

Risk Literacy and Transparent Risk Communication in Health: A Review

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Acknowledgments

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Abstract

Numerical skills have become increasingly necessary for navigating the modern health care environment. Unfortunately, a significant proportion of the population lacks basic numeracy, which limits their risk literacy (i.e., their ability to accurately interpret and make good decisions based on information about risk). In this article, we review recent research investigating how to improve risk literacy by using transparent information formats for risk communication. This research focuses on simple messages containing visual aids that improve risk comprehension and medical decision making. This research also investigates the psychological mechanisms mediating the effect of visual aids. Our review includes data from 60 countries (e.g., China, England, Japan, India, Pakistan, Spain, Sweden, and the United States) with participants from diverse walks of life (e.g., health professionals, patients, high-risk individuals, probabilistic national samples, and web panels). Results converge with a growing body of research showing that appropriately designed visual aids can be highly effective, transparent, and ethically desirable tools for improving risk communication, particularly among people with limited numerical skills. Open questions and emerging applications of our research are discussed.

Keywords: Visual aids, risk communication, medical decision making, risk literacy, numeracy.

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Informed decision making rests on an assumption that doctors and patients are statistically numerate.^{1,2} They should understand simple, health-relevant ratio concepts, fractions, proportions, percentages, and probabilities.³⁻⁵ Doctors, for instance, need to interpret and communicate numerical information about benefits and risks of different medical treatments, screenings, and lifestyle choices.⁶ Patients need to understand and use this information to consent on their own behalf to medical treatment and adhere to medical advice.⁷ In fact, both doctors and patients often recognize the relevance of numeracy for clinical practice.^{8,9}

Unfortunately, many people struggle to grasp numerical concepts that are essential for understanding health-relevant information.^{4,5,10} Even doctors and highly educated patients tend to have difficulties interpreting and using a host of elementary probability expressions that are essential components of risk literacy (i.e., the ability to accurately interpret and make good decisions based on information about risk).^{11,12} To illustrate, Anderson and Schulkin⁷ conducted a systematic review on physicians' understanding and use of numerical information about health. In this research, numeracy was assessed using an eleven question test developed by Schwartz et al.¹³ and Lipkus et al.¹⁴ The test assesses basic skills including comparing risk magnitude, converting percentages to proportions, converting proportions to percentages, converting probabilities to proportions, and computing probabilities. Examples of items are "which of the following numbers represents the biggest risk of getting a disease? 1 in 10, 1 in 100, or 1 in 1000?" and "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.” Importantly, Anderson and Schulkin⁷ found that 25%–47% of the sampled physicians could not correctly answer most of these basic questions (see also¹⁵⁻²⁰).

Research in the general population and in patients has revealed similar results. Lipkus et al.¹⁴ conducted a series of 4 studies on community samples of well-educated adults in North Carolina. Among other tasks, participants answered the eleven numeracy questions from Schwartz et al.¹³ and Lipkus et al.¹⁴ described above. The results showed that even among this educated US community sample, some sizable proportion of individuals were statistically innumerate (e.g., 20% failed questions dealing with risk magnitude). Another recent study¹⁰ using large probabilistic national samples of the whole populations of two countries (i.e., the United States and Germany; N=2010) indicated that more than 25% of participants answered most of the basic questions incorrectly. Cokely et al.¹¹ and Garcia-Retamero et al.²¹ found similar results in studies conducted on more than 5000 people from 30 countries (e.g., China, England, Japan, India, Pakistan, Spain, Sweden, and the United States), including participants from diverse walks of life (e.g., medical professionals, patients, probabilistic national samples, and web panels). These results are consistent with findings from several extensive longitudinal studies conducted in large adult and student samples such as the National Assessment of Adult Literacy (NAAL)²² and the Programme for International Student Assessment.²³ Moreover, Rodriguez et al.²⁴ conducted a study on patients’ understanding of numerical information in a large sample of patients in Florida. The authors concluded that on average patients are older, less educated, and less numerate than the general population (e.g., more than 40% of the patients correctly answered less than half of the items developed by Schwartz et al.¹³ and Lipkus et al.¹⁴; see also^{6,25} for similar results). Overall this body of research indicates that many doctors and

patients struggle with basic numerical concepts. Unfortunately, this lack of numeracy affects judgment, decision making, and health outcomes.

1. Influence of numeracy on judgment, decision making, and health outcomes

Numeracy is related to the accuracy of perceptions of health-related benefits and risks in doctors and patients.^{3,4} Less numerate doctors and patients have more difficulties interpreting numerical risks of side effects,^{26,27} and make less accurate diagnostic inferences based on numerical information about medical tests.^{18,28} Less numerate doctors and patients are also more susceptible to being influenced by the way the health information is framed in problems involving probabilities²⁹⁻³³—presumably because they are more influenced by non-numerical information (e.g., mood states).^{5,34,35} Compared to patients with high numeracy, less-numerate patients tend to overestimate their risk of suffering several diseases,^{36,37} they are less able to use risk reduction information to adjust their risk estimates (e.g., screening data),¹³ they tend to overestimate benefits of uncertain treatments,^{38,39} and they have more deficits in understanding the information necessary to follow dietary recommendations.⁴⁰

Numeracy has pronounced effects on medical decision making.⁵ Compared to patients with high numeracy, less-numerate patients tend to search for less information about their disease^{41,42} and often choose lower-quality health options (e.g., health insurance plans).^{19,43} Less-numerate doctors and patients also tend to favor a paternalistic model of medical decision making, in which doctors are dominant and autonomous and make decisions on their patients' behalf,⁴⁴ and patients prefer not to participate and instead delegate decision making.⁴⁵ This is troubling given that the paternalistic model of medical decision making is increasingly being questioned.⁴⁶

Finally, numeracy is related to important health outcomes in patients. Compared to patients with adequate numerical skills, less-numerate patients show higher prevalence of comorbidity.⁴⁷ The risk that less-numerate patients suffer myocardial infarction, chronic obstructive pulmonary disease, peptic ulcer disease, liver disease, and HIV/AIDS are 2.4 to 10 times larger than the risk for patients with high numeracy. Importantly, these results hold after statically controlling for the effect of demographics (e.g., age, education, ethnicity, and household income), risky habits, body mass index, and trust in physicians—suggesting that numeracy has a unique and significant contribution to health outcomes above and beyond the effect of these factors.⁴⁷

Numeracy may affect the prevalence of comorbidity via several mediating processes, including accuracy of perceptions of health-related benefits and risks, and quality of medical decision making (see causal framework in Figure 1). Accuracy of perceptions of benefits and risks might in turn affect prevalence of comorbidity by influencing patients' actions to promote health and prevent disease, and actions to comply with diagnosis and treatment.^{48,49} In accord with evidence supporting these claims, previous research suggests that patients with low numeracy act as-if they weight immediate rewards more than temporally distant rewards³—presumably because they are not able to carefully evaluate or accurately interpret long-term, probabilistic information.⁴ Because disease prevention often depends on taking actions now to prevent serious uncertain consequences later, patients with low numeracy can require more extensive interventions (e.g., education) before they adopt healthy behaviors and lifestyles.^{3,50,51}

<Insert Figure 1 here>

Compared to patients with high numeracy, less-numerate patients have less effective disease management skills.^{49,52-54} Management of illness can also depend on the

accuracy of risk perception. Patients with limited numeracy may have difficulties understanding the probabilistic link between adherence and treatment effectiveness, which is consistent with evidence indicating that less-numerate patients have more difficulty following a complicated dosing regimen,^{55,56} and show lower medication compliance as compared to patients with more adequate numerical skills.^{57,58} Low-numeracy patients' inaccurate perceptions of their risks (e.g., likelihood of suffering a disease or benefits of uncertain treatments³⁶⁻³⁹) may also partially explain why these patients use emergency department services more often,⁵⁹ and why they are at higher risk for hospitalization.⁶⁰ Therefore, numeracy, through its effect on accuracy of perceptions of health-related benefits and risks, may affect management of health and illness, which in turn can influence prevalence of comorbidity.⁴⁷

Research investigating medical decision making provides further evidence supporting the conclusion that numeracy indirectly affects prevalence of comorbidity. Compared to patients with adequate levels of numeracy, less-numerate patients often avoid asking doctors questions about their symptoms and medical treatments,⁴⁸ and spend less time gathering information about their disease during medical sessions.^{41,42} In addition, health professionals frequently become frustrated at the failure of less-numerate patients to understand health-relevant risk information,⁶³ which interferes with patient-centered and informed decision making.^{44,45} Thus patients with low numeracy have more negative interactions with their doctors,^{61,62} which influences information search and shared decision making, and limits patients' access to good medical treatments and other health resources (e.g., regular medical check-ups, screenings, and immunization). These obstacles to access of high-quality health care can ultimately affect prevalence of comorbidity.⁴⁷

In summary, the literature reviewed in this section shows that a significant proportion of the population has problems understanding health-relevant numerical expressions of probability about health. Many doctors and patients are essentially innumerate. Those who have adequate levels of numeracy have more accurate perceptions of health-related benefits and risks, and make better health-relevant decisions. Patients who have adequate levels of numeracy also show lower prevalence of comorbidity. Educational efforts designed to improve risk understanding and decision making competence are crucial and a part of the long-term solution. However, research indicates there are also powerful, simple interventions that can have substantial benefits at minimal costs, particularly among vulnerable populations with limited numeracy.

2. Improving risk understanding and decision making by using transparent information formats of risk communication

Visual aids are simple graphical representations of numerical expressions of probability and include bar and line charts, and icon arrays, among others^{64,65} (see Figure 2). Visual aids have long been known to confer benefits when communicating health-relevant risk information. However, not all visual aids are equally effective. Visual aids tend to provide an effective means of risk communication when they are *transparent*⁶⁶—that is, when their elements are well defined and they accurately and clearly represent the relevant risk information by making part-to-whole relationships in the data visually available^{67,68} (see Table 1 for a summary of the characteristics of transparent visual aids; see also⁶⁹⁻⁷¹).

<Insert Figure 2 and Table 1 here>

Previous research indicates that transparent visual aids improve comprehension of risks associated with different medical treatments, screenings, and lifestyles, and they

promote consideration of beneficial treatments despite side-effects.^{64,73,75,104} Visual aids also increase appropriate risk-avoidance behaviors, they promote healthy behaviors, they reduce errors induced by anecdotal narratives,¹⁰⁵⁻¹⁰⁷ and they aid comprehension of complex concepts such as incremental risk.¹⁰⁸ Risk information presented visually is also judged as easier to understand and recall than the same information presented numerically.^{95,109-111} Nevertheless, the benefits of visual aids are different for different people.

2.1. Using visual aids to improve risk understanding in people with limited numeracy

People with high numeracy often understand risks even if visual aids are not provided.^{90,91} A major challenge is to reach people who are less numerate and more likely to make errors or avoid decision making altogether. In a series of studies, Garcia-Retamero and Galesic^{38,79,90} showed that visual aids are particularly helpful for people with low numeracy as long as they have moderate-to-high graph literacy (i.e., as long as they are able to understand basic graphical representations of quantitative information⁹⁶). The authors examined accuracy of perceptions of the effectiveness of a medical treatment in probabilistic national samples in the United States and Germany. The authors compared the efficacy of different types of visual aids (i.e., icon arrays and bar graphs), representing either affected individuals only or the entire population at risk. In addition, the authors tested the efficacy of visual aids when the numerical information added to the visual aids was presented either as absolute or relative risk reduction.

Garcia-Retamero and Galesic³⁸ observed similar increases in accuracy with icon arrays and bar graphs. Visual aids were useful additions when the numerical information was presented both in terms of absolute and relative risk reductions. Importantly, visual

aids were most beneficial for individuals who had low numeracy but relatively moderate-to-high graph literacy, especially when the visual aids presented the entire population at risk (see Figure 3). Among this group of people, accuracy increased from less than 20% to nearly 80% when visual aids were used (see also^{95,97}). In fact, providing visual aids about the effectiveness of medical treatments eliminated differences in accuracy between this group of people and those with high numeracy. Unfortunately, people with both low numeracy and low graph literacy did not benefit from visual aids.

<Insert Figure 3 here>

Visual aids can also reduce errors and biases that affect accuracy of perceptions of the effectiveness of medical treatments, especially in people with low numeracy. A bias with important consequences is *denominator neglect*—the tendency to focus on the number of times a target event has happened (i.e., the numerator) and ignore the overall number of opportunities for it to happen (i.e., the denominator).¹¹² To illustrate, when estimating the effectiveness of a medical treatment, people with low numeracy often focus on the number of affected individuals who received and did not receive the treatment (i.e., the numerator; see Figure 4a). In contrast, they ignore the entire population at risk (i.e., the overall number of individuals in the treated and nontreated groups; the denominator). In other words, when estimating the effectiveness of a medical treatment less-numerate people often focus on absolute numbers (rather than proportions) of affected individuals. As a consequence, they often make inaccurate estimates of the effectiveness of the treatment—especially when the information is reported using samples of treated and nontreated individuals of different size (see Figure 4b).^{80,81} In such case, computing or otherwise representing proportions is essential to accurately infer treatment risk reduction.

<Insert Figure 4 here>

Garcia-Retamero and Galesic⁸⁰ investigated accuracy of perceptions of treatment risk reduction using samples of treated and nontreated individuals of different size. The study was conducted in probabilistic national samples in the United States and Germany. Half of the participants received the information about the treatment in numbers, while the rest received the information represented visually. The authors showed that denominator neglect was effectively eliminated by using visual aids, especially in less-numerate participants (see Figure 5). Likewise, a study by Okan, Garcia-Retamero, Cokely, and Maldonado⁸³ showed that visual aids were effective for reducing denominator neglect in participants with relatively high—but not low—graph literacy.

<Insert Figure 5 here>

Visual aids can also reduce the influence of other errors and biases in populations with limited numerical skills, including the effect of message framing. Garcia-Retamero and Galesic³¹ examined the effect of framed messages in perceptions of the effectiveness of medical surgery. The surgery was described in terms of chances of dying or surviving. As in some of the studies described above, participants were probabilistic national samples in the United States and Germany. Again, some of the participants received the information about the surgery in numbers (i.e., 9/991 in 1,000 people die/survive this surgery), while the rest received the information represented visually. Results showed that participants with low numeracy often perceived the surgical procedure as less risky when the associated risk was presented in positive terms (i.e., chances of surviving) than in negative terms (i.e., chances of dying). In contrast, participants with high numeracy often provided equal estimates when the risk was expressed in positive and negative terms. However, when visual aids were added to the numerical information, the effect of framing was reduced, and participants with low and high numeracy provided similar estimates (see also⁸⁵ for similar results).

Visual aids are also helpful to vulnerable populations with limited numeracy. For instance, older adults often struggle with numerical and complex reasoning because of age-related cognitive decline and other cohort effects.¹¹³ In addition, older adults frequently suffer chronic diseases and confront health-related decision making. Nevertheless, a study by Garcia-Retamero, Galesic, and Gigerenzer⁸¹ showed that visual aids can help less numerate older adults make accurate assessments of the effectiveness of medical treatments. However, visual aids confused rather than helped some older adults. Again, those who were both low in numeracy and low in graph literacy did not benefit from the visual aids.^{89,99}

A study conducted by Garcia-Retamero and Dhami⁷⁶ showed similar results in immigrants with limited numerical and language skills. This group of people often has problems understanding concepts such as “risk factors” and “being at risk,” and has special difficulties with numerical health risks.¹¹⁴ Garcia-Retamero and Dhami⁷⁶ showed that translated resources offer a helpful, but not sufficient, approach to communicating health information to immigrants. However, results further revealed that providing visual aids in addition to numerical information about the effectiveness of medical treatments eliminated differences between native and immigrant samples, even when the information was not presented in the immigrant participants’ native language.

Visual aids can also improve risk comprehension in physicians with limited numeracy. Garcia-Retamero, Cokely, Wicki, and Hanson²⁷ conducted an intervention in a large sample (n= 292) of surgeons from 60 countries. Surgeons read a scenario describing the results of a randomized controlled trial examining the risk of post-surgical side-effects, and provided an estimate of the risk. Half of the surgeons received the information in numbers. The other half received the information represented visually. Results showed that many surgeons

were not numerate enough to correctly interpret the surgical risk without additional support. Compared to surgeons with high numeracy, surgeons with low numeracy often made inaccurate risk estimates. However, the intervention using visual aids was an effective means of improving risk comprehension, eliminating differences between surgeons with high and low numeracy.

Visual aids eliminated differences between surgeons with high and low numeracy by making risks more transparent. Presenting visual aids to less numerate surgeons helped them identify and infer essential aspects of information (e.g., “gross-level information”^{72,73}). Visual aids also increased the ability of less numerate surgeons to recognize superordinate classes (e.g., overall number or proportion of patients allocated to different medical treatments).^{67,68} Finally, visual aids improved risk comprehension among less numerate surgeons by increasing the amount of time these surgeons spent considering the risk information, that is, by increasing the amount of time they spent deliberating on their risk estimates.²⁷ Recent research also shows that visual aids can help promote healthy behavior.

2.2. Behavioral interventions involving visual aids

Messages promoting a health behavior can be framed in terms of the benefits afforded by adopting the behavior (a gain-framed appeal) or in terms of the costs associated with failing to adopt the behavior (a loss-framed appeal).¹¹⁵ To illustrate, a message promoting condom use can emphasize the benefits of this practice (e.g., using condoms helps prevent sexually transmitted diseases or STDs) or the costs of avoiding this practice (e.g., failing to use condoms increases the risk of STDs). In a longitudinal study, Garcia-Retamero and Cokely⁸⁶ examined the effects of a brief risk awareness intervention (i.e., a sexual health information brochure) in a large sample of sexually active young adults with

limited numerical skills in Spain. Garcia-Retamero and Cokely⁸⁶ showed that gain-framed messages induced greater adherence for a prevention behavior (condom use), whereas loss-framed messages were more effective for promoting an illness-detecting behavior (STD screening). This was the case even if the two types of framed messages were comparable in terms of length and general content. However, when visual aids reporting numerical information about STDs were added to the health information, both the gain- and loss-framed messages became equally and highly effective (i.e., the framing bias was eliminated). Providing the same information in numbers, however, did not reduce the effect of the framed messages.⁸⁶

Follow-up interventions conducted in large samples of sexually active young adults in Spain showed that well-constructed visual aids promoted condom use as effectively as an extensive 8–10 hour evidence-based educational risk awareness program.⁸⁷ Young adults disadvantaged by their lack of numerical skills benefited more from the visual aids than those who had higher numeracy as long as they were moderately-to-high graph literate.⁸⁸ Of note, this research also investigated the underlying psychological mechanisms mediating the effect of the visual aids on behavior. On the whole, this research shows that visual aids improved decisions and promoted healthy behavior because they changed attitudes and behavioral intentions. In other words, visual aids increased adherence to condom use and STD screening by improving attitudes and fostering intentions to perform these behaviors, which in turn reduced risky behavior and improved decision making.¹¹⁶

Visual aids have also been found to boost accuracy of perceptions of health-related benefits and risks above and beyond the effect of other transparent information formats. As we mentioned above, doctors and patients often have difficulties inferring the predictive value of medical tests from information about the prevalence of diseases and the sensitivity

and false-positive rate of the tests. To illustrate, in an influential study on how doctors process information about the results of mammography, Eddy¹¹⁷ gave 100 doctors the following information:

“The probability that a woman has breast cancer is 1%. When a woman has breast cancer, it is not sure that she will have a positive result on the mammography: she has an 80% probability of having a positive result on the mammography. When a woman does not have breast cancer, it is still possible that she will have a positive result on the mammography: she has a 10% probability of having a positive result on the mammography.”

After having read this information, doctors were required to estimate the probability that a woman with a positive mammography actually has breast cancer. Eddy¹¹⁷ reported that 95 of 100 doctors estimated this probability to be about 80%. If one inserts the numbers presented above into a Bayes' theorem, however, one gets a value of 8%, that is, an estimate one order of magnitude smaller. Research in patients showed similar results.¹¹⁸

Gigerenzer and Hoffrage¹¹⁹ showed that communicating information about medical tests in natural frequencies as compared to probabilities improves diagnostic inferences. Natural frequencies are final tallies in a set of objects or events randomly sampled from the natural environment.^{120,121} For the mammography task and for a sample of 10,000 women, the statistical information provided in terms of natural frequencies reads:

“One hundred out of every 10,000 women have breast cancer. When a woman has breast cancer, it is not sure that she will have a positive result on the mammography: 80 of every 100 such women will have a positive result on the mammography. When a woman does not have breast cancer, it is still possible that she will have a positive result on the mammography: 990 out of every 9900 such women will have a positive result on the mammography.”

Even though the effect of numerical format (probabilities vs. natural frequencies) is substantial, the performance in the natural frequency condition still leaves room for improvement. A study conducted by Garcia-Retamero and Hoffrage¹⁸ showed that visual aids improve diagnostic inferences in both doctors and their patients beyond the effect of natural frequencies (see Figure 6).¹⁸ This research also indicated that doctors tend to be more accurate in their diagnostic inferences than their patients, who had no medical training—a difference in accuracy that disappeared when differences in numeracy were statistically controlled.¹⁸ Thus, previous formal medical education and expertise did not seem to improve judgment beyond the effect of numerical skills, at least with respect to inferring the positive predictive value from statistical information about diseases and medical tests.

<Insert Figure 6 here>

Ongoing research conducted in large samples of patients in Spain indicates that visual aids can also encourage patients' trust in their own physician and their willingness to participate in decision making about their health.¹²² Importantly, visual aids seem particularly beneficial for patients who have relatively low numeracy—a group that generally tends to be more passive in health decision-making.⁴⁵

3. What have we learned so far?

The research reviewed in this article shows that well designed visual aids can be especially useful for people with limited numerical skills as long as they have moderate-to-high levels of graph literacy. Although less numerate individuals typically have problems understanding risks, visual aids tend to confer benefits and may even eliminate differences between more and less numerate decision makers. In short, well-constructed visual aids offer a highly effective, transparent, and ethically desirable means of risk communication.^{2,66}

Although our studies take center stage in this article, this work reflects advances of a large, active interdisciplinary field.^{4,5,67,75,77,91} There is good reason to think that our conclusions are robust given that they are based on a variety of studies conducted in diverse groups of doctors, patients, and high-risk individuals from a wide-range of countries (e.g., the United States, Germany, Great Britain, and Spain), as well as studies of the general public (e.g., large, probabilistic national samples). The studies reviewed in this article examined risk communication in different ecologically valid tasks that accurately reproduced the problems that people commonly encounter when they face health decisions. These ecological studies covered diverse topics including estimates of risk and risk reduction; diagnostic inferences and perceptions of treatment effectiveness; confidence and accuracy; and changes in attitudes, behavioral intentions, actual behavior, and decisions making. In addition, the general findings hold across different types of visual aids (e.g., icon arrays, bar charts, and line plots, presenting either affected individuals only or these individuals and the entire population at risk); results hold when visual aids differ in iconicity (i.e., when they are more or less abstract⁹⁵); results also hold when visual aids are provided either in addition to or instead of numerical information; and when the numerical

information is presented using different information formats (e.g., absolute or relative risks).^{2,66,116}

Our research adds to the literature by shedding some light on why visual aids increase accuracy and improve decision making in people with limited numerical skills. Presenting visual aids to less numerate people helps them identify and infer essential aspects of the risk information (e.g., “gross-level information”^{72,73}). Visual aids also increase the ability of less numerate people to recognize superordinate classes, making part-to-whole relations in the data visually available.^{67,68} Moreover, visual aids improve risk comprehension by increasing the likelihood that less numerate people deliberate on the available risk information.²⁷ Deliberation tends to be important for problem solving because it promotes more thorough, complex, and durable information representations in long-term memory—an important component of risk comprehension.¹²³ By influencing memory encoding and representation, visual aids also give rise to enduring changes in attitudes and behavioral intentions, which in turn affect behavior and risky decision making. Thus visual aids can improve decision making and help promote healthy behavior by improving understanding, establishing enduring attitudes and fostering intentions to perform the behavior.⁸⁶⁻⁸⁸

Some caution is warranted because we have also learned ways in which visual aids are limited or can be misused.^{82,124,125} For example, visual aids can increase overestimates of low probabilities and underestimates of high probabilities (i.e., the magnifier effect¹²⁶). However, the opposite effect (i.e., less overestimation) on low probabilities and no effect on high probabilities have also been described.¹²⁷ In addition, numerical representations can be better suited than visual aids to convey precise aspects of the information (e.g., detailed-level information), whereas visual aids have been shown to be best suited to convey

essential aspects of the information (i.e., gross-level information^{72,73}). Thus, a potential concern when using visual aids is that people might focus more on the pattern of data than the precise values. Finally, specific visual aids are better suited for certain tasks (e.g., line graphs for trends over time and bar graphs for comparison across groups).^{75,77,78} Therefore, risk communicators should avoid using misleading visual aids by validating their graphs and materials before conducting an intervention.⁷⁰

Where Do We Go Next?

Although there is a growing body of work that sheds light on why visual aids improve judgment and decision making in people with limited numerical skills, more research is needed. Future studies should investigate the cognitive processes that underlie differences in graph understanding in people with different levels of numeracy and graph literacy.¹²⁸ Theories of mathematical cognition^{3,129,130} and graph comprehension¹³¹⁻¹³³ can provide a foundation for this understanding. To model underlying individual differences in cognitive processing of visually represented health risks, studies recording people's cognitive processes including their eye movements and decision latencies while exploring graphs can be particularly useful.^{101,102}

Future research can also explore age-related changes in numeracy and graph literacy throughout the life-span,^{134,135} as well as the role of cultural factors in the development of these skills.² What are the developmental precursors of limited numeracy and graph literacy? Is the nature of limited numeracy and graph literacy in older adults different from that in younger populations?⁸⁹ Future studies should also identify suitable strategies for communicating health risks to people who are neither graph literate nor numerate. For example, ongoing work using analogies from people's everyday lives shows that these

analogies are relatively undemanding in terms of numeracy and graph literacy, and may be useful for promoting more custom-tailored risk communication.¹³⁶ However, to identify strategies for communicating health risks to people who are neither graph literate nor numerate, we will need to refine our theoretical understanding of the underlying cognitive mechanisms of risk perception.^{137,138}

Modifying risky behavior is difficult. To the extent that our results generalize, visual aids offer a relatively efficient means of reaching other vulnerable individuals, such as children, people in the criminal justice system, people with mental illnesses, and people in rural and inner-city areas. For example, visual aids could provide low-cost supplements for individual, community-based, or school-based interventions with potentially long-lasting effects. To maximize potential benefits, more research on these groups and other applications of visual aids is needed, as are more prospective studies investigating the comparative effects of visual aids in the long run (e.g., years after interventions).

Looking forward, risk communication will increasingly be integrated with information technology. There are well established standards for the construction of decision aids,⁶⁹⁻⁷¹ and theories of numeracy and graph literacy are now starting to be embodied in adaptive instruments and software. Some such programs provide free online tools allowing anyone to build better graphs (e.g., www.iconarray.com). Other online programs provide fast, free, validated assessments of numeracy and risk literacy for use by researchers and the public alike (e.g., www.RiskLiteracy.org; see also GraphLiteracy.org available summer 2015). The use of similar instruments may eventually help health care professionals quickly assess individual differences in numeracy, with only a couple of questions (see the Berlin Numeracy Test¹¹ for an example). Adaptive, internet-based tutoring programs and custom-tailored educational brochures are also under development. These interactive educational

and decision aid technologies hold great promise for leveraging what we already know about communicating risk and supporting informed decision making.

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Figure captions

Figure 1. A causal framework about the effects of numeracy on prevalence of comorbidity and the mediating effect of accuracy of perceptions of benefits and risks and quality of interactions with physicians.

Figure 2. Examples of transparent visual aids. A pie chart reports the proportion of deaths by cause of death (a). Icon arrays represent benefits and side effects of a medical treatment and a placebo (b). A bar chart compares the efficacy of two medical treatments (SBP = systolic blood pressure; DBP = diastolic blood pressure) (c). A visual grid is used to help infer the predictive value of mammography screening (d). A line plot compares the efficacy of several therapies (e). Icon arrays are used to communicate treatment-risk reduction (f). Pictograms report dosage, timing, and action information about prescribed medications (g).

Figure 3. Percentage of participants with low and high numeracy and low and high graph literacy who correctly inferred treatment risk reduction, by visual aids condition. In the visual aids condition, icon arrays and bars reported the entire population at risk. Error bars represent one standard error.

Figure 4. Icon arrays representing a treatment risk reduction of 50% with equal (a) and different (b) samples of treated and nontreated individuals. Affected individuals are represented in dark grey. Healthy individuals are represented in light grey.

Figure 5. Percentage of participants with low and high numeracy who correctly inferred treatment risk reduction, by visual aids condition when the risk information was reported using equal and different samples of treated and nontreated individuals. Error bars represent one standard error.

Figure 6. Percentage of participants who made accurate diagnostic inferences, by visual aids condition, numerical format, and type of participant. Error bars represent one standard error.

Table 1. Characteristics of effective visual aids.

Keep Information Simple and Focused on Essentials⁷²

- Only visually represent important information: Graphs have been shown to be best suited to convey essential aspects of the information (i.e., “gross-level information”), bottom line meaning, or gist.^{66,73-75} Focus on the two or three key messages that you would like to communicate.^{70,72}
- Keep visual aids simple (e.g., avoid using shadows and truncated scales, use clear captions and titles, use the same scale for comparison).^{66,69}
- Use friendly, simple language to describe the visual information and translate the materials into the target’s language.⁷⁶

Identifying the Goal of the Communication Helps Identify the Best Type of Visual Aid^{67,71,77}

- Use bar graphs to compare several data points.^{71,77,78}
- Use line graphs to depict trends over time.^{71,77,78}
- Use grids to depict very large numbers.¹⁸
- Use a magnifier risk scale (including a magnifying lens) to depict very small numbers.⁶⁷
- Use icon arrays to communicate treatment risk reduction and risk of side effects.^{38,79} To improve risk understanding...
 - Represent results of the baseline risk (i.e., sample of nontreated individuals) and the incremental/reduced risk due to treatment (i.e., sample of treated individuals) using different icon arrays.^{38,80,81}
 - Depict the entire population at risk rather than only depicting the number of affected individuals.^{38,79}
 - Arrange icon arrays as groups in a block rather than in a random scattering.^{73,82}
 - Keep the size of denominators (i.e., entire population at risk) in the treated and nontreated groups of individuals constant for comparison.^{80,81,83}

Depict Numerical Information in Addition to Visual Aids⁷¹

- Pay attention to the frame of the numerical information. Depict the numerical information...
 - In absolute rather than relative risks.^{38,84}
 - Using both positive and negative frames.^{31,85,86-88}
 - Keeping time frames constant.⁷¹

Table 1. Characteristics of effective visual aids (cont')**Take Individual Differences into Account**^{2,38,66}

- Learn about your target group and use the appropriate reading level (e.g., 5th grade v. 11th grade).^{76,89}
- Visual aids are especially useful for people with relatively low numeracy, those with limited knowledge about medical facts, and people with low levels of education.^{27,38,80,87-91}
 - Objective and subjective numeracy scales can help quickly identify individuals with low and high numeracy.^{4,5,10,11,13,14,92-94}
- People vary in their ability to extract data and meaning from visual aids (i.e., graph literacy).^{38,83,95-97}
 - To improve risk understanding in people with low graph literacy, encourage active, elaborative information processing by including reflective questions about the visual information, followed by accuracy feedback. Use additional labels and simple explanations to convey the meaning of important information in the visual aid.⁹⁸
 - If this strategy is not feasible...
 - Use visual aids only with people who have moderate-to-high levels of graph literacy. People who lack basic graph literacy may be better off with mere numbers.^{70,89,99}
 - Objective and subjective graph literacy scales can help quickly identify individuals with low and high graph literacy.^{96,97}

Validate Visual Aids Before Conducting an Intervention^{66,70,71,100}

- Validate visual aids before conducting an intervention by soliciting feedback and conducting usability studies including cognitive process tracing (e.g., eye-tracking, verbal protocols).^{101,102}
- Involve the target audience in the design, evaluation, and dissemination of visual aids.^{71,103}

Figure 1

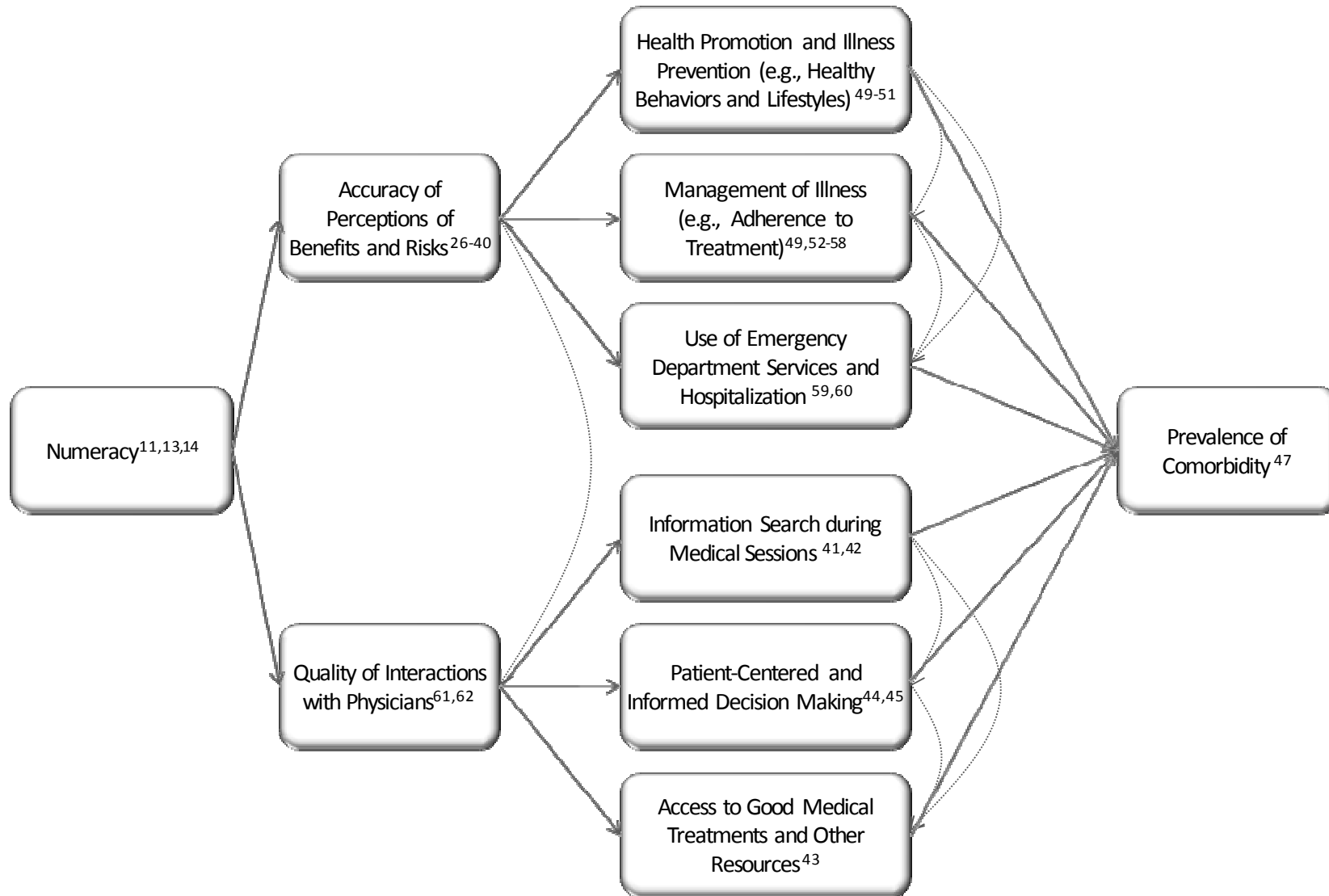


Figure 2

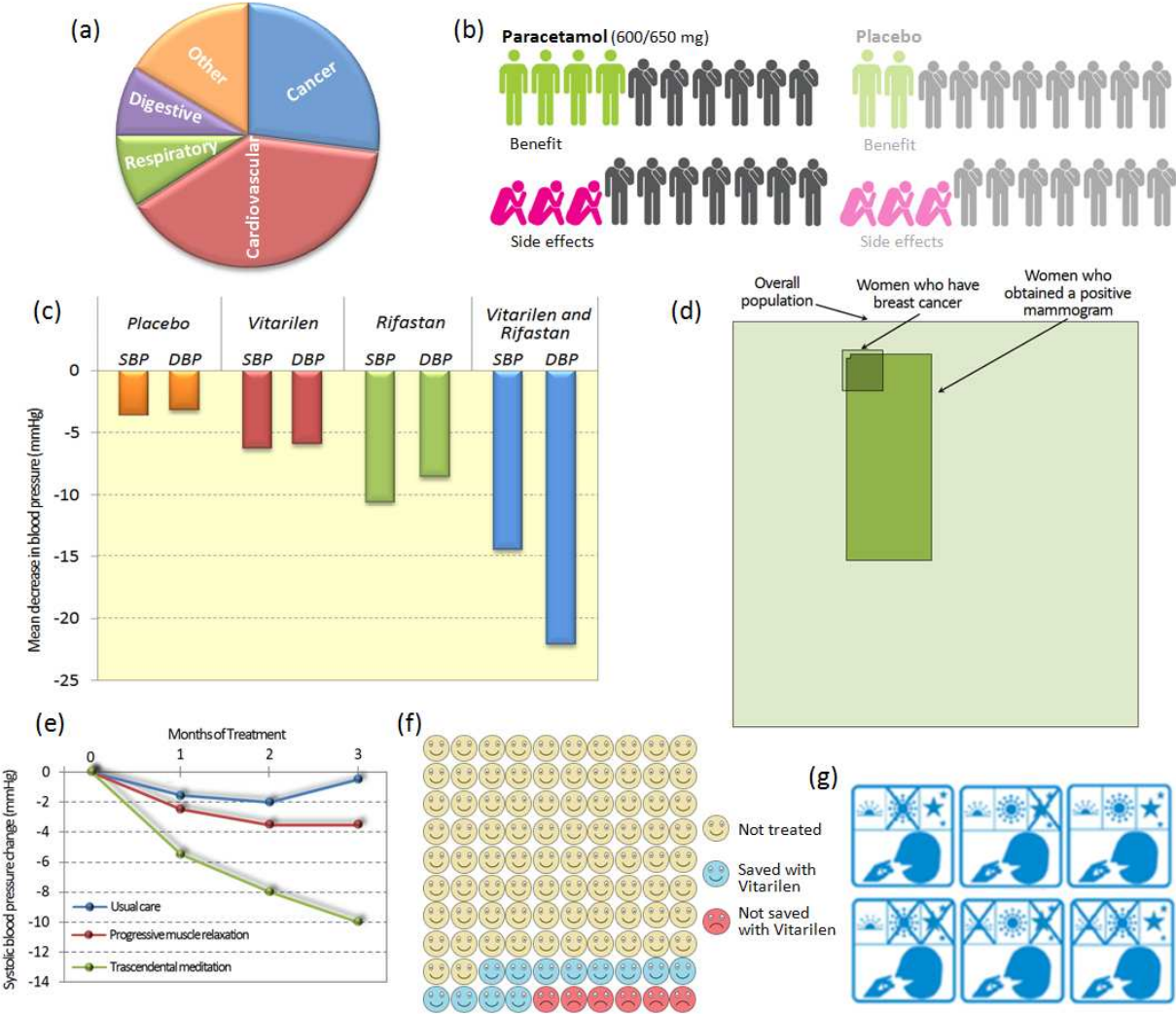


Figure 3

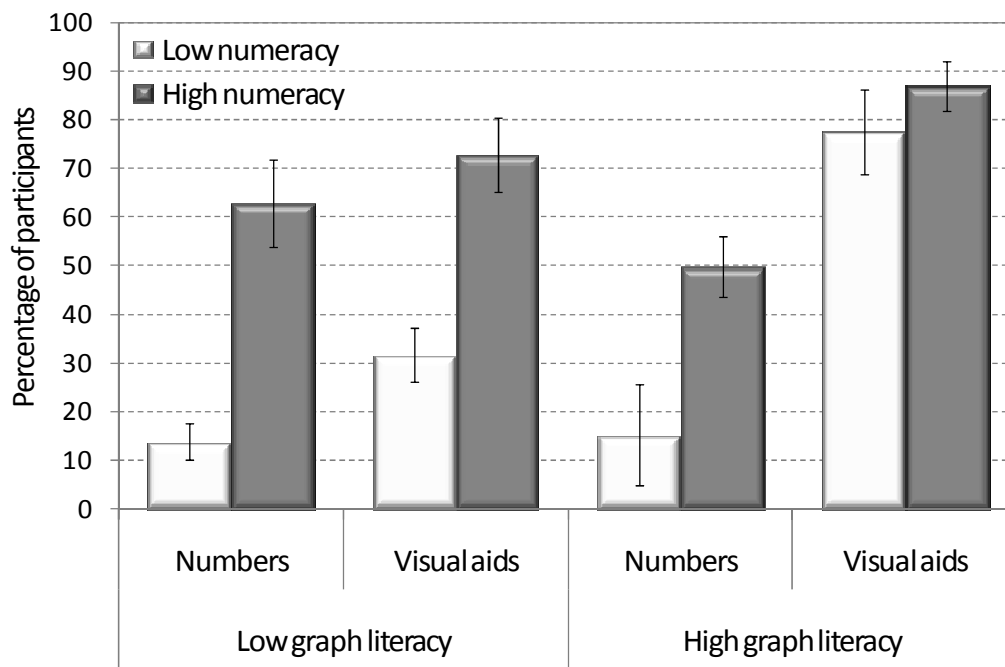


Figure 4

(a)

Treated individuals



Nontreated individuals



(b)

Treated individuals



Nontreated individuals

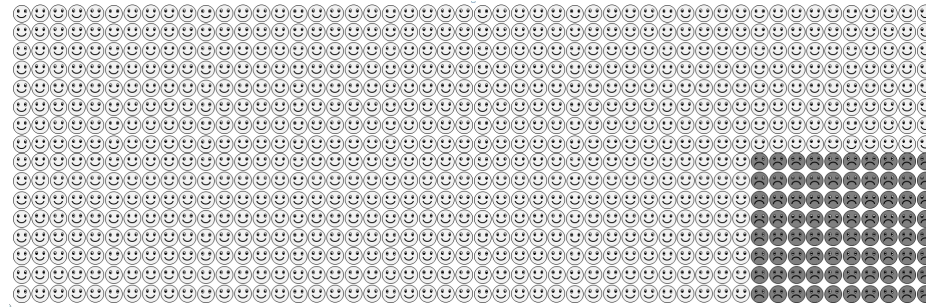


Figure 5

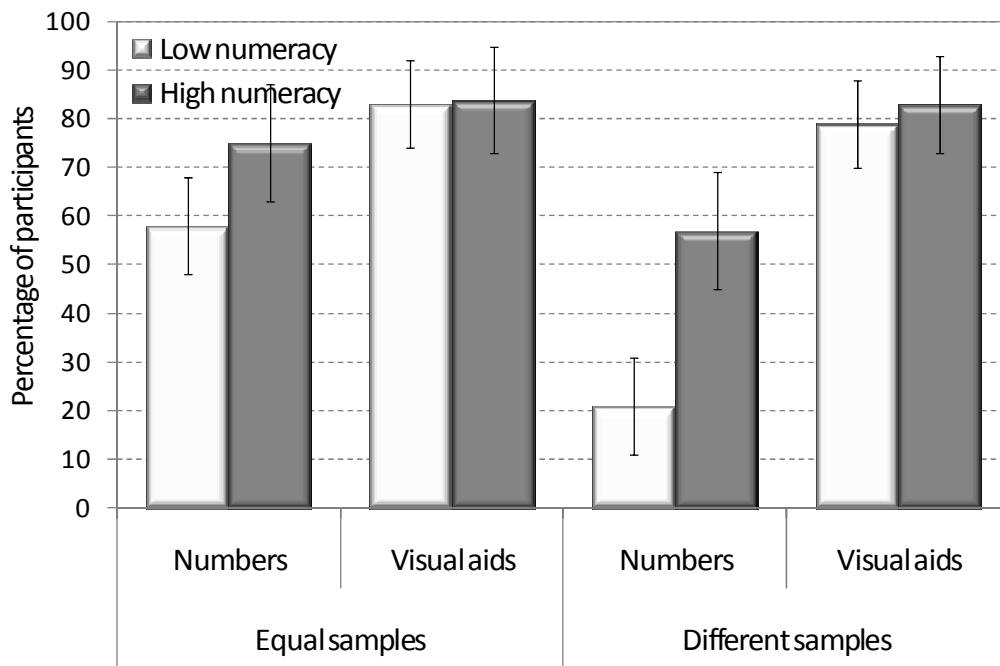


Figure 6

