low numeracy (ANQ score ≤ 2). During the study period, there were 96 hospitalizations, 49 asthma-related, and 172 ED visits for any cause, 88 for asthma.

TABLE II. Baseline health literacy

Health literacy measures	
ANQ*	
Overall score†	2.3 ± 1.2
Number of patients answering each item correctly, n (%)	
Item 1 (arithmetic word problem)	229 (81)
Item 2 (simple percent, risk)	123 (43)
Item 3 (simple percent, peak flow meter)	198 (70)
Item 4 (interpretation of percent for peak flow meter)	94 (33)
Number of patients scoring correctly, n (%)	
0 item	26 (9)
1 item	54 (19)
2 items	76 (27)
3 items	74 (26)
4 items	54 (19)
S-TOFHLA‡	
Raw score†	30.9 ± 7.9
No. of patients whose score was, n (%)	
Inadequate (score 0-16)	20 (7)
Marginal (score 17-22)	14 (5)
Adequate (score 23-36)	248 (87)

*ANQ,[10] range 0-4.
†Mean ± SD.
‡S-TOFHLA,[44] range 0-36, with score ≥23 adequate.

The regression models of the associations of the health literacy measures with adherence and asthma outcomes are displayed in Table IV. In model 1, the unadjusted analysis, higher health literacy, measured by both numeracy and print literacy, was associated with better adherence, asthma control, and AQOL. These associations were maintained in model 2, adjusting for age, sex, and randomization assignment. However, when also adjusting for race (model 3), which was correlated with income and educational attainment, higher numeracy was associated only with better quality of life ($\beta = 0.14$, CI, 0.02-0.26). This means that for every ANQ question correct there is a 0.14-unit increase in quality of life. The parameter (beta) estimates indicate the mean change in the outcome with a unit increase in the literacy measure. When adjusting for all variables in model 3, higher print literacy was associated with better asthma control ($\beta = -0.52$, CI, −0.89 to −0.16) and better AQOL ($\beta = 0.63$, CI, 0.18-1.07). There was a trend in the model 3 analysis to an association of better reading comprehension (print literacy) with better adherence ($\beta = 8.00$, CI, −0.77 to 16.77); ($P = .07$). ED visits and hospitalizations, occurred, respectively, in 18.7% and 10.2% of the participants during the 26-week observation period and were not associated with either literacy measure.

When controlling for income, the associations diminished because of collinearity with other confounders; therefore, we reported results of Table IV that did not control for income. There was no significant interaction between time and literacy or between treatment assignment (PS, AE) and literacy.

DISCUSSION

We examined whether health literacy was associated with adherence and asthma outcomes. Health literacy was assessed both as numeracy and as print literacy. Numeracy, which is infrequently examined in studies of health literacy, used items specifically related to asthma self-management concepts. Health-related print literacy was measured as reading comprehension, using more general health-related content. In unadjusted analyses

TABLE III. Spearman correlation coefficients of sociodemographic factors with each other and with literacy measures

	Race		Household income		Educational attainment		Numeracy	
	ρ	*P* value	ρ	*P* value	ρ	*P* value	ρ	*P* value
Household income	0.36	<.001						
Educational attainment	0.32	<.001	0.48	<.001				
Numeracy	0.32	<.001	0.41	<.001	0.49	<.001		
Print literacy	0.12	.04	0.24	<.001	0.32	<.001	0.37	<.001

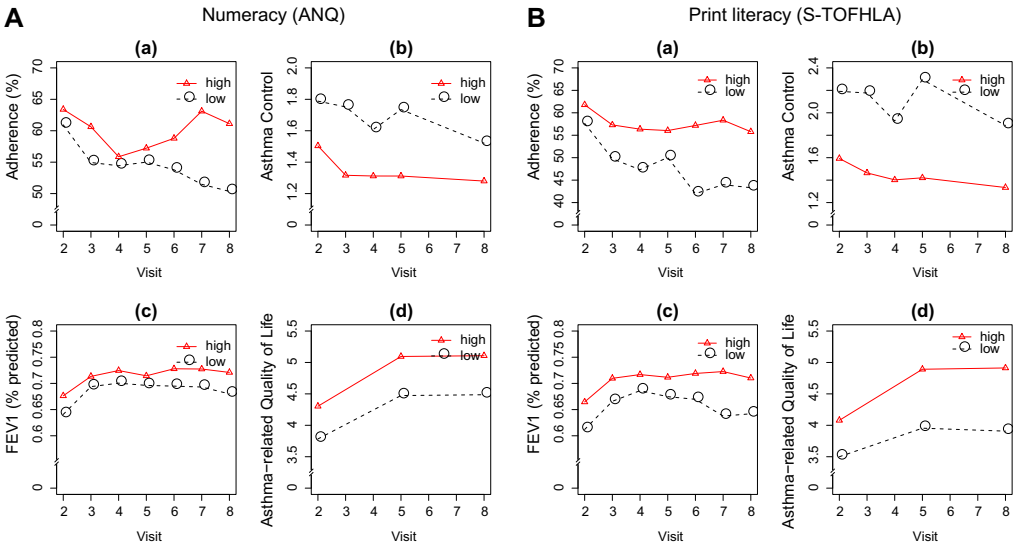

FIG 1. Distribution of outcomes by high or low numeracy **(A)** and print literacy **(B)** over the observation period: *a*, adherence, *b*, asthma control, *c*, FEV_1, and *d*, AQOL. High numeracy is a score greater than 2. Randomization occurred at visit 2. Adherence at any time point, for example, downloaded at visit 2, represents data downloaded at that visit and represents medicine-taking in the weeks preceding the visit.

TABLE IV. Mixed-effects linear regression models of the association between literacy and adherence and asthma outcomes: model 1 (unadjusted), model 2 (adjusted for age, sex, and randomization assignment), and model 3 (adjusted for age, sex, African American, Latino, and randomization assignment)*

	Asthma-related numeracy (ANQ)						Print literacy (S-TOFHLA)					
	Model 1		Model 2		Model 3		Model 1		Model 2		Model 3	
	Parameter estimate (SE)	*P* value	Parameter estimate (SE)	*P* value	Parameter estimate (SE)	*P* value	Parameter estimate (SE)	*P* value	Parameter estimate (SE)	*P* value	Parameter estimate (SE)	*P* value
Adherence (%)†	2.93 (1.15)	.01	3.17 (1.12)	.005	1.86 (1.22)	.13	7.45 (4.30)	.08	8.90 (4.17)	.03	8.00 (4.47)	.07
Asthma control‡	−0.13 (0.05)	.005	−0.12 (0.04)	.01	−0.04 (0.05)	.38	−0.65 (0.17)	<.001	−0.62 (0.17)	<.001	−0.52 (0.19)	.005
Quality of life§	0.25 (0.06)	<.001	0.25 (0.06)	<.001	0.14 (0.06)	.03	0.78 (0.22)	<.001	0.82 (0.22)	<.001	0.63 (0.23)	.006
FEV_1% predicted	0.01 (0.01)	.17	0.01 (0.008)	.10	0.004 (0.009)	.63	0.05 (0.03)	.08	0.05 (0.03)	.10	0.05 (0.03)	.14

*The parameter estimates indicate the mean change in the outcome with a unit increase in the literacy measure. Randomization assignment indicates whether the subject was assigned to PS or AE in the parent randomized controlled trial.

†Daily adherence was defined as (number of actuations recorded/number prescribed) × 100.[33,34] We truncated adherence at 100% for each monitoring period.

‡*Asthma control* was measured at each visit by using the 7-item version of the Asthma Control Questionnaire[36-38] that asks about symptoms over the past week. The score is the mean of all responses (0 = total control, 6 = extremely uncontrolled). The minimal important clinical difference is 0.5, and a score of >1.5 is considered inadequate control.[39]

§AQOL was measured with the Mini-Asthma Quality of Life Questionnaire.[40-42] This 15-item questionnaire, reflecting well-being over the past 2 weeks, has a 7-point response scale that provides a mean summary score. A 0.5-unit change is considered clinically meaningful within individuals.[42]

(model 1), better health literacy, using both measures, was related to better adherence, asthma control, and AQOL. This result was maintained when controlling for age, sex, and randomization sequence (model 2). However, when adjusting for race (model 3), which was associated with income and educational attainment, both health literacy measures remained associated with better quality of life and only print literacy was also associated with better asthma control.

This study supports the importance of considering patients' health literacy when clinicians communicate with patients and is consistent with the findings relating health literacy to adherence and health outcomes in other settings. For example, among

diabetic patients in a primary care practice, inadequate health literacy was associated with poorer glycemic control and higher rates of retinopathy.[48] In another study, better literacy reduced the relationship between race and adherence to HIV medications.[49] Finally, in a randomized controlled trial of an educational intervention among heart failure patients using picture-based materials, a digital scale, and telephone, follow-up was associated with a lower rate of hospitalization or death and the benefits of the intervention were greater for those with low literacy.[50]

We observed strong collinearity with race, income, and educational attainment underscoring the complexity of the relationship of health literacy and health. Poverty and minority race increase the risk of poor health through many pathways, including access and quality of health care, environmental exposures, social stressors, as well as health literacy. Race, culture, and education may also influence relevant health beliefs that influence adherence, including distrust of inhaled steroids or a belief that asthma is best treated acutely.[20] Health literacy likely influences health through a variety of pathways that need further exploration such as knowledge of self-management regimens, health beliefs, accessing care, and promoting self-efficacy.

This study is also important for its longitudinal rather than the cross-sectional design that is found in most studies because such an analysis is more feasible. We found that baseline health literacy influences subsequent asthma control and quality of life. Our analysis supports the findings of cross-sectional studies that there is an important relationship between health literacy and health.

It is noteworthy that screening measures for low health literacy such as the S-TOFHLA generally identify adults only with very low print literacy.[51] The proportion of adults with low health literacy we report is within the range of rates seen for nongeriatric adult populations—the elderly have higher rates of low literacy.[52] This is similar to our findings in other studies.[10,11] Rates of significantly limited literacy of 13% to 28% (as in our current report) are viewed in the literature related to social determinants of health as substantial.[53,54]

It is also noteworthy that the 2 literacy tests gave somewhat different results and were correlated only moderately as we have previously observed.[10] While this is not unexpected, our result suggests that literacy skills are complex and diverse and more than 1 skill is needed for patients to manage their health. For example, these measures do not account for other likely important aspects of literacy such as electronic literacy and ability to navigate a complicated health system.

We did not observe an association between the literacy tests and ED visits and hospitalizations. This could be because the observation time was of short duration resulting in relatively few events, because the literacy measures did not measure the aspects of literacy associated with their need, or because other precipitants of these urgent visits such as access to care or the severity of asthma are more significant. Certainly, further research is needed.

Our study, like all studies, has limitations. The observation of participants was of relatively limited duration: 5 months. Nevertheless, this is one of the first examinations of the impact of health literacy on the management of a chronic illness over time. Our measurements of literacy may not perfectly reflect the literacy skills needed to communicate with health care providers and access care. That is, we did not measure listening, speaking skills, or ability to write or perhaps the most relevant content areas in the measures we used. Nevertheless, print and numerical information are encountered everywhere by patients seeking health information and attempting to access health care.

The measurement of adherence also has limitations. Electronic monitoring of medication use requires giving the medication to patients, yet we know that many patients do not fill their medication once prescribed and do not renew them.[55] While electronically measuring the actual use of medication is precise, data were missing when the electronics failed, the patients returned to us so late the battery had died, or if monitors were lost. For missing data that are not a result of mechanical failure of the monitor, another study has demonstrated that such data are not missing at random but associated with lower adherence.[56] However, the mixed-effects model we used accounts for missingness that depends on previous measurements and other covariates and assumes that a lower adherent patient with missing data would have continued on the same trajectory. In addition, monitoring has a potential Hawthorne effect: behavior is changed by observation, which may also lead to an overestimate of adherence.[57] Finally, the interactions of the subjects with the researchers for data collection and intervention could have influenced adherence as participants reported liking to work with researchers. However, interactions were scripted, and we taped and also periodically observed interactions for consistency and uniformity. It is likely that all these limitations result in an overestimate of adherence. This overestimate should not bias the overall findings of our study because the impact of health literacy on adherence remains unchanged.

In conclusion, the relationship between literacy and health is complex, and this study is important for illustrating its complexity and pointing out that this is more than a cross-sectional association. Further research is required to understand the mechanisms explaining the relationship and then to develop effective interventions that will also address health disparities.

We dedicate this article to the memory of Thomas R. Ten Have, PhD, brilliant biostatistician, collaborator, and friend. We also acknowledge the valuable contributions of Xingmei Wang to the analysis.

Clinical implications: In adults with moderate or severe asthma, higher health literacy scores were associated with better subsequent quality of life and asthma control.

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