General Performance on a Numeracy Scale among Highly Educated Samples

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Background. Numeracy, how facile people are with basic probability and mathematical concepts, is associated with how people perceive health risks. Performance on simple numeracy problems has been poor among populations with little as well as more formal education. Here, we examine how highly educated participants performed on a general and an expanded numeracy scale. The latter was designed within the context of health risks. *Method*. A total of 463 men and women aged 40 and older completed a 3-item general and an expanded 7-item numeracy scale. The expanded scale assessed how well people 1) differentiate and perform simple mathematical operations on risk magnitudes using percentages and proportions, 2) convert percentages to proportions, 3) convert proportions to percentages, and 4) convert probabilities to proportions. *Results*. On average, 18% and 32% of participants correctly answered all of the general and expanded numeracy scale items. Approximately 16% to 20% incorrectly answered the most straightforward questions pertaining to risk magnitudes (e.g., Which represents the larger risk: 1%, 5%, or 10%?). A factor analysis revealed that the general and expanded risk numeracy items tapped the construct of global numeracy. *Conclusions*. These results suggest that even highly educated participants have difficulty with relatively simple numeracy questions, thus replicating in part earlier studies. The implication is that usual strategies for communicating numerical risk may be flawed. Methods and consequences of communicating health risk information tailored to a person's level of numeracy should be explored further. *Key words:* risk; numeracy; communication. **(Med Decis Making 2001;21:37-44)**

Risk communication is fraught with many challenges, some of which involve how well people understand numerical expressions of risks, such as probabilities, percentages, and frequencies. For example, a familiar risk statistic is that 1 in 8 women will develop breast cancer in their lifetimes. An implicit assumption made by government and health officials is that people will understand what these risk estimates mean. Moreover, shared decision-making (SDM) is increasingly being identified as a goal or standard in communication with patients and physicians, particularly when 2 treatments or other method interventions are regarded as producing equivalent outcomes.[1,2] Most decision aids, critical tools for SDM, help patients to weigh the risks and benefits of different choices.[3] Numbers are an inherent part of the process. Basic numeracy on the part of the intended audience is assumed.

Recently, this common assumption that people are numerate, that is, facile with basic probability and mathematical concepts, has been questioned.[4–8] Indeed, being innumerate may interfere with estimations of personal health risks.[4,9] For example, Black and colleagues[4] asked 200 women ages 40 to 50 to estimate their chances of developing and dying from breast cancer over the next 10 to 20 years. They also asked women to indicate how many times, out of 1000 coin flips, a fair coin would be expected to land on heads. A woman was considered numerate if she 1) estimated her chance of developing breast cancer in the next 10 years as greater than or equal to her chance of dying of breast cancer in the next 10 years, 2) estimated her chance of dying of breast cancer over the next 20 years as greater than or equal to her chance of dying of breast cancer over the next 10 years, and 3) correctly answered the coin flip question (i.e., 500). Of the 145 women who answered these questions, 62% were numerate. Numeracy was related strongly to perceptions of risk. Numerate women were less likely to overestimate both their chances of dying from breast cancer and the absolute risk reduction

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obtained by breast cancer screening (e.g., mammography or clinical breast exams).

In another study, Schwartz and colleagues[6] asked 500 women veterans 3 general numeracy questions that were aimed at assessing their basic familiarity with probability, ability to convert a percentage to a proportion (e.g., 1% to 10 in 1000), and convert a proportion into a percentage (e.g., 1 in 1000 to 0.1%), and to indicate how many times, out of 1000 coin flips, a fair coin would be expected to land on heads. Of the 287 women who responded to the questionnaire, only 16% responded correctly to all 3 questions. Similarly, using a sample of 96 women patients from the Dartmouth-Hitchcock Medical Center and the Mayo Clinic between the ages of 50 of 79, Woloshin and colleagues[10] found that only 38% answered correctly 3 questions using the same basic mathematical operations used by Schwartz and colleagues.[6] Thus, in both studies, using basically the same mathematical processes, numeracy was poor.

The overall poor performance among participants in Schwartz and colleagues' study, and the better performance among participants in the Woloshin and colleagues' study, may reflect the different education level of the participants. In the Schwartz et al. study, 36% of participants had at least some college education, whereas 77% of participants in the Woloshin et al. study had at least some college. Nonetheless, it is still disconcerting that among such a well-educated sample, performance on simple numeracy questions was poor. Hence, an aim of this study was to examine performance on the items used by Schwartz and colleagues in 3 independent samples using highly educated participants—see endnote 1.

A second aim of this study was to examine performance using an expanded numeracy scale. Because studies to date have explored the relationship between numeracy and risk perceptions, we developed several questions entailing the same or similar mathematical operations (e.g., converting percentages to a proportion) used by Schwartz and colleagues, only phrased within the context of health risks. Specifically, we focused attention on how well people 1) can discern differences in magnitudes of health risks, 2) differentiate and perform simple mathematical operations on risk magnitudes using percentages and proportions, 3) convert percentages to proportions, 4) convert proportions to percentages, and 5) covert probabilities to proportions.

We concentrated on probabilities, proportions, and percentages because of their 1) common usage in the communication of risks for educational materials, decision aids, and explaining risks and benefits during the consenting process, and 2) incorporation in other numeracy measures. By asking general numeracy questions, and numeracy questions framed within the context of risk, we can discern with greater reliability the specific types of mathematical processes that pose computational challenges, and whether couching these questions within the context of risk affects performance. In general, a subtle change in context should not affect performance if the same construct (i.e., numeracy) is being assessed. We tested this assumption.

Methods

PARTICIPANTS

Our findings are based on a total of 463 men and women aged 40 and older who participated in 4 separate studies pertaining to breast and colon cancer screening. All participants were recruited by newspaper advertisements. Study 1 and study 2 involved 124 and 121 women, respectively, who participated in studies testing different formats for individualizing breast cancer risk, and how the receipt of this information affected risk perceptions and intentions to get mammograms.[11] Study 3 consisted of 40 men and 82 women. They participated in a study testing different formats for communicating colon cancer risk and how these formats affected intentions to get screened for colon cancer.[12] Study 4 consisted of 47 men and 79 women who participated in a study testing messages to overcome people's barriers to colon cancer screening. For present purposes, we combined participants from studies 3 and 4 into what we will call sample 3. We eliminated 33 women from this sample because they participated in an earlier breast risk communication study. The sample characteristics are presented in Table 1. In general, participants were White, well-educated, and nonsmokers.

PROCEDURE

Based on newspaper advertisements, women and men interested in participating in these studies

Table 1 • Demographic Information for Samples 1 to 3

Characteristic	Sample 1 (n = 124)		Sample 2 (n = 121)		Sample 3 (n = 218)	
Mean age (SD)	47.9	(5.5)	53.4	(10.9)	62.7	(9.7)
Percentage women	100.0		100.0		58.0	
Race						
Caucasian	71.8		72.7		83.5	
African American	25.8		23.1		16.0	
Other	2.4		4.2		0.5	
High school education or less	6.4		11.6		15.6	
Is a smoker	8.9		9.9		9.6	

Note: With the exception of age, all numbers refer to percentages.

were asked to call the Duke Medical Center's Risk Communication Lab (RCL) for study information. Interested callers were told they would come to the RCL to evaluate health education materials designed to communicate information about either breast or colon cancer.

When participants arrived at the RCL, a research assistant reviewed the specific study's purpose and procedures and obtained written consent. Participants then completed general and expanded numeracy scales before receiving any study materials. Participants across the 3 samples responded to the same general and expanded numeracy items that included both multiple choice response options and open-ended responses. They first completed the general numeracy questionnaire, which closely mirrors the questions posed by Schwartz and colleagues,[6] and then a 7-item expanded numeracy questionnaire that framed questions within the context of health risks. The general and expanded numeracy questions are shown in Table 2 along with the correct answers. After completing the numeracy scales, participants were presented with the materials appropriate to each study and were debriefed. The reader is referred to published work[11,12] for more detailed descriptions of the individual studies.

STATISTICAL ANALYSES

Descriptive statistics were used to describe performance on the numeracy items (e.g., percentage correct). A further aim was to assess whether the expanded numeracy items tapped the construct of global numeracy. To assess this relationship, we dichotomized item responses to the general and expanded numeracy questions to be either correct or incorrect—scored 1 and 0, respectively. We then pooled samples and computed an 11×11 matrix of tetrachoric correlations (mean tetrachoric correlation = 0.45, SD = 0.14). Tetrachoric correlations are often used to assess relationships among dichotomous variables.[13]

A factor analysis, using TESTFACT version 2.13,[14] was conducted using the matrix of tetrachoric correlations. Although specialized methods were required to take into account the dichotomous nature of the input variables,[15–17] the resulting factor analysis can be essentially interpreted in the usual manner. An item was categorized as falling within a factor if its loading was 0.30 and above. The number of factors to retain was based on the mineigen value criteria and a scree plot.

Results

PERFORMANCE ON THE NUMERACY SCALES

The percentage of correct responses to each of the general and expanded numeracy items for each sample and pooling across samples is presented in Table 2. On the general numeracy items, about 40% of the sample could not solve a basic probability problem or convert a percentage to a proportion (see items 1 and 2). Participants faired worse at converting proportions into percentages (item 3). They did better at solving the expanded numeracy scale items, although a sizable number erred on very basic problems. For example, roughly 20% incorrectly identified the larger of risk magnitudes presented either as a proportion or percentage (see items 1 and 2). Similarly, on average, 20% to 30% could not convert percentages to proportions and vice versa (see items 5 and 6). Among all the expanded numeracy items, the poorest performance

Table 2 • General and Risk Numeracy Questions Accompanied by the Percentage of Participants Who Responded Correctly to Each Numeracy Item

Question	Sample 1 (n = 124)	Sample 2 (n = 121)	Sample 3 (n = 218)	Total (n = 463)
General numeracy scale items				
1. Imagine that we rolled a fair, six-sided die 1,000 times. Out of 1,000 rolls, how many times do you think the die would come up even (2, 4, or 6)? Answer: 500 out of 1000.	60.5	51.2	54.6	55.3
2. In the BIG BUCKS LOTTERY, the chances of winning a $10.00 prize is 1%. What is your best guess about how many people would win a $10.00 prize if 1,000 people each buy a single ticket to BIG BUCKS? Answer: 10 persons out of 1000.	61.3	57.0	60.6	59.8
3. In the ACME PUBLISHING SWEEPSTAKES, the chance of winning a car is 1 in 1,000. What percent of tickets to ACME PUBLISHING SWEEPSTAKES win a car? Answer: 0.1%	23.4	23.1	18.4	20.9
Expanded numeracy scale items				
1. Which of the following numbers represents the biggest risk of getting a disease? ___ 1 in 100, ___ 1 in 1000, _X_ 1 in 10	81.4	80.2	75.2	78.2
2. Which of the following numbers represents the biggest risk of getting a disease? ___ 1%, _X_ 10%, ___ 5%	83.1	82.6	84.4	83.6
3. If Person A's risk of getting a disease is 1% in ten years, and person B's risk is double that of A's, what is B's risk? Answer: 2%	91.2	90.1	90.4	90.5
4. If Person A's chance of getting a disease is 1 in 100 in ten years, and person B's risk is double that of A's, what is B's risk? Answer: 2 out of 100	86.3	86.0	87.2	86.6
5. If the chance of getting a disease is 10%, how many people would be expected to get the disease:				
A: Out of 100? Answer 10	78.2	81.0	82.1	80.8
B: Out of 1000? Answer 100	75.8	75.2	79.8	77.5
6. If the chance of getting a disease is 20 out of 100, this would be the same as having a ____% chance of getting the disease. Answer: 20	71.0	70.2	70.2	70.4
7. The chance of getting a viral infection is .0005. Out of 10,000 people, about how many of them are expected to get infected? Answer: 5 people	50.8	45.4	49.1	48.6

Note: Before answering the numeracy questionnaires, as a practice question, participants were asked, Imagine that we flip a fair coin 1,000 times. What is your best guess about how many times the coin would come up heads in 1,000 flips? This question was part of the general numeracy questionnaire by Schwartz and colleagues.[6] The die question was used as a practice question in their study. Questions that were left blank were assessed as being incorrect.

was in converting a probability to a proportion (see item 7).

The proportion of total correct responses to the general and expanded numeracy scales is presented in Table 3 for each sample and pooling across samples. With respect to the general numeracy scale, between 15% and 21% of participants correctly answered all 3 general numeracy questions. With respect to the expanded numeracy scale, 29% to 34% of participants correctly answered all of the numeracy questions.

We computed the correlations (Kendall's Tau) between the sums of the 2 numeracy scales. The correlations were 0.44, 0.44, and 0.49 across samples 1 to 3, respectively (all $ps < 0.0001$). Alphas for the general numeracy scale were 0.63, 0.61, and 0.57 for samples 1 to 3, respectively. Alphas for the expanded numeracy scale were 0.74, 0.70, and 0.75 for samples 1 to 3, respectively.

FACTOR ANALYSIS OF THE GENERAL AND EXPANDED NUMERACY ITEMS

A single to 3-factor solution was computed to examine the dimensionality of all the numeracy items. The first, second, and third factors had eigenvalues of 5.57, 1.24, and 1.19, respectively, that accounted for 49.4%, 11.9%, and 8.1% of the variance, respectively. Much of the variance not attributable to the first factor was due to the high correlations between questions 1 and 2 ($r_{tetrachoric}$ = 0.87 for items 1 and 2) and between question 5a and 5b ($r_{tetrachoric}$ = 0.98 for items 5a and 5b). These high

Table 3 • Percentage Correct Responses to the General and Expanded Numeracy Scales

Correct Responses	Sample 1 (n = 124)	Sample 2 (n = 121)	Sample 3 (n = 218)	Total (n = 463)
General numeracy scale				
0	23.0	25.0	24.0	24.0
1	29.0	39.0	33.0	34.0
2	27.0	16.0	28.0	24.0
3	21.0	20.0	15.0	18.0
Expanded numeracy scale				
0	0.8	0.8	0.9	0.9
1	1.6	1.6	1.8	2.0
2	2.4	4.0	4.0	4.0
3	5.0	5.0	6.0	5.0
4	11.0	7.0	6.0	8.0
5	10.0	12.0	13.0	12.0
6	12.0	17.0	12.0	13.0
7	25.0	23.0	23.0	24.0
8	31.0	29.0	34.0	32.0

Note: Percentages may not add to 100% due to rounding.

correlations essentially represented common method variance. Specifically, the question and anchor formats are almost if not identical for items 1 and 2 and for the 2-part answer to question 5. Thus, we concluded that a 1-factor solution seemed appropriate and that factors 2 and 3 primarily reflected common measurement variance rather than significant theoretical constructs.

The biserial item correlations with the underlying factor and factor loadings for the 1-factor solution are presented in Table 4. Overall, the biserial correlations ranged from 0.678 to 0.907, and the factor loadings ranged from 0.549 to 0.826. Pooling all items, the coefficient alpha was 0.78. In sum, the general and expanded numeracy items were tapping into the same construct, global numeracy.

Discussion

In a series of studies, we examined how a sample of well-educated individuals performed on several numeracy questions. In addition, we assessed the extent to which the general and expanded numeracy items tapped the construct of global numeracy. Consistent with prior findings,[6] a significant proportion of our study participants had difficulty answering a simple probability question and converting percentages to proportions and vice versa (see global numeracy items 1-3 in Table 2). For example, Schwartz and colleagues found that only 16% correctly answered all 3 numeracy questions. Although we slightly modified their scale by substituting a die for a coin flip question, across samples, the proportion of respondents who answered correctly all 3 questions was very similar (range 15% to 21%) despite notable differences in education. Moreover, our results replicate the relatively poor performance by participants in the Woloshin and colleagues study,[10] who used the same basic numeracy questions as were used by Schwartz et al., among a relatively highly educated sample.

Participants did better on the expanded numeracy scale items. However, here too, mistakes were made on very simple questions, such as indicating which numbers represented the highest risks using percentages and proportions. Across the 3 samples, as high as 20% of participants incorrectly answered these questions. These results should cause concern given that most risk communicators assume that people will at least be able to distinguish magnitudes of 2 or more expressions of numerical risks. Moreover, such tasks are inherent in many of the decision aids used to facilitate shared decision-making.

An additional aim was to examine whether the items on the general and expanded numeracy scales tapped into the primary construct of global numeracy. All the numeracy items were tapping the central construct, global numeracy. Therefore, there was no evidence to suggest that performing mathematical operations in the context of health risks differs from other simple mathematical processes in other contexts. Thus, previously used measures of numeracy probably can be used to assess mathematical performance in the health risk domain. This does not necessarily translate to knowing what a risk means. That is, performing well on numeracy items posed in the context of health risks does not mean that a person

Table 4 • Item-Total Correlations and Factors Loadings for the General and Numeracy Scale Items

Question	Item-Total Correlation	Factor Loading
General numeracy items		
1. Imagine that we role a fair, six-sided die 1,000 times. Out of 1,000 roles, how many times do you think the die would come up even (2, 4, or 6)?	.779	.699
2. In the BIG BUCKS LOTTERY, the chances of winning a $10.00 prize is 1%. What is your best guess about how many people would win a $10.00 prize if 1,000 people each by a single ticket to BIG BUCKS?	.709	.583
3. In the ACME PUBLISHING SWEEPSTAKES, the chance of winning a car is 1 in 1,000. What percent of tickets to ACME PUBLISHING SWEEPSTAKES win a car?	.779	.826
Risk numeracy items		
1. Which of the following numbers represents the biggest risk of getting a disease? ___ 1 in 100, ___ 1 in 1000, ___ 1 in 10	.769	.626
2. Which of the following numbers represents the biggest risk of getting a disease? ___ 1%, _ __ 10%, ___ 5%	.875	.740
3. If Person A's risk of getting a disease is 1% in ten years, and person B's risk is double that of A's, what is B's risk?	.739	.584
4. If Person A's chance of getting a disease is 1 in 100 in ten years, and person B's risk is double that of A's, what is B's risk?	.811	.695
5. If the chance of getting a disease is 10%, how many people would be expected to get the disease:		
A: Out of 100? Answer 10	.907	.720
B: Out of 1000? Answer 100	.847	.678
6. If the chance of getting a disease is 20 out of 100, this would be the same as having a ____% chance of getting the disease.	.809	.705
7. The chance of getting a viral infection is .0005. Out of 10,000 people, about how many of them are expected to get infected?	.678	.549

Note: Item-total correlations are biserial correlations.

understands the magnitude or the consequences of the risk or appropriately personalizing the information.[18] Indeed, the individual may fail to personalize the risk information because he or she lacks a full understanding of the magnitude or consequences of risk or may find the information not highly credible. Therefore, communication efforts should try to assist individuals in understanding the risks whenever possible so that they are more likely to be used in health decisions and taking precautionary actions.[19] Indeed, according to Weinstein,[18] there are several facets to knowing a risk. These include knowing not only the probabilities and magnitude of the risk but also how the risk magnitude compares to other hazards (i.e., relative risks), how risk factors may modify one's risk (e.g., length and time smoked), and about the ease or difficulty of avoiding harm. In sum, improving and understanding the effects of numeracy on risk communication is only a small piece of a larger puzzle of helping people understand health risks.

Our study results have several implications. As voiced by others,[6,9] greater research efforts are needed to develop and test useful formats for communicating cancer and other disease risks. For example, verbal translations that accompany numeric risks may help people better comprehend risk messages. However, given that wide variations exist in how people interpret verbal categories of risk (e.g., very unlikely, likely, etc.[20]), even this approach may not help those who are least numerate. In addition, visual displays should be tested to determine whether they interact with numeracy to affect understanding of risk. Unfortunately, we know little about which visuals are most effective at communicating risk, especially low-probability events, and if effective, how much additional variance they contribute to people's understanding of risk.[21] Nonetheless, it seems reasonable to assume that visual displays are likely to benefit the least numerate.

From a practical perspective, it may be worthwhile to assess numeracy in patient populations, perhaps using 2 to 3 very simple measures of mathematical ability such as described herein, and target different communications based on numeracy level—which items best discriminate performance on various tasks has yet to be studied. Based on patients' levels of numeracy, physicians and other medical personnel may need to spend additional time explaining medical interventions that involve numerical information. In addition, they may want to ascertain that these patients understand the information—naturally, this assumes that physicians and other medical personnel are numerate. This might be especially germane when patients are asked to consent to medical procedures involving risks and benefits, or in other situations that involve use of basic math (e.g., dose to take for a prescription). The outcomes of these processes would empower the patient, by increasing understanding, in reaching shared informed decisions between the patient and the medical specialist.

Educational materials intended to convey health risks should use risk communication strategies that are sensitive to errors based on numeracy (e.g., visual, oral communication). Alternatively, or in combination with these approaches, communicators of health risks should use numbers that are least likely to produce errors, such as rates rather than proportions or perhaps using proportions rather than probabilities (e.g., 1/10 rather than 0.1).[22,23] Our results strongly suggest that errors are likely to occur when people are asked to switch from one metric to another (e.g., proportions to percentages), so this should be avoided. A future challenge will be to identify and assess the consequences of using different methods of communicating health risks that are less prone to biases due to numeracy. As Woloshin and Schwartz suggested,[24] people might also benefit from training to become more numerate. The advantage would be increased comfort with and competence in using numerate risk information to make informed health decisions.

The reader should interpret our findings cautiously in light of several limitations. First, our sample is not representative of the general U.S. population. Our sample was primarily White and highly educated, which is consistent with most other studies used to assess the effects of numeracy.[4,10] Therefore, future studies should use more heterogeneous populations. Second, our expanded and global numeracy items reflect only a few examples of a larger number of possible questions. With these caveats in mind, our results 1) contribute to the growing evidence suggesting that even among highly educated samples, the ability to solve basic numeracy problems is, on average, relatively poor, and 2) identify the types of numeracy problems that pose computational challenges. Researchers should examine how best to communicate health risks to people in general, but especially to those with low numeracy. This is important if we are to help people make informed health decisions. As the science of risk assessment becomes increasingly well developed, more precise risk estimates will be available for use in health decision-making. The challenge will be to find effective ways to communicate this information to diverse audiences. Finding more effective ways to communicate risk, cost-effectiveness, and quality of life would increase the likelihood that our efforts are understood, acted upon, and ultimately help to improve the quality of health care decisions and medical care.

Note

1. At the time these studies were conducted, the questions posed by Woloshin and colleagues were unknown to us. Therefore, we could not test performance using 2 of their 3 items. However, the main difference between the questions posed by Schwartz and colleagues and those used by Woloshin and colleagues is the context of the questions. The questions posed by Woloshin and colleagues were primarily posed within the context of health outcomes (e.g., allergic reactions to taking a drug), whereas those posed by Schwartz and colleagues were within the context of gambling situations (e.g., lottery, sweepstakes). Nonetheless, the mathematical processes and results in both cases were identical. Therefore, we expect participants' responses to the Schwartz and colleagues questions would be very similar to the answers participants would give to the Woloshin and colleagues questions.

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