Is Patients' Numeracy Related to Physical and Mental Health?

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Objective. *There is compelling evidence showing that health literacy influences health outcomes. However, there is a dearth of research investigating this issue in the vast literature on numeracy—the ability to accurately interpret numerical information about risk, a skill that is only moderately correlated with health literacy. In a cross-sectional study, we investigated whether objective and subjective numeracy is related to objective and subjective health outcomes. Objective (subjective) numeracy is actual (self-reported) numerical competence. Objective outcomes include prevalence of comorbidity and prescribed medications. Subjective outcomes include perceptions of physical and mental health.* ***Methods.*** *A convenience sample of 502 male individuals receiving outpatient care at a Veterans Affairs Medical Center reported their demographics and answered a survey measuring objective and subjective numeracy, trust in physicians, satisfaction with role in medical decision making, perceptions of physical and mental health, and risky habits. We computed patients' body mass index (BMI) and their age-adjusted Charlson index—an extensively studied comorbidity index for predicting mortality in clinical research. We retrieved number of prescribed medications from medical records.* ***Results.*** *Compared with patients who had high objective numeracy, patients with low objective numeracy showed higher prevalence of comorbidities and took more prescribed medications. Compared with patients who had high subjective numeracy, patients with low subjective numeracy had more negative perceptions of their physical and mental health. These conclusions held after controlling for the effect of demographics, risky habits, BMI, trust in physicians, and satisfaction with role in decision making, suggesting that numeracy has a unique, significant contribution to health outcomes beyond the effect of these factors.* ***Conclusions.*** *Our research documents for the first time that self-reported numeracy is related to perceptions of health, whereas objective numeracy is related to actual health, laying the groundwork for future research on the effect of numeracy on health outcomes.* ***Key words:*** *objective numeracy; subjective numeracy; health literacy; risk literacy; health outcomes; comorbidity.* ***(Med Decis Making 2015;35:501–511)***

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Over the past 20 years, numerical skills have become increasingly necessary for navigating the modern health care environment. Health professionals often provide numerical information about benefits and risks of medical interventions and lifestyles, and direct-to-consumer advertising often summarizes changes in incidence of various diseases and describes the effects of screenings and novel drugs. Unfortunately, many patients struggle to grasp numerical concepts that are essential for understanding health-relevant information.[1–3] Even highly educated patients tend to have difficulties interpreting and using a host of elementary probability expressions.[4–6]

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Recent research has shown that numeracy is related to accuracy of perceptions of health-related benefits and risks. Compared with patients who have high numeracy, less-numerate patients tend to overestimate the risk of several diseases[7,8] and are less able to use risk reduction information (e.g., about screening) to adjust their risk estimates.[9] Patients with low numeracy also overestimate benefits of uncertain treatments[10,11] and make less accurate estimates of their risk of experiencing side effects.[12]

Numeracy also has important effects on decision making. Less-numerate patients often choose lower-quality health options[13] and are more susceptible to being influenced by the way the health information is framed in problems involving probabilities[14–18]—presumably because they are more influenced by nonnumerical information (e.g., mood states) and show less sensitivity to different levels of numerical risks.[19,20] Less-numerate doctors and patients also favor a paternalistic model of medical decision making, in which doctors are dominant and autonomous[21] and patients prefer not to participate and instead delegate decision making.[22] This is troubling given that the paternalistic model of medical decision making is increasingly being questioned.[23]

Finally, numeracy can influence health outcomes. The most compelling evidence supporting this claim was inferred from research on health literacy[24,25]—which is the ability to understand written health information and to communicate orally about health.[26,27] In fact, some of the measures of health literacy include items assessing quantitative skills,[28,29] and both health literacy and numeracy are moderately correlated.[30] Thus, research on health literacy suggests that numeracy might also be related to health outcomes. This research shows that lower levels of health literacy are associated with lower utilization of preventive medical services, higher utilization of emergency department services, and more hospitalization.[31–33] Lower levels of health literacy are also associated with less health-relevant information seeking,[34] more difficulty in understanding prescription medication warning labels,[35] lower medication adherence,[36,37] and higher health care costs.[38] Finally, lower levels of health literacy are associated with higher risk for all-cause mortality,[39,40] worse quality of life and physical function,[41,42] and poorer mental health.[40,43,44]

Surprisingly, there is a dearth of research investigating long-term health outcomes in the vast literature on numeracy, which would have important clinical implications.[45,46] The few studies on this issue showed that compared with patients with adequate numerical skills, less-numerate patients search for less information about their disease during medical sessions and are at higher risk of hospitalization.[30,47,48] These studies also showed that patients with lower numeracy are more vulnerable to having difficulty following a complicated dosing regimen[49,50] and have less effective disease management skills[51–54] (but see Schapira and others[55]). However, these studies focused on specific groups of patients (e.g., patients taking specific drugs or with specific diseases). In addition, these studies did not investigate whether numeracy is related to other important health outcomes involving physical and mental health.

In the current research, we extend the previous literature by investigating whether numeracy is related to objective and subjective health outcomes. In particular, we investigated whether numeracy is related to prevalence of comorbidity, number of prescribed medications, and perceptions of physical and mental health in a large sample of male patients. Toward this end, we measured both objective and subjective numeracy. Objective numeracy refers to patients' numerical competence and basic arithmetic and statistical skills, such as their ability to convert percentages to proportions.[5,9,56–58] In contrast, subjective numeracy encompasses patients' perceptions and beliefs of their numerical competence rather than their actual competence.[59–61]

We also measured and controlled for the effect of several potential variables that might affect the relationship between numeracy and health outcomes. In particular, we controlled for the effect of characteristics of patients and of the patient-physician relationship. Characteristics of patients include demographics (age, educational level, marital status, ethnicity, and household income), risky habits (smoking and substance abuse or dependence), and body mass index (BMI). Characteristics of the patient-physician relationship include patients' levels of trust in their physicians and satisfaction with their role in medical decision making.

METHODS

Participants

A cross-sectional study was conducted from January through February 2012 on 502 men receiving outpatient care at the Bruce W. Carter VAMC (Miami, Florida). Participants were conveniently recruited at outpatient clinics and met the following inclusion criteria: enrollment in a VA clinic and having a minimum education level of 8th grade. Patients were not included if they had unstable medical illness or

Table 1 Demographics and Characteristics of the Sample of Patients

Variable	Score[a]
Educational level, n (%)	
Less than high school	9 (2)
High school	303 (61)
Some colleague or higher	181 (37)
Marital status, n (%)	
Single	227 (47)
Married	147 (30)
Divorced	96 (20)
Widowed	17 (3)
Ethnicity, n (%)	
White Americans	172 (35)
African Americans	278 (56)
Other	47 (9)
Body mass index, n (%)	
Underweight	7 (1)
Healthy weight	125 (25)
Overweight	179 (36)
Obese	191 (38)
Satisfaction with role in medical decision making, n (%)	
Prefer a more active role	136 (27)
Satisfied with their current role	295 (59)
Prefer a more or more passive role	71 (14)
Age, average in years (range)	58 (23–83)
Tobacco use, n (%)	100 (20)
Substance abuse or dependence, n (%)	35 (7)
Household income, average in US$ (range)	33,899 (11,873–100,481)
Perception of physical health, average score (range)	2.8 (1–5)
Perception of mental health, average number (range)	1.5 (0 –5)
Comorbidity, average number (range)	3.4 (0–14)
Prescribed medications, average number (range)	6.1 (0–21)
Trust in physicians, average score (range)	58.2 (10–70)
Objective numeracy, average score (range)	5.3 (0–12)
Subjective numeracy, average score (range)	34.2 (8–56)

a. Percentages based on valid cases only.

significant sensory impairment. We obtained full institutional review board approval from the Bruce W. Carter VAMC, and all patients consented to participation through a consent form. They received a $5 voucher for participating in the study.

Materials and Procedure

All patients completed a paper-and-pencil survey that included the measures discussed below (see also Table 1).

Demographic information. Patients reported their age, level of education, marital status, and ethnicity.

Objective numeracy. This was measured with a scale consisting of 9 items developed by Schwartz and others[9] as well as Lipkus and others[56] and the 4 items of the Berlin Numeracy Test.[5,62] The scale assesses the ability to compare risk magnitude, convert percentages to proportions, convert proportions to percentages, convert probabilities to proportions, and compute probabilities. The scale showed adequate internal consistency in previous research, with Cronbach's alpha scores ranging from 0.70 to 0.75.[5,56] Tests of criterion validity have indicated that scores in the questionnaire are highly correlated with correct answers to ecologically valid probabilistic medical decisions.[63] The Cronbach alpha coefficient in the current study was 0.74.

Subjective numeracy. This was measured with a scale developed by Fagerlin and others,[60] which is an 8-item self-report measure of the perceived

ability to perform various mathematical tasks and preferences for use of numerical versus prose information. The scale demonstrates good reliability (Cronbach's alpha = 0.82) and is significantly correlated with the Lipkus and others[56] objective numeracy scale (r = 0.63–0.68[56,57]). The Cronbach alpha coefficient in the current study was 0.83.

Trust in physicians. This was measured with an instrument developed by Anderson and Dedrick.[64] It includes 11 items and assesses patients' trust in their physicians in the domains of dependability, confidence, and confidentiality of information. Patients answered the questions by using 7-point scales ranging from 1 (not at all) to 7 (very much). The instrument showed adequate internal consistency in previous research, with a Cronbach's alpha score of 0.85.[64] The Cronbach alpha coefficient in the current study was 0.94.

Satisfaction with role in medical decision making. Patients answered 2 questions adapted from the classic study by Strull, Lo, and Charles.[65] One of the questions asked about the role patients believe they should play in interactions with their physician. The other question asked about the usual role they play in these interactions. To answer the questions, patients had to select 1 of 5 options reflecting potential roles that could be played in medical decision making, ranging from active to collaborative to passive roles.

Perception of physical health. Patients selected 1 of 5 options reflecting perceptions of their physical health. Options were *poor, fair, good, very good*, and *excellent*.

Perception of mental health. This was measured with a scale consisting of 5 items developed by the National Center for Health Promotion and Disease Prevention (NCP), from the US Departments of Veterans Affairs. The instrument was successfully used in the Move! Weight Management Program (http://www.move.va.gov) and assesses whether patients felt stressed, unhappy, depressed, or anxious/nervous and whether they had family/relationship problems. The Cronbach alpha coefficient of the instrument in the current study was 0.74.

Risky habits. Patients mentioned whether they smoked and/or abused substances (substance dependence).

There were no time constraints, but the entire survey took approximately 45 min to complete. In addition, we measured patients' weight and height. We retrieved from medical records the number of prescribed medications that patients were taking at that time and whether they had a range of comorbid conditions when they completed the survey, including myocardial infarction, congestive cardiac failure, peripheral vascular disease, dementia, chronic obstructive pulmonary disease (COPD), connective tissue disease, peptic ulcer disease, mild liver disease, severe liver disease, diabetes without organ damage, diabetes with organ damage, hemiplegia/stroke, renal failure, any cancer within 5 years, malignant lymphoma, leukemia, metastatic cancer, and human immunodeficiency virus infection/acquired immunodeficiency syndrome (HIV/AIDS).

Analyses

We computed patients' levels of objective numeracy by adding the number of items answered correctly. We computed patients' levels of subjective numeracy and trust in physicians by averaging ratings across all items in the corresponding instrument. We inferred patients' satisfaction with their role in medical decision making by computing discrepancies between their preferred and usual roles. In particular, we deducted patients' answers to the question about usual role from their answers to the question about their preferred role. We then classified patients as those who 1) would prefer to have a more active role than they usually had, 2) were satisfied with their current role, or 3) would prefer a more passive role than they usually had.

We computed patients' levels of mental health by adding positive responses in the corresponding instrument. We computed BMI on the basis of patients' weight and height. We computed patients' age-adjusted Charlson index[66] on the basis of prevalence of the comorbid conditions mentioned above. The Charlson index is the most valid, reliable, and extensively studied comorbidity index for predicting mortality in clinical research.[67–69] Each condition received a score depending on the associated risk of dying. Higher scores indicate greater prevalence of comorbidity.

Finally, we used the 5-digit Zip Code Tabulation Area (ZCTA) and the median household income in the past 12 months (in 2011 inflation-adjusted dollars) by racial group from the US Census Bureau, 2007–2011, American Community Survey (African American, B19013B; white, B19013A; Asian, B19013D; and American Indian/Alaska Native, B19013C) to infer patients' average household income.[70–72] In patients with no race information,

we considered the general median household income (B19013).

Patients' demographics were analyzed using descriptive statistics. To test whether objective and subjective numeracy is related to objective and subjective health outcomes, we used a multivariable approach. In particular, we conducted factorial regression analyses with objective and subjective numeracy as continuous predictor variables and with patients' age-adjusted Charlson index, number of prescribed medications, and perceptions of physical and mental health as outcome variables. To evaluate the strength of the relationship between numeracy and health outcomes, we computed odds ratios that included objective and subjective numeracy as continuous variables. We included age, educational level, marital status, ethnicity, household income, BMI, smoking, substance abuse or dependence, trust in physicians, and satisfaction with role in medical decision making as control variables in all the analyses. Finally, we classified patients into 4 levels of objective and subjective numeracy based on whether their overall score falls into the first, second, third, or fourth quartile in the corresponding instruments (see References 5, 10, 15, 18, and 73 for a similar procedure). We then compared average scores in health outcomes in patients in the first (lowest) and fourth (highest) quartile.

RESULTS

Demographics and characteristics of the sample of patients are reported in Table 1. Patients had an average age of 58 years (range 23−83 years); 56% were African Americans, 35% were white Americans, and the rest (9%) were Indian or Asian Americans. Most of the patients (63%) had a high school degree or less; 47% were single and 30% were married. The patients had a median household income of US$33,899. Twenty percent of the patients smoked and 7% abused substances; 36% were overweight, 38% were obese, and only 26% had a weight within the health range or were underweight.

Most patients perceived their health as fair (33%) or good (40%), and only 20% and 7% reported that their health was very good/excellent and poor, respectively. On average, patients took several prescribed medications (6.1) and showed high prevalence of comorbidities (3.4) and poor mental health (1.5). They also showed low levels of objective (5.3) and subjective (34.2) numeracy. Many patients were satisfied with their current role in medical decision making (59%) and showed moderate to high levels of trust in their physicians (58 on average).

Is Objective Numeracy Related to Objective and Subjective Health Outcomes?

Results of the regression analyses showed that objective numeracy is related to prevalence of comorbidity ($\beta = -0.24$, $t_{414} = -4.00$, $P = 0.001$) and number of prescribed medications ($\beta = -0.18$, $t_{414} = -3.11$, $P = 0.002$) beyond the effect of the other control variables (see Table 2). In contrast, objective numeracy is not related to subjective health outcomes (i.e., perceptions of physical or mental health).

Table 3 shows odds ratios describing the strength of the relationship between objective numeracy and prevalence of comorbidity. There was a moderate but significant association between objective numeracy and prevalence of COPD, peptic ulcer disease, liver disease, diabetes, and HIV/AIDS after controlling for the effect of the control variables. Odds ratios associated with a 1-unit increase in objective numeracy ranged from 1.13 (diabetes) to 1.31 (peptic ulcer). Results for prevalence of myocardial infarction, congestive cardiac failure, and dementia were similar, but differences were only marginally significant. The odds ratio for the likelihood of suffering at least 1 of these diseases is 1.18.

The risk that patients with low objective numeracy (lowest quartile) suffer at least 1 comorbid condition was 40% larger than that of patients with high objective numeracy (highest quartile) (i.e., 4.7 v. 2.8). In addition, compared with patients who had high objective numeracy, patients with low objective numeracy took 20% more prescribed medications (5.5 v. 6.7).

Is Subjective Numeracy Related to Objective and Subjective Health Outcomes?

Results of the regression analyses showed that subjective numeracy is related to perceptions of physical ($\beta = 0.13$, $t_{414} = 2.22$, $P = 0.027$) and mental health ($\beta = -0.19$, $t_{414} = -3.38$, $P = 0.001$) beyond the contribution of the other factors (see Table 2). In contrast, subjective numeracy is not related to prevalence of comorbidity or the number prescribed medications.

Table 4 shows odds ratios describing the strength of the relationship between subjective numeracy and perceptions of mental health. There is a small but significant association between subjective numeracy and being unhappy, depressed, and

Table 2 Effect of Objective and Subjective Numeracy on Health Outcomes, Demographics, Risky Habits, Body Mass Index, and Characteristics of the Patient-Physician Relationship

		Objective Numeracy			Subjective Numeracy		
		β	*t*	*P*	β	*t*	*P*
Health outcomes	Prevalence of comorbidity	–0.24	−4.00	0.001[a]	–0.02	–0.28	0.778
	Prescribed medications	–0.18	−3.11	0.002[a]	–0.07	−1.27	0.206
	Perception of physical health	–0.01	–0.09	0.931	0.13	2.22	0.027[a]
	Perception of mental health	0.06	0.97	0.334	–0.19	−3.38	0.001[a]
Demographics	Age	0.07	1.63	0.103	0.11	2.44	0.015[a]
	Educational level	0.28	6.37	0.001[a]	0.30	7.01	0.001[a]
	Marital status	0.07	1.54	0.124	0.04	0.99	0.322
	Ethnicity	–0.30	−6.82	0.001[a]	–0.20	−4.49	0.001[a]
	Household income	0.21	4.79	0.001[a]	0.12	2.65	0.008[a]
Risky habits and body mass index	Tobacco use	–0.09	−2.03	0.043[a]	–0.06	−1.40	0.163
	Substance abuse or dependence	–0.07	−1.55	0.122	–0.05	−1.20	0.229
	Body mass index	–0.01	–0.10	0.922	0.02	0.36	0.722
Characteristics of the patient-physician relationship	Trust in physicians	0.08	1.77	0.070[b]	0.13	2.93	0.004[a]
	Satisfaction with role in medical decision making	–0.04	–0.83	0.409	0.06	1.45	0.147

Note: Demographics, risky habits, body mass index, and characteristic of the patient-physician relationship were also included as control variables in the analyses of the effect of objective and subjective numeracy on health outcomes.
a. $P < 0.05$. b. $P < 0.10$.

Table 3 Odds Ratios Describing the Strength of the Association between Objective Numeracy and Prevalence of Comorbidity

Type of Disease	OR	95% CI	Wald	*P*
At least 1 disease	1.18	1.08–1.30	12.17	0.001[a]
Myocardial infarction	1.14	0.99–1.31	3.40	0.065[b]
Congestive cardiac failure	1.18	0.99–1.41	3.35	0.067[b]
Peripheral vascular disease	1.09	0.87–1.36	0.54	0.462
Dementia	1.32	0.96–1.80	2.87	0.090[b]
Chronic obstructive pulmonary disease	1.26	1.08–1.48	8.13	0.004[a]
Connective tissue disease	0.98	0.90–1.08	0.12	0.726
Peptic ulcer disease	1.31	1.03–1.67	4.86	0.028[a]
Liver disease	1.27	1.11–1.45	12.39	0.001[a]
Diabetes	1.13	1.03–1.25	6.57	0.010[a]
Hemiplegia/stroke	1.15	0.94–1.41	1.90	0.168
Renal failure	1.04	0.90–1.21	0.26	0.612
Cancer	0.98	0.85–1.13	0.09	0.763
HIV/AIDS	1.17	1.03–1.34	5.50	0.019[a]

Note: Lower objective numeracy is related to higher odds of prevalence of comorbidity. Demographics, risky habits, body mass index, and characteristic of the patient-physician relationship were included as control variables in the analyses.
[a]$P < 0.05$. [b]$P < 0.10$.

anxious after accounting for the effect of the control variables. The odds ratio associated with a 1-unit increase in subjective numeracy is 1.03 for these psychological problems and for the likelihood of suffering at least 1 psychological problem.

While 54% of the patients with low subjective numeracy (lowest quartile) thought that their physical health was poor or fair, 65% of the patients with high subjective numeracy (highest quartile) considered that their physical health was good, very good, or excellent. In addition, the risk that patients with low subjective numeracy felt stressed, unhappy, depressed, or anxious/nervous or had family/relationship problems was 32% larger than that of patients with high subjective numeracy (1.9 v. 1.3).

Table 4 Odds Ratios Describing the Strength of the Association between Subjective Numeracy and Perception of Mental Health

Type of Mental Health Problem	OR	95% CI	Wald	*P*
At least 1 psychological problem	1.03	1.01–1.05	7.47	0.006[a]
Too much stress	1.01	0.99–1.03	1.51	0.219
Unhappiness	1.03	1.01–1.05	5.86	0.015[a]
Depression	1.03	1.01–1.05	8.65	0.003[a]
Anxiety problems and nervousness	1.03	1.01–1.05	5.98	0.015[a]
Family or relationship problems	1.01	0.99–1.04	1.51	0.220

Note: Lower subjective numeracy is related to higher odds of mental health problems. Demographics, risky habits, body mass index, and characteristic of the patient-physician relationship were included as control variables in the analyses.
[a]$P < 0.05$. [b]$P < 0.10$.

DISCUSSION

To make informed decisions about health, patients need to have the ability to accurately interpret information about medical risks. Unfortunately, our research shows that many patients lack basic numeracy, which can have health-relevant consequences. In particular, patients with low *objective* numeracy showed higher prevalence of comorbidity (e.g., COPD, diabetes, or HIV/AIDS) and took more prescribed medications than those with high objective numeracy. Patients with different levels of objective numeracy, however, had similar perceptions of their physical and mental health. Our results also showed that patients with low *subjective* numeracy had more negative perceptions of their physical health and more often reported that they felt unhappy, depressed, and anxious than those with high subjective numeracy. Patients with different levels of subjective numeracy, however, showed similar prevalence of comorbidities and did not differ in the number of prescribed medications that they were taking. In sum, our research suggests that an objective measure of numerical competence can predict objective health outcomes, whereas a subjective measure of perceived ability can predict self-reported health outcomes. Of note, these conclusions hold after controlling for the effect of patients' demographics (age, educational level, marital status, ethnicity, and household income), risky habits (smoking and substance abuse or dependence), BMI, patients' trust in their physicians, and satisfaction with their role in medical decision making, suggesting that numeracy has a unique significant contribution to health outcomes beyond the effect of these factors.

Our results are in line with research on health and skill assessment, which shows that people can be highly inaccurate when judging their health condition and competence. For example, Dunning and others[59] conducted a systematic review of the literature and concluded that people often underestimate their own health risks and overestimate those of other people. In addition, people often misdiagnose themselves[59,74]—a phenomenon that can have severe consequences.[75] Dunning and others[59] also concluded that people's self-views only hold a tenuous to modest relationship with their actual performance. Most people say that they are ''above average'' in skill (a conclusion that defies statistical possibility), they overestimate the likelihood that they will engage in desirable behaviors and achieve favorable outcomes, they furnish overly optimistic estimates of when they will complete future projects, and they reach judgments with too much confidence. Similarly, Sheridan and others[76] showed that 70% of the participants in their study reported that they considered themselves to be ''good with numbers,'' while only 2% of those participants correctly answered 3 objective numeracy questions. Finally, Ghazal and others[62] showed that less numerate individuals are especially overconfident when assessing their numerical competence.

In sum, self-assessments of health and skill tend to be flawed in substantive and systematic ways, which might explain why objective numeracy was only related to objective health outcomes in our study. This result is in line with previous research that showed that objective health literacy is related to objective health outcomes.[46–50,54] Only a few studies, however, showed a relationship between objective health literacy and health perceptions.[77,78] Finally, it is also likely that patients in our study might have overestimated their numerical skills, which would explain why subjective numeracy was not related to objective health outcomes after controlling for objective numeracy.

Our research extends the vast literature on numeracy by documenting for the first time that self-reported numeracy seems to be related to perceptions of health, whereas objective numeracy is related to actual health. The strengths of our study are the use of both medical record information and subjective measures in a large sample of patients. As with any research, our study also has some limitations. In particular, our study is cross-sectional, limiting our conclusions about the causal effect of numerical competence on health outcomes. For instance, we cannot rule out a possible effect of some health outcomes (e.g., dementia) on numerical skills. Nevertheless, we think that our results and conclusions can have important clinical implications and can inspire future theoretical and empirical work.

Our assumption is that objective numeracy might affect prevalence of comorbidity via an effect of several processes, including actions to promote health and prevent disease and actions to comply with diagnosis and treatment.[27,79] Thus, numeracy might have an *indirect* effect on health outcomes. For instance, previous research suggests that patients with low objective numeracy weight immediate rewards more than temporally distant rewards[24]—presumably because they are not able to understand long-term, probabilistic information.[25] As disease prevention depends in large part on taking actions now to prevent serious uncertain consequences later, patients with low objective numeracy might require more extensive explanations of risks to engage in long-term healthy behaviors and lifestyles.[24,52,80] Management of illness might also depend on accuracy of risk understanding.[49,54] For instance, patients with limited objective numeracy might have difficulties understanding the probabilistic link between adherence and treatment effectiveness, which is consistent with evidence showing that less-numerate patients showed lower medication adherence than patients with more adequate numerical skills.[36,38,81,82] Patients with low objective numeracy also have inaccurate perceptions of their risk of suffering a disease and overestimate benefits of uncertain treatments,[7] which might also affect their use of preventive and emergency medication services.[47] Therefore, objective numeracy, through its effect on accuracy of perceptions of health-related benefits and risks, might affect management of health and illness, which in turn would influence health outcomes. In terms of subjective numeracy, the evidence is scant. A recent study[83] demonstrated an association of low subjective numeracy with an increased risk of recidivism in patients with heart failure, suggesting that subjective numeracy might also affect actions to comply with diagnosis and treatment.

Research investigating interactions between health professionals and patients provides further evidence supporting the conclusion that objective numeracy can indirectly affect prevalence of comorbidity.[34,84,85] To illustrate, compared with patients who have adequate levels of objective numeracy, less-numerate patients often avoid asking their doctors questions about their symptoms and medical treatments[27] and are less willing to participate in decision making about their health.[21,22] In addition, health professionals frequently become frustrated at the failure of the less-numerate patients to understand health-relevant risk information,[86] which interferes with patient-centered and informed decision making. Thus, patients with low numeracy have more negative interactions with their doctors, which might limit their access to good medical treatment and other important health resources (e.g., regular medical check-ups, screenings, and immunization). These difficulties in having access to high-quality health care might ultimately affect health outcomes.

In sum, numeracy might affect health outcomes via an effect of several mediating processes, including accuracy of risk understanding, which might affect actions to promote health and prevent disease, management of illness, and use of emergency department services and hospitalization. Numeracy might also affect health outcomes via an effect of quality of patient-provider interactions, which would affect patients' access to good medical treatment and other resources. Future research can investigate the mediating role of these factors. Future research can also investigate the influence of numeracy in other important long-term health outcomes such as quality of life and mortality. Our ongoing work along these lines suggests promising results.

Our research was conducted on a convenient hospital-based sample of male patients in a Veterans Affair Medical Center in the United States. Future studies can also investigate the relationship between numeracy and health outcomes in population-based, national samples in other countries. In addition, we used zip code median income as a proxy for patients' household income. Research shows that this measure is not ideal but can offer some predictive power and reliability. For instance, median household income derived from ZCTA data has been consistently validated as the most reliable indicator of income after individual-reported income for population-based studies in the United States.[70–72] Zip code data,

however, are typically based on both male and females, and all our participants were males. Future studies investigating the relationship between numeracy and health outcomes can ask patients about their annual income or use census track median income from patients' addresses, which would be a more reliable measure of household income. Finally, future studies can investigate whether effective educational efforts aiming at improving numerical skills influence health outcomes. Adaptive, internet-based tutoring programs and custom-tailored educational brochures are under development (e.g., www.RiskLiteracy.org) and hold great promise.[87] The use of communication formats that do not require high levels of numeracy can also effectively improve risk comprehension and risk communication in patients with limited numerical skills[2] and possibly can help promote health. Visual aids,[18,88–93] analogies,[94] and reports of consequences of health-related behaviors expressed in terms of life expectancy[95] are prominent examples of transparent information formats and might help less-numerate patients feel more comfortable as partners in medical decision making.[96] Interactive educational and decision aid technologies thus hold great promise for leveraging what we already know about communicating risk, improving numeracy, supporting informed decision making, and promoting health.

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