**Article:**

Okan, Y orcid.org/0000-0001-7963-1363, Janssen, E, Galesic, M et al. (1 more author) (2019) Using the Short Graph Literacy Scale to Predict Precursors of Health Behavior Change. Medical Decision Making, 39 (3). pp. 183-195. ISSN 0272-989X

https://doi.org/10.1177/0272989X19829728

Running Head: SHORT GRAPH LITERACY SCALE

Manuscript accepted for publication in Medical Decision Making

# Using the Short Graph Literacy scale to predict precursors of health behavior change

Yasmina Okan, PhD [1] Eva Janssen, PhD [2] Mirta Galesic, PhD [3,4] Erika A. Waters, PhD [5]

[1]Centre for Decision Research, Leeds University Business School, University of Leeds, Charles Thackrah Building, Leeds, LS2 9LB, United Kingdom; E-mail: y.okan@leeds.ac.uk, Phone: +44 113 343 2622

[2] Department of Work and Social Psychology, Faculty of Psychology and Neuroscience, Maastricht University, P.O. Box 616, 6200 MD Maastricht, The Netherlands; E-mail: eva.janssen@rivm.nl

[3] Santa Fe Institute, 1399 Hyde Park Road, Santa Fe, NM 87501, United States, E-mail: galesic@santafe.edu

[4] Harding Center for Risk Literacy, Max Planck Institute for Human Development, Lentzeallee 94, 14195 Berlin, Germany

[5] Washington University School of Medicine, Division of Public Health Sciences, 660 S. Euclid Ave, Campus Box 8100, Saint Louis, MO 63110, United States, E-mail: waterse@wustl.edu

Corresponding author: Yasmina Okan. Financial support for this work was provided by the U.S. National Cancer Institute (R01CA190391; UL1TR000448), the Informed Medical Decisions Foundation, and the Worldwide Universities Network (Fund for International Research Collaborations). Yasmina Okan's time was in part supported by a Population Research Fellowship awarded by Cancer Research UK (C57775/A22182). The funding agreements ensured the authors' independence in designing the study, interpreting the data, writing, and publishing the report. This work was presented at the 17th Biennial European Conference of the Society for Medical Decision Making and the 38th Annual Conference of the Society for Judgment and Decision Making.

**Abstract**

Background: Visual displays can facilitate risk communication and promote better health choices. Their effectiveness in improving risk comprehension is influenced by graph literacy. However, the construct of graph literacy is still insufficiently understood, partially because existing objective measures of graph literacy are either too difficult or too long. Objectives: We constructed a new 4-item Short Graph Literacy (SGL) scale and examined how SGL scores relate to key cognitive, affective, and conative precursors of health behavior change described in common health behavior theories. Methods: We performed secondary analyses to adapt the SGL scale from an existing 13-item scale. The initial construction was based on data collected in a laboratory setting in Germany (n=51). The scale was then validated using data from nationally representative samples in Germany (n=495) and the United States (n=492). To examine how SGL scores relate to precursors of health behavior change, we performed secondary analyses of a third study involving a nationwide US sample comprised of 47% racial/ethnic minorities and 46% with limited formal education (n=835). Results: Graph literacy was significantly associated with cognitive precursors in theoretically expected ways (e.g., positive associations with risk comprehension and response efficacy, and a negative association with cognitive risk perception). Results for affective precursors generally mirrored those for cognitive precursors, although numeracy was a stronger predictor than graph literacy for some affective factors (e.g., feelings of risk). Additionally, graph literacy (but not numeracy) predicted key conative precursors such as defensive processing. Conclusions: Our data suggest that the SGL scale is a fast and psychometrically valid method for measuring objective graph literacy. Our findings also highlight the theoretical and practical relevance of graph literacy.

Keywords: Visual aids; risk communication; risk perception; health behavior; individual differences; graph literacy

Simple graphical displays such as bar graphs or icon arrays can represent risk information in accessible ways, often helping to overcome widespread difficulties in understanding numerical concepts [1,2]. Accordingly, graphical displays are increasingly used and recommended to communicate health risks [3–5], support informed medical decision making, and promote risk-avoidant behaviors e.g., [6]. Yet, individuals with low graph literacy—the ability to understand graphically-presented information [7]— benefit to a lesser extent from graphical displays than individuals with high graph literacy. For instance, graph literacy can moderate the effectiveness of graphical displays in improving health risk comprehension [1,8,9], promoting health-management tasks [10] and healthy behaviors [11,12]. Graph literacy is associated with doctors' and patients' self-reported use of graphs to communicate health risks to others [13] and use of health portals containing graphs [12].

Despite these findings, the construct of graph literacy is insufficiently understood. There is evidence that low graph literacy is generally associated with reduced attention to decision-relevant information in graph titles, axes labels, and scales, as well as with stronger reliance on salient spatial features such as heights of bars [14,15]. However, extant research focused primarily on assessing how this construct relates to a limited number of cognitive outcomes such as comprehension of graphically presented health information [1,8,9,14–17] and user evaluations of graphical displays such as perceived helpfulness and attractiveness [8,18,19]. It remains unclear how graph literacy relates to other key cognitive as well as affective and conative precursors of behavior change described in several theories of health behavior [20,21], including cognitive risk perception, feelings of risk, and behavioral intentions. In addition, only a few studies [12,16,17] have assessed whether graph literacy is independent of numeracy—the ability to understand and manipulate different numerical expressions of probability. Yet, numeracy can also affect processing and comprehension of graphically presented risks [22,23], and numeracy and graph literacy are moderately correlated [7].

An impediment to a more thorough investigation of graph literacy is that existing measures are often too difficult or too long for the general population [24] [7]. This may discourage their use in research and medical practice [12], and make them difficult to implement in costly studies on representative samples. Indeed, previous studies have largely involved convenience samples of students [1,11,19,25] and people with high education [8,14,15,17], limiting the generalizability of findings. One solution could be to use a brief subjective graph literacy assessment that assesses people's self-reported ability to process and use graphically presented information [13]. However, subjective and objective assessments may measure different constructs [26,27], subjective measures typically capturing more motivational and emotional aspects [28].

In the current work we sought to improve understanding of the theoretical and practical relevance of the construct of graph literacy. Our first aim was to construct a short objective graph literacy scale, evaluate its psychometric properties, and compare its predictive validity to that of a longer 13-item scale [7]. Our second aim was to examine how graph literacy relates to key precursors of behavior change described in theories of health behavior and the risk perception and communication literature. Specifically, we sought to test hypotheses about the relationship of graph literacy to key cognitive, affective, and conative precursors of behavior change, while controlling for numeracy and socio-demographic factors that are related to graph literacy and numeracy (e.g., education) [7,29].

To achieve our first aim, we conducted secondary analyses of data collected in a laboratory setting in Germany [15] and probabilistic national samples in Germany and the US

[9]. For the second aim, we conducted secondary analyses of an experiment that examined how well different risk ladders (i.e., vertical bar graphs) conveyed the importance of physical activity for reducing the risk of several diseases to a nationwide US sample [30]. Data for the two studies relating to the first aim can be obtained from the first author, and data for the study relating to the second aim can be obtained from the last author.

**Cognitive, affective, and conative precursors of behavior change**

Research has distinguished among three categories of attitudinal precursors of behavior change: cognitive factors (i.e., thoughts, beliefs and knowledge about the behavior), affective factors (i.e., feelings, moods, or emotional responses to the behavior), and conative factors (i.e., action tendencies, intentions, and dispositions towards the behavior; self-monitoring and self-assessment related to the behavior [31–33]). We use this tripartite distinction to explore how graph literacy relates to key precursors of behavior change.

**Cognitive precursors.** We examined six cognitive precursors of behavior change. Three originate from the Health Action Process Approach model (HAPA) [20], which includes factors common to several key health behavior theories [21,34,35]. HAPA states that motivation to act stems from a combination of cognitive risk perceptions (i.e., people's opinion concerning the likelihood that they will be affected by the risk), perceived severity of the potential disease, and response efficacy (i.e., believing that engaging in a given behavior will reduce risk). Two additional key cognitive precursors originate from the risk perception and communication literature; risk comprehension [36] and message acceptance (i.e., user evaluations of the communications [37,38]). Finally, we examined uncertainty about cognitive risk perceptions, reflected by answering "don't know" to cognitive risk perception items. These responses are more common among individuals with lower education, lower numeracy and who have lower engagement in some cancer prevention and detection behaviors [39–41]. Thus, examining such responses enables obtaining critical data about individuals who may be most vulnerable to poor health outcomes.

Just as difficulty interpreting numerical information often promotes overestimations of risk [42], confusion about graphically presented information may also result in higher risk perceptions. Thus, we expected that graph literacy would be negatively related with cognitive risk perceptions. We did not have any hypothesis concerning the link between graph literacy and perceived severity, given the absence of relevant literature. We expected a positive link with response efficacy for graphs including risk reduction information, as the ability to comprehend this information should increase the belief that physical activity reduces the risk of the diseases depicted. We also expected that graph literacy would be positively associated with risk comprehension and message acceptance, as these factors are related to the ability to extract and comprehend information in graphical displays [15,25]. Finally, we expected a negative link between graph literacy and uncertainty about cognitive risk perception, as “don’t know” responses can reflect difficulties with processing risk information [39,40].

**Affective precursors.** Although cognitive and affectively-laden beliefs about health risks are correlated, affective factors make independent contributions to health behavior [43–45]. Based on the risk perception and communication literature, we assessed feelings of risk (i.e., how people report feeling about their risk), worry (i.e., people’s concerns about a particular risk) and anticipated regret (i.e., how regretful people think they would feel if a disease occurred due to their risk behavior). Additionally, we assessed uncertainty about feelings of risk (i.e., whether people know how they feel about their risk), equivalent to the uncertainty about cognitive risk perception discussed above.

Difficulties interpreting numerical information can promote not only overestimation of risks (as noted earlier), but also negative affective responses to the risk [42]. Similarly, confusion about graphically presented risks may promote negative affect. Hence, we reasoned that graph literacy may be negatively related with feelings of risk and worry. However, it is also possible that misunderstanding of graphically presented risks will not translate into corresponding feelings of risk or worry, as differences can exist between what people think and what they feel when dealing with risks [46,47]. We did not have any specific expectations concerning the relation between graph literacy and anticipated regret. Finally, we reasoned that graph literacy might be negatively related with uncertainty about feelings of risk, as accurate comprehension of the graph may also reduce the likelihood of "don't know" responses to items assessing feelings of risk.

**Conative precursors.** Conative factors can have a more proximal influence on health behavior change than cognitive and affective factors. Based on the HAPA model we assessed self-efficacy, which refers to a person's belief concerning their capability to execute a given behavior, and behavioral intentions [20]. We also explored defensive processing, which refers to the tendency to disregard or dismiss personally threatening health information [48]. Due to the absence of previous research, we conducted exploratory analyses to examine the relationships between graph literacy and conative factors.

## Aim 1 Methods

Detailed information about the parent study's methods and results can be found in Okan et al. [15], Galesic and Garcia-Retamero [7], and Garcia-Retamero and Galesic [9]. Here we provide a brief overview of the methods. Ethics approval for the collection of all data corresponding to Aim 1 was obtained from the Ethics Committee of the Max Planck Institute for Human Development, Berlin, Germany.

**Initial construction**

Participants (n=51) were recruited between January 1 and January 31, 2013 from the respondent pool of the Max Planck Institute for Human Development in Berlin (39% male, average age 25.2 years, age range 18-38 years). Participants completed a 13-item graph literacy scale [7] and 4 additional items from other scales. The original 13-item scale had satisfactory psychometric properties (i.e., reliability, validity, discriminability; see [7] for further details). Participants with a variety of graph literacy scores were invited one week later to complete a questionnaire including 16 items involving complex visual displays, items assessing numeracy, and self-reports of careless responding [49], including effort expended in the study (‘I put forth ____ effort towards this study’), attention (‘I gave this study ____ attention’), diligence answering the graph items (e.g., ‘I carefully read every item’), and interest (e.g., ‘I care about my performance in this study’). All the complex visual displays had health-related content and included spatial features, such as height of bars, that were incongruent with the information conveyed by conventional features, such as titles, labels, and scales. To select items for the SGL scale, we used four criteria: correlations of each item with 1) the total score on the 13-item scale, 2) comprehension of the 16 complex visual displays, and 3) numeracy (low-to-medium correlations); as well as 4) discrimination rate of each item (percentage correct answers). We also included items reflecting different types of graphs that are often used in health communications (bar, line, pie chart, and icon array). The application of these criteria resulted a total of four items.

**Validation**

The selected items were used in a second study to predict accuracy of understanding health risk information presented numerically vs. numerically plus different types of visual aids (bar charts and icon arrays). This second study was conducted on probabilistic national samples of people 25 to 69 years of age in Germany (n=495) and the United States (n=492) and included the full graph literacy scale [9]. Of the 4 SGL scale items, participants solved on average 2.2 correctly (SD=1.12) in the U.S. and 2.0 (SD=1.10) in Germany.

## Aim 1 Results

### Psychometric properties

Scores of all items from the 13-item scale on the four criteria outlined above are shown in Table 1. Figure 1 shows the four items that achieved balanced scores on all criteria and were selected for the SGL scale. The items can be downloaded from the Open Science Framework at https://doi.org/10.17605/OSF.IO/FRJBQ. Each of the four items involves a different type of display, covering the range of displays most often used to communicate health related information [50]. The items have satisfactory psychometric properties: the correlation between the total scores on the short and long scale was r=.90, suggesting good construct validity, and r=.44 with comprehension of complex items, indicating reasonable predictive validity. Correlations with items assessing self-reported carelessness were low, indicating discriminant validity (effort: r=.05; attention: r=.03; diligence: r=–.14; interest: r=–.04). SGL scale scores were weakly to moderately correlated with numeracy scores (basic numeracy: r=.29; advanced numeracy: r=.38). Cronbach's alpha was .53, which should be expected from a four–item scale that purposively varied the type of graph and graph comprehension skills required [7]. The average inter-item correlation was .21, indicating an acceptable level of internal consistency [51,52]. The SGL scale took 3 minutes to complete on average, whereas the long version took 10 minutes. Distributions of SGL scores in all three studies reported in this paper are shown in Table 2.

<Figure 1>

<Table 1>

<Table 2>

**Predictive validity of the SGL vs the 13-item scale**

We investigated how the SGL scale compares with the full scale [7] in predicting accuracy of risk understanding with or without visual aids. Following the original analysis of Garcia-Retamero and Galesic [9], graph literacy and numeracy subgroups were defined according to the sample's median scores in each scale. In an ANOVA with presence vs. absence of visual aids, graph literacy, numeracy, and country as between-participant factors, we found a significant interaction between visual aids and graph literacy for both the full scale, $F(1,978)=8.99$, $p=.003$, and the SGL scale, $F(1,978)=7.74$, $p=.005$ (see full results in the online Supplementary materials, Tables S1-S2), suggesting that participants with high graph literacy benefited more from visual aids. These results suggest that the SGL scale was able to recover the same patterns as the long scale, while taking substantially less time to complete.

## Aim 2 Methods

Detailed information about the parent study's methods and results can be found in [30]. We provide a brief overview of the methods below. Ethics approval for the collection of all data corresponding to Aim 2 was obtained from the Human Research Protection Office of the Washington University School of Medicine (IRB approval number 201501028).

**Participants**

Data for Aim 2 were collected from November 11 to December 7, 2015 using GFK KnowledgePanel®, an Internet survey panel designed to be representative of the U.S. population. GFK emailed an invitation to a randomly selected subsample of individuals from its English language database who were 30-65 years old. Eligible participants were required to obtain fewer than 150 minutes per week of moderate intensity aerobic physical activity because the parent study sought to encourage individuals who did not meet U.S. national physical activity guidelines [53]. Stratified recruitment was used to ensure sufficiently large samples of people with no college experience and of racial/ethnic minorities.

GfK invited 5926 individuals, and, although 3400 (57.4%) responded to the survey invitation, 1530 of those (45.0%) were ineligible. Of the remaining 1870 potential participants, 1161 agreed to participate (62.1%). Only the 835 individuals who completed all items needed for the analyses in this study and had survey completion times that fell between the 3rd and 97th percentiles are included in the analyses. Participants were on average 48.3 years old (SD=10.22) and 57.4% were female. Almost half of the sample had no college experience (46.4%) and 40.7% had an income below $50,000. 53.3% of the sample was non-Hispanic white, whereas 17.3% were non-Hispanic black, 12.6% were non-Hispanic other, and 16.9% were Hispanic.

**Procedure and Measures**

Participants were randomly assigned to one of 12 conditions in which risk ladders displayed hypothetical risk calculator results. The risk ladders varied orthogonally according to whether: (a) the risk information was presented as words or words and numbers, (b) risk reduction information was or was not present, and (c) participants were told that their risk was higher than average, much higher than average, or whether they were not provided any social comparison information. The ladder with the most extensive information is shown in Figure 2. All ladders can be found in the supplementary material to [30].

<Figure 2>

Next, participants completed items assessing precursors of behavior change in the following order: risk comprehension [54], message acceptance [37], self-efficacy, cognitive risk perceptions [55], feelings of risk (adapted from [56]), worry [55], perceived severity, response efficacy [24], anticipated regret (adapted from [57]), behavioral intentions [58], and defensive processing (adapted from [48]). To reduce participant burden, items focused either on colon cancer specifically (for risk comprehension) or on colon cancer and “any of the diseases shown in the picture.” Other psychosocial variables were assessed but were not included in the present analyses because they were outside the scope of the research question. Finally, participants completed the SGL scale, two numeracy items adapted from the scale developed by Schwartz et al. [29], and demographic questions (gender, age, education, income, and racial and ethnic background). Two out of the three numeracy items included in the scale developed by Schwartz and colleagues were selected considering insights from cognitive interviews, to avoid participant burden. Similarly, minor changes were made to simplify the wording and sentence structure of items assessing graph literacy. For instance, “forms of cancer” was expressed as “types of cancer”. The exact wording of all items used to assess graph literacy, numeracy, and precursors of behavior change can be found in online Supplementary materials (Table S3). The full questionnaire can be obtained from the last author.

**Statistical analyses**

We used hierarchical regressions to examine the relationship of graph literacy with cognitive, affective, and conative precursors of behavior change. Graph literacy was entered in the first block, followed by numeracy in the second block, to examine the additional contribution of numeracy to the prediction of each precursor. Socio-demographics (gender, age, education, racial/ethnic background, and income) were entered in the third block. Graph literacy scores did not vary across the three experimental manipulations tested in [30] (all Fs<1, all ps>.5), so we collapsed all 12 experimental conditions for the analyses, with the exception of an additional analysis for response efficacy, described below. Analyses were conducted using SPSS 24.0.

## Aim 2 Results

The average graph literacy score was 2.2 (SD=1.10; range 0-4) and the average numeracy score was 1.3 (SD=0.76; range 0-2). Table 2 provides details about the distribution of scores. Graph literacy was higher among people with higher education and people with higher income. It was also slightly higher among men (Table 3). Differences in graph literacy were also found among people with different racial/ethnic backgrounds, but graph literacy and age were not correlated. The online Supplementary materials include descriptive statistics for all outcomes (Table S4) and full regression results (Tables S5-S7).

<Table 3>

### Cognitive precursors

As can be seen in Table 4, the first step of the linear regression showed that, as expected, graph literacy was positively associated with risk comprehension, message acceptance, and response efficacy. Also as expected, graph literacy was negatively associated with cognitive risk perception, uncertainty about cognitive risk perception, and perceived severity. Adding numeracy in the second step significantly improved predictions of all cognitive precursors except cognitive risk perception and response efficacy. There was still an independent contribution of graph literacy on all cognitive outcomes except message acceptance, which did not reach conventional levels of significance in this step. For other outcomes (e.g., risk comprehension) the effect of graph literacy was smaller after adding numeracy, but remained significant (Tables S5a and S5b in Supplementary materials). Adding socio-demographic factors only improved predictions for response efficacy and perceived severity, and the effect of graph literacy remained significant for both of these precursors (Table 4). Of note, the relationship between graph literacy and response efficacy did not vary significantly depending on whether risk reduction information was depicted in risk ladders, contrary to our expectations. This was seen in an additional analysis where the interaction term between graph literacy and presence vs. absence of risk reduction information was added following the first step of the regression, $\beta$=.19, t=1.44, p=.15.

**Affective precursors**

As anticipated, graph literacy was negatively associated with feelings of risk, worry, and uncertainty about feelings of risk. In contrast, no relation was found between graph literacy and anticipated regret (Table 4). Numeracy significantly improved predictions of all affective precursors except for anticipated regret. After numeracy was added there was still an independent contribution of graph literacy on uncertainty about feelings of risk and worry, but not on feelings of risk. Adding socio-demographic factors improved predictions for anticipated regret and worry and eliminated the independent contribution of graph literacy for worry.

**Conative precursors**

Graph literacy was positively associated with behavioral intentions and negatively associated with defensive processing. No relationship was found with self-efficacy. Numeracy did not improve predictions of any of the conative precursors, whereas socio-demographic factors improved predictions of all conative precursors (Table 4). After adding socio-demographics, the independent contribution of graph literacy still existed for defensiveness, and the effect size remained unchanged (Table S7 in Supplementary materials). However, the relation between graph literacy and behavioral intentions no longer reached conventional levels of significance after adding socio-demographics.

<Table 4>

## Discussion

The first two studies in this paper demonstrate that the new SGL scale demonstrates sufficient construct, discriminant, and predictive validity to be used in future research studies that prioritize minimizing participant burden. The third study demonstrates that graph literacy, as measured by the SGL scale, is associated with key cognitive precursors of behavior change in theoretically expected ways among participants with a wide range of education levels and racial/ethnic backgrounds. Furthermore, it provides the first evidence that graph literacy is related to some key affective and conative precursors. It also demonstrated that graph literacy has predictive value for most cognitive and affective precursors beyond numeracy, and that graph literacy (but not numeracy) was associated with conative factors.

### Implications for health risk communication practice and research

Our short objective graph literacy scale provides a quick and simple method to identify individuals who may be at risk of misinterpreting commonly used graphical health risk communications. Our findings suggest that low graph literacy may have far-reaching consequences that extend beyond limited understanding of risk information, and that may ultimately affect key health outcomes. Identifying individuals with low graph literacy enables tailoring graphical health risk communications. For instance, communications targeted at less graph literate individuals can include simple graph design features such as explanatory labels

([16]; see [4] for a review of custom-tailored graphical risk communications). Additionally, our work highlights the relevance of assessing graph literacy in studies on graphical health risk communication and decision making, as key outcomes may be affected by this skill. Our scale provides a feasible and concise method for researchers to do so while reducing the time burden associated with longer scales, and potential detrimental impact on data quality.

The finding that graph literacy independently predicts some key precursors of health behavior (above and beyond effects of numeracy) also highlights the importance of developing methods that can support the development of graph literacy from an early age. Fortunately, ongoing work is developing promising online tutors for diverse adults that provide training on the foundations of graph literacy, including the selection and design of graphs that are common in risk communications [59]. Such efforts should be complemented by the implementation of programs that lay strong foundations of graph literacy among young students.

That the relationships between graph literacy and two health behavior change precursors (i.e., worry and behavioral intentions) could be partly explained by sociodemographic factors suggests that graph literacy may be a proximal indicator of social and environmental influences that are more challenging to intervene upon than graph literacy. Thus, our findings also highlight the need for educational programs that are accessible and relevant to people of diverse life experiences and backgrounds.

**Mechanisms underlying the association of graph literacy with precursors of behavior change**

The positive relation documented between graph literacy and both risk comprehension and message acceptance supports the notion that this skill facilitates the extraction and comprehension of graphically presented information [15,17]. More efficient processing of graphical displays may not only help more graph literate participants to understand the information objectively better, but also to perceive it as more compelling. Of note, however, previous studies have shown that  graph literacy is not always related to user evaluations [8][16,23]. Future work could hence examine whether links between graph literacy and user evaluations depend on specific graph types and/or design features.

In our study graph literacy was also positively related with response efficacy, regardless of whether risk reduction information was presented to participants. An accurate understanding that the risk of suffering diseases without exercise was moderate to very high may have overall contributed to the belief that physical activity would reduce such risks. Graph literacy was also negatively related to cognitive risk perceptions (in bivariate analyses), and to perceived severity of the diseases. These findings expand previous work documenting negative links between numeracy and risk perception [60–62], and show that confusion about the meaning of graphically presented risks may result in overestimations of such risks, independently of numeracy. Perceived risk, in turn, is often related to perceptions of severity of the consequences of a hazard [63]. Additionally, our findings revealed that confusion about the meaning of graphically presented risks can also be associated with an increased likelihood of “don’t know” responses to items assessing risk perception.

Our results also suggest that difficulties comprehending graphically presented risks may in some cases have similar consequences on both people’s thoughts and feelings about the risks. Indeed, results of bivariate analyses for affective precursors overall mirrored those for cognitive precursors, where analogous outcomes existed (i.e., feelings of risk and uncertainty about feelings of risk). Of note, however, numeracy accounted for graph literacy’s predictive power for feelings of risk. People with high numeracy tend to derive a more precise affective meaning from numbers [42,64], perhaps explaining why numeracy played a stronger role for feelings of risk.

Finally, our findings also revealed new, interesting links with conative factors. More graph literate participants were less likely to disregard the importance of engaging in physical activity, as seen in results for the defensive processing measure. Better understanding of the risks among people with higher graph literacy may have reduced their resistance to engage in this recommended risk-reducing behavior. This may also account for the positive relation documented between graph literacy and willingness to engage in physical activity. However, as noted earlier, the effect of graph literacy on behavioral intentions no longer reached conventional levels of significance after controlling for socio-demographic factors. Factors such as educational level may affect both graph literacy and intentions to engage in recommended behaviors. Future research could further explore these interrelationships as well as their practical importance.

**Limitations and future research**

Our findings should be evaluated in the context of several limitations. First, only two items were used to assess numeracy in our study investigating precursors of behavior change. Although these items were adapted from a well-established numeracy scale [29], future work should examine the predictive power of numeracy vs. of graph literacy for precursors of health behavior using a different numeracy scale. Second, in our study of precursors of behavior change, participants viewed only a risk ladder. This type of graph is used and recommended to improve risk understanding and promote behavior change, and it relates to other common formats such as bar graphs in that it uses height to represent risk likelihood [5]. Although we have no clear reason to expect that links between graph literacy and precursors of health behavior change will vary depending on the type of graph used to depict risks, future work could examine this issue. Third, it is worth noting that one of the SGL scale items is a pie chart, which is a graph format that is frequently used (Hallgreen et al.,2016), albeit not always recommended by experts (Spence, 2005). Finally, it should also be noted that some of the relationships documented between graph literacy and the precursors were relatively small. Although some of these may not be meaningful on an individual level, they may be relevant at the population level.

**Conclusions**

Our data suggest that the new 4-item SGL scale is a fast and psychometrically valid objective measure of graph literacy, capable of uncovering theoretically expected but previously untested links between graph literacy and key cognitive, affective, and conative precursors of health behavior. Our results highlight the theoretical and practical relevance of graph literacy for promotion of healthier choices and behaviors based on effective graphical risk communications.

**Acknowledgments**

We are grateful to Erich Petushek for preparing scalable vectorized images corresponding to the items in the Short Graph Literacy scale. We are also grateful to Brian Zikmund-Fisher for his valuable comments and suggestions.

**References**

1. Okan Y, Garcia-Retamero R, Cokely ET, Maldonado A. Individual differences in graph literacy: Overcoming denominator neglect in risk comprehension. J Behav Decis Mak. 2012;25:390–401.
2. Waters EA, Weinstein ND, Colditz GA, Emmons KM. Reducing aversion to side effects in preventive medical treatment decisions. J Exp Psychol Appl. 2007;13:11–21.
3. Garcia-Retamero R, Cokely ET. Designing visual aids that promote risk literacy: A systematic review of health research and evidence-based design heuristics. Hum Factors. 2017;59(4):582–627.
4. Lipkus IM. Numeric, verbal, and visual formats of convening health risks: Suggested best practices and future recommendations. Med Decis Making. 2007;27:695–713.
5. Trevena LJ, Zikmund-Fisher BJ, Edwards A, Gaissmaier W, Galesic M, Han PK, King J, Lawson ML, Linder SK, Lipkus I, Ozanne E, Peters E, Timmermans D, Woloshin S. Presenting quantitative information about decision outcomes: a risk communication primer for patient decision aid developers. BMC Med Inform Decis Mak. 2013;13:S7.
6. Stone ER, Sieck WR, Bull BE, Yates JF, Parks SC, Rush CJ. Foreground: background salience: Explaining the effects of graphical displays on risk avoidance. Organ Behav Hum Decis Process. 2003;90:19–36.
7. Galesic M, Garcia-Retamero R. Graph literacy: A cross-cultural comparison. Med Decis Making. 2011;31:444–457.
8. Gaissmaier W, Wegwarth O, Skopec D, Müller AS, Broschinski S, Politi MC. Numbers can be worth a thousand pictures: Individual differences in understanding graphical and numerical representations of health-related information. Health Psychol. 2012;31:286–96.

9. Garcia-Retamero R, Galesic M. Who profits from visual aids: Overcoming challenges in people's understanding of risks. Soc Sci Med. 2010;70:1019–1025.
10. Sharit J, Lisigurski M, Andrade AD, Karanam C, Nazi KM, Lewis JR, Ruiz JG. The roles of health literacy, numeracy, and graph literacy on the usability of the VA's personal health record by veterans. J Usability Stud. 2014;9(4):173–193.
11. Garcia-Retamero R, Cokely ET. The influence of skills, message frame, and visual aids on prevention of sexually transmitted diseases. J Behav Decis Mak. 2014;27:179–189.
12. Ruiz JG, Andrade AD, Hogue C, Karanam C, Akkineni S, Cevallos D, Anam R, Sharit J. The association of graph literacy with use of and skills using an online personal health record in outpatient veterans. J Health Commun. 2016;21(sup2):83–90.
13. Garcia-Retamero R, Cokely ET, Ghazal S, Joeris A. Measuring graph literacy without a test: A brief subjective assessment. Med Decis Making. 2016;36(7):854–867.
14. Okan Y, Garcia-Retamero R, Galesic M, Cokely ET. When higher bars are not larger quantities: On individual differences in the use of spatial information in graph comprehension. Spat Cogn Comput. 2012;12:1–25.
15. Okan Y, Galesic M, Garcia-Retamero R. How people with low and high graph literacy process health graphs: Evidence from eye-tracking. J Behav Decis Mak. 2016;29:271–294.
16. Dowding D, Merrill JA, Onorato N, Barrón Y, Rosati RJ, Russell D. The impact of home care nurses' numeracy and graph literacy on comprehension of visual display information: implications for dashboard design. J Am Med Inform Assoc. 2017;ocx042.
17. Nayak JG, Hartzler AL, Macleod LC, Izard JP, Dalkin BM, Gore JL. Relevance of graph literacy in the development of patient-centered communication tools. Patient Educ Couns. 2016;99(3):448–454.

18. Zikmund-Fisher BJ, Witteman HO, Dickson M, Fuhrel-Forbis A, Kahn VC, Exe NL, Valerio M, Holtzman LG, Scherer LD, Fagerlin A. Blocks, Ovals, or People? Icon Type Affects Risk Perceptions and Recall of Pictographs. Med Decis Making. 2014;34:443–453.

19. Okan Y, Garcia-Retamero R, Cokely ET, Maldonado A. Improving risk understanding across ability levels: Encouraging active processing with dynamic icon arrays. J Exp Psychol Appl. 2015;21:178–194.

20. Schwarzer R. Social-cognitive factors in changing health-related behaviors. Curr Dir Psychol Sci. 2001;10(2):47–51.

21. Witte K. Putting the fear back into fear appeals: The extended parallel process model. Commun Monogr. 1992;59(4):329–349.

22. Hess R, Visschers VH, Siegrist M. Risk communication with pictographs: The role of numeracy and graph processing. Judgm Decis Mak. 2011;6:263–274.

23. Kreuzmair C, Siegrist M, Keller C. High numerates count icons and low numerates process large areas in pictographs: Results of an eye-tracking study. Risk Anal. 2016;36(8):1599–1614.

24. Kramarski B, Mevarech ZR. Enhancing mathematical reasoning in the classroom: The effects of cooperative learning and metacognitive training. Am Educ Res J. 2003;40:281–310.

25. Shah P, Freedman EG. Bar and line graph comprehension: An interaction of top-down and bottom-up processes. Top Cogn Sci. 2011;3:560–578.

26. Liberali JM, Reyna VF, Furlan S, Stein LM, Pardo ST. Individual differences in numeracy and cognitive reflection, with implications for biases and fallacies in probability judgment. J Behav Decis Mak. 2012;25:361–381.

27. Waters EA, Biddle C, Kaphingst KA, Schofield E, Kiviniemi MT, Orom H, Li Y, Hay JL. Examining the Interrelations Among Objective and Subjective Health Literacy and Numeracy and Their Associations with Health Knowledge. J Gen Intern Med. 2018;1–9.
28. Peters E, Bjalkebring P. Multiple numeric competencies: When a number is not just a number. J Pers Soc Psychol. 2015;108(5):802.
29. Schwartz LM, Woloshin S, Black WC, Welch HG. The role of numeracy in understanding the benefit of screening mammography. Ann Intern Med. 1997;127:966–972.
30. Janssen E, Ruiter RA, Waters EA. Combining risk communication strategies to simultaneously convey the risks of four diseases associated with physical inactivity to socio-demographically diverse populations. J Behav Med. 2017;1–15.
31. Agapito D, Oom do Valle P, da Costa Mendes J. The cognitive-affective-conative model of destination image: A confirmatory analysis. J Travel Tour Mark. 2013;30(5):471–481.
32. Hilgard ER. The trilogy of mind: Cognition, affection, and conation. J Hist Behav Sci. 1980;16(2):107–117.
33. Tait-McCutcheon SL. Self-efficacy in mathematics: Affective, cognitive, and conative domains of functioning. In: Goos M, Brown R, Makar K, editors. Proceedings of the 31st Annual Conference of the Mathematics Education Research Group of Australasia. 2008. p. 507–513.
34. Becker MH. The Health belief model and personal health behavior. C. B. Slack; 1974. 172 p.
35. Rogers RW, Prentice-Dunn S. Protection motivation theory. In: Gochman DS, editor. Handbook of health behavior research I: Personal and social determinants. New York: Plenum Press; 1997. p. 113–32.

36. Weinstein ND. What does it mean to understand a risk? Evaluating risk comprehension. JNCI Monogr. 1999;1999(25):15–20.

37. Brennan E, Durkin SJ, Cotter T, Harper T, Wakefield MA. Mass media campaigns designed to support new pictorial health warnings on cigarette packets: Evidence of a complementary relationship. Tob Control. 2011;412–418.

38. McGuire WJ. Public communication as a strategy for inducing health-promoting behavioral change. Prev Med. 1984;13(3):299–319.

39. Hay JL, Orom H, Kiviniemi MT, Waters EA. “I don’t know” my cancer risk: Exploring deficits in cancer knowledge and information-seeking skills to explain an often-overlooked participant response. Med Decis Making. 2015;35(4):436–445.

40. Waters EA, Hay JL, Orom H, Kiviniemi MT, Drake BF. “Don’t know” responses to risk perception measures: implications for underserved populations. Med Decis Making. 2013;33(2):271–281.

41. Waters EA, Kiviniemi MT, Orom H, Hay JL. “I don’t know” my cancer risk: Implications for health behavior engagement. Ann Behav Med. 2016;50(5):784–788.

42. Peters E. Beyond comprehension: The role of numeracy in judgments and decisions. Curr Dir Psychol Sci. 2012;21:31–35.

43. Janssen E, van Osch L, Lechner L, Candel M, de Vries H. Thinking versus feeling: Differentiating between cognitive and affective components of perceived cancer risk. Psychol Health. 2012;27(7):767–783.

44. Moser RP, Mccaul K, Peters E, Nelson W, Marcus SE. Associations of perceived risk and worry with cancer health-protective actions data from the Health Information National Trends Survey (HINTS). J Health Psychol. 2007;12:53–65.

45. Brewer NT, DeFrank JT, Gilkey MB. Anticipated regret and health behavior: A meta-analysis. Health Psychol. 2016;35(11):1264–75.

46. Loewenstein GF, Weber EU, Hsee CK, Welch N. Risk as feelings. Psychol Bull. 2001;127(2):267–286.

47. Denes-Raj V, Epstein S. Conflict between intuitive and rational processing: When people behave against their better judgment. J Pers Soc Psychol. 1994;66:819–829.

48. McQueen A, Vernon SW, Swank PR. Construct definition and scale development for defensive information processing: An application to colorectal cancer screening. Health Psychol. 2013;32(2):190–202.

49. Meade AW, Craig SB. Identifying careless responses in survey data. Psychol Methods. 2012;17:437–455.

50. Hallgreen CE, Mt-Isa S, Lieftucht A, Phillips LD, Hughes D, Talbot S, Asiimwe A, Downey G, Genov G, Hermann R, Noel R, Peters R, Micaleff A, Tzoulaki I, Ashby D. Literature review of visual representation of the results of benefit–risk assessments of medicinal products. Pharmacoepidemiol Drug Saf. 2016;25:238–250.

51. Clark LA, Watson D. Constructing validity: Basic issues in objective scale development. Psychol Assess. 1995;7:309–319.

52. Streiner DL. Starting at the beginning: an introduction to coefficient alpha and internal consistency. J Pers Assess. 2003;80(1):99–103.

53. U.S. Department of Health and Human Services. Physical Activity Guidelines for Americans, 2008. 2008.

54. Tait AR, Voepel-Lewis T, Zikmund-Fisher BJ, Fagerlin A. The effect of format on parents' understanding of the risks and benefits of clinical research: a comparison between text, tables, and graphics. J Health Commun. 2010;15(5):487–501.

55. National Cancer Institute. Health Information National Trends Survey (HINTS) items for years 2003-2007. [Internet]. 2009 [cited 2018 Feb 28]. Available from: https://hints.cancer.gov/view-questions-topics/all-hints-questions.aspx

56. Janssen E, van Osch L, de Vries H, Lechner L. Measuring risk perceptions of skin cancer: Reliability and validity of different operationalizations. Br J Health Psychol. 2011;16(1):92–112.

57. Weinstein ND, Kwitel A, McCaul KD, Magnan RE, Gerrard M, Gibbons FX. Risk perceptions: assessment and relationship to influenza vaccination. Health Psychol. 2007;26(2):146–151.

58. Conner M. The theory of planned behaviour and health behaviours. In: Norman P, Conner M, Sparks P, editors. Predicting health behaviour. Philadelphia, PA: Open University Press; 1995. p. 121–162.

59. Ybarra VT, Cokely ET, Adams C, Woller-Carter M, Allan JN, Feltz A, Garcia-Retamero R. Training graph literacy: Developing the RiskLiteracy. org outreach platform. In: Gunzelmann G, Howes A, Tenbrink T, Davelaar E, editors. Proceedings of the 39th Annual Meeting of the Cognitive Science Society. 2017. p. 3566–3571.

60. Burns WJ, Peters E, Slovic P. Risk perception and the economic crisis: A longitudinal study of the trajectory of perceived risk. Risk Anal. 2012;32(4):659–677.

61. Davids SL, Schapira MM, McAuliffe TL, Nattinger AB. Predictors of pessimistic breast cancer risk perceptions in a primary care population. J Gen Intern Med. 2004;19(4):310–315.

62. Dieckmann NF, Slovic P, Peters EM. The use of narrative evidence and explicit likelihood by decisionmakers varying in numeracy. Risk Anal. 2009;29:1473–1488.

63. Slovic P, Fischhoff B, Lichtenstein S. Characterizing perceived risk. In: Kates W, Hohenemser C, Kasperson JX, editors. Perilous progress: Managing the hazards of technology. Boulder, CO: Westview; 1985. p. 91–125.

64. Petrova DG, van der Pligt J, Garcia-Retamero R. Feeling the Numbers: On the Interplay Between Risk, Affect, and Numeracy. J Behav Decis Mak. 2014;27(3):191–9.

Table 1. Scores of all items from the 13-item scale on the four criteria used to select items for the Short Graph Literacy (SGL) Scale, obtained in the initial construction sample (n=51). Items selected for the SGL are in bold.

| Item # in the 13-item scale (and short scale) | Type of graph | Correlation with: Total score on the 13-item scale[1] | Score on 16 complex visual displays[2] | Basic numeracy[3] | Advanced numeracy[4] | Discrimination rate (% correct) |
|---|---|---|---|---|---|---|
| 1 | bar | 0.10 | -0.08 | -0.03 | -0.06 | 0.98 |
| 2 | bar | 0.14 | 0.01 | 0.07 | -0.02 | 0.84 |
| 3 | pie | 0.29 | -0.05 | -0.03 | 0.08 | 0.98 |
| **4 (1)** | **pie** | **0.46** | **0.24** | **0.21** | **0.14** | **0.84** |
| 5 | line | 0.20 | 0.02 | 0.06 | 0.08 | 0.98 |
| 6 | line | 0.29 | 0.06 | 0.35 | 0.02 | 0.96 |
| 7 | line | 0.20 | -0.05 | 0.33 | 0.08 | 0.98 |
| 8 | icons | - | - | - | - | 1.00 |
| **9 (3)** | **icons** | **0.61** | **0.38** | **0.25** | **0.34** | **0.69** |
| **10 (2)** | **bar** | **0.53** | **0.21** | **-0.12** | **0.14** | **0.80** |
| **11 (4)** | **line** | **0.69** | **0.28** | **0.37** | **0.34** | **0.37** |
| 12 | line | 0.30 | -0.11 | -0.17 | 0.06 | 0.94 |
| 13 | bar | 0.45 | -0.03 | 0.14 | 0.09 | 0.73 |

Notes: Sources of different measures: [1]Galesic & Garcia-Retamero, 2011; [2]Okan et al, 2016; [3]Lipkus, Samsa, & Rimer, 2001; and Schwartz, Woloshin, Black, & Welch, 1997; [4]Cokely et al, 2012

Table 2. Percentage of participants answering correctly each of the items in the Short Graph Literacy Scale, and the percentage answering different total number of items correctly, in different studies.

| | % of participants answering correctly | | | |
|---|---|---|---|---|
| | Initial construction - lab Germany (n=51) | Validation sample - national Germany (n=495) | Validation sample - national U.S. (n=492) | Aim 2 sample - national U.S. (n=835) |
| Item 1 | 84.3 | 74.2 | 77.6 | 74.6 |
| Item 2 | 80.4 | 62.8 | 66.1 | 55.8 |
| Item 3 | 68.6 | 51.0 | 58.1 | 65.4 |
| Item 4 | 37.3 | 15.5 | 19.3 | 21.8 |
| 0 items | 0.0 | 9.6 | 9.1 | 8.4 |
| 1 item | 5.9 | 21.8 | 14.6 | 18.0 |
| 2 items | 25.5 | 32.5 | 33.7 | 31.6 |
| 3 items | 25.5 | 27.7 | 30.7 | 31.7 |
| 4 items | 43.1 | 8.4 | 11.8 | 10.3 |

Table 3**.** Graph literacy by socio-demographic characteristics (n=835)

| **Socio-demographic characteristic** | **n** | **Mean graph literacy (SD)** | **Test result** | **p** |
|---|---|---|---|---|
| Education | | | | |
| Vocational-technical training or less | 387 | 1.9 (1.10) | t(833)=-7.97 | <.001 |
| More than vocational-technical training | 448 | 2.4 (1.03) | | |
| Race/ethnicity | | | | |
| White, Non-Hispanic | 445 | 2.4 (1.06)[a] | F(3,831)=18.38 | <.001 |
| Black, Non-Hispanic | 144 | 1.7 (1.05)[b] | | |
| Hispanic | 141 | 2.0 (1.12)[c] | | |
| Other, Non-Hispanic | 105 | 2.4 (1.05)[a,d] | | |
| Income | | | t(833)=-7.59 | |
| ≤$49,999 | 340 | 1.8 (1.10) | | <.001 |
| ≥$50.000 | 495 | 2.4 (1.04) | | |
| Gender | | | | |
| Male | 356 | 2.3 (1.08) | t(833)=3.41 | <.01 |
| Female | 479 | 2.1 (1.10) | | |
| Age | 835 | -- | Pearson's r=-0.05 | .15 |

Note: [a-d] Post-hoc comparisons were used to examine differences in graph literacy among racial groups. Different superscripts indicate significant differences between groups (all p's<.02).

Table 4. Summary of precursors of behavior change investigated and their hypothesized direction of relationship to graph literacy (where previous relevant literature was available), and results observed.

| Outcome Variable | Hypothesized relationship | Observed relationship, bivariate (Step 1) | Observed relationship, after controlling for numeracy (Step 2) | Observed relationship, after controlling for numeracy and demographics (Step 3) |
|---|---|---|---|---|
| **Cognitive precursors** | | | | |
| Risk comprehension | + | + | + * | n.s. |
| Message acceptance | + | + | n.s. * | + |
| Response efficacy | + | + | + | + * |
| Cognitive risk perception | – | – | – | n.s. |
| Uncertainty about cognitive risk perception | – | – | – * | n.s. |
| Perceived severity | ? | – | – * | – * |
| **Affective precursors** | | | | |
| Feelings of risk | – | – | n.s. * | n.s. |
| Worry | – | – | – * | n.s. * |
| Uncertainty about feelings of risk | – | – | – * | n.s. |
| Anticipated regret | ? | n.s. | n.s. | n.s. * |
| **Conative precursors** | | | | |
| Behavioral intentions | ? | + | + | n.s. * |
| Defensive processing | ? | – | – | – * |
| Self-efficacy | ? | n.s. | n.s. | n.s. * |

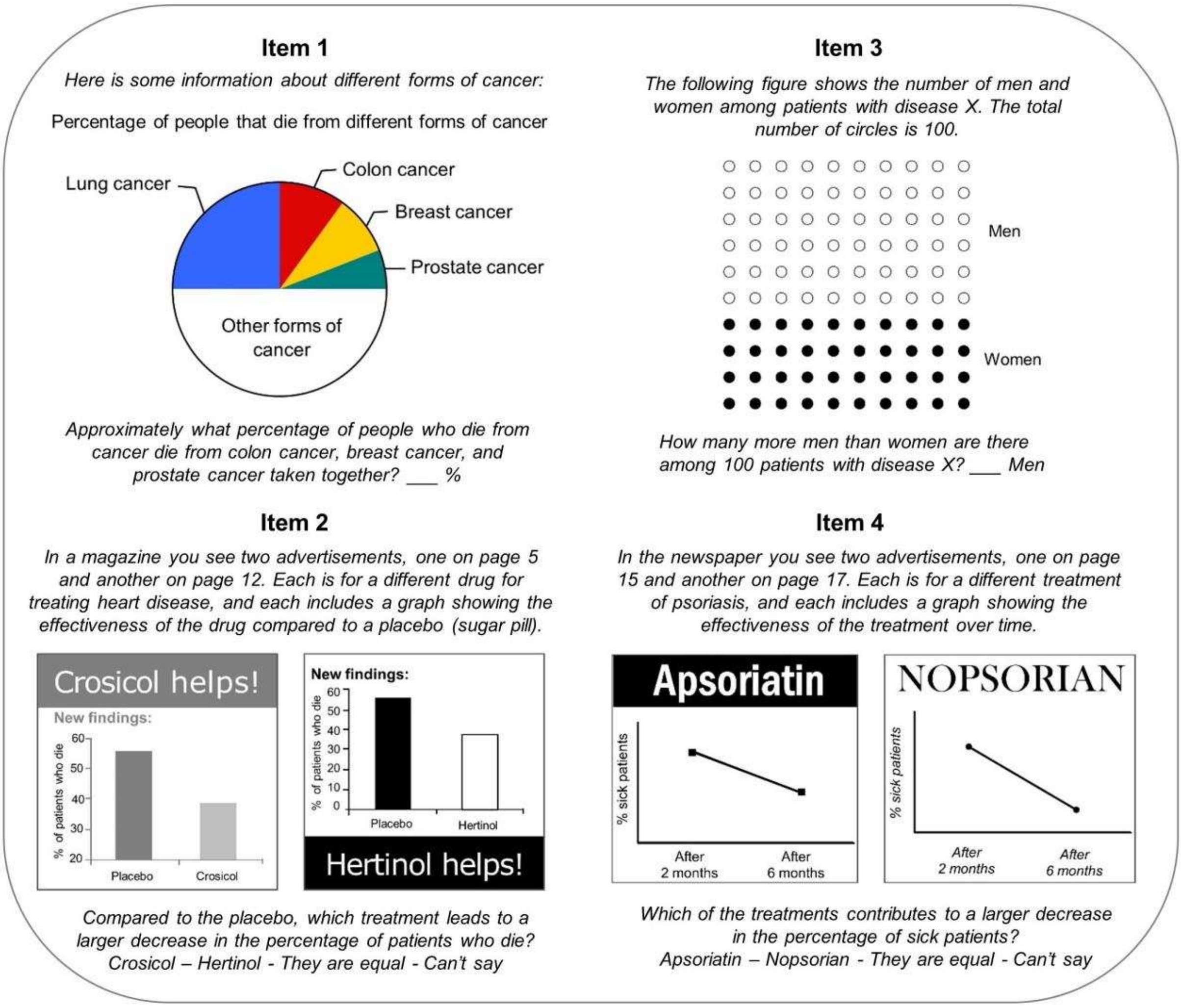
Note: + indicates the hypothesized/observed relationship was positive (i.e., higher graph literacy associated with higher levels of the construct);
– indicates the hypothesized/observed relationship was negative;
? indicates that no hypothesis was developed; n.s. indicates a non-significant relationship;
* indicate that the variables added in this step significantly improved predictions, as determined by F change ($X^2$ for risk comprehension).

## Figure captions

Figure 1. Short Graph Literacy (SGL) scale. Partial reproduction with permission from SAGE. Galesic M, Garcia-Retamero R. Graph literacy: A cross-cultural comparison. Med Decis Making. 2011;31:444–457. The SGL scale items can be downloaded from the Open Science Framework at https://doi.org/10.17605/OSF.IO/FRJBQ.

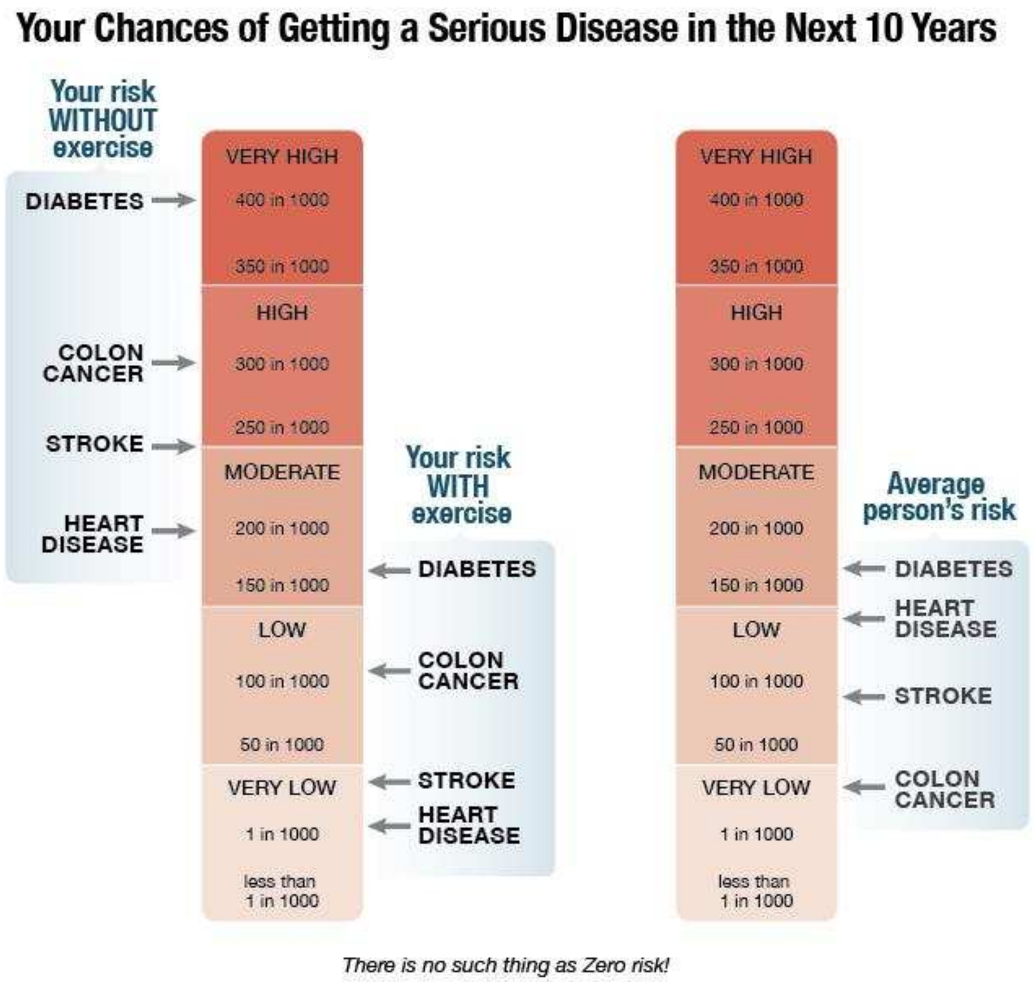
Figure 2. Risk ladder including words+numbers, risk reduction information, and social comparison information stating that participants' risk was much higher than average. Reprinted with permission from Springer Nature. Janssen E, Ruiter RA, Waters EA. Combining risk communication strategies to simultaneously convey the risks of four diseases associated with physical inactivity to socio-demographically diverse populations. J Behav Med. 2017;1–15.

Figure 1



Item 1
Here is some information about different forms of cancer:
Percentage of people that die from different forms of cancer
Lung cancer
Colon cancer
Breast cancer
Prostate cancer
Other forms of cancer
Approximately what percentage of people who die from cancer die from colon cancer, breast cancer, and prostate cancer taken together? ___ %
Item 2
In a magazine you see two advertisements, one on page 5 and another on page 12. Each is for a different drug for treating heart disease, and each includes a graph showing the effectiveness of the drug compared to a placebo (sugar pill).
Crosicol helps!
New findings:
% of patients who die
60
50
40
30
20
Placebo
Crosicol
New findings:
% of patients who die
60
50
40
30
20
10
0
Placebo
Hertinol
Hertinol helps!
Compared to the placebo, which treatment leads to a larger decrease in the percentage of patients who die?
Crosicol – Hertinol - They are equal - Can't say
Item 3
The following figure shows the number of men and women among patients with disease X. The total number of circles is 100.
Men
Women
How many more men than women are there among 100 patients with disease X? ___ Men
Item 4
In the newspaper you see two advertisements, one on page 15 and another on page 17. Each is for a different treatment of psoriasis, and each includes a graph showing the effectiveness of the treatment over time.
Apsoriatin
% sick patients
After 2 months
After 6 months
NOPSORIAN
% sick patients
After 2 months
After 6 months
Which of the treatments contributes to a larger decrease in the percentage of sick patients?
Apsoriatin – Nopsorian - They are equal - Can't say

Figure 2


Your Chances of Getting a Serious Disease in the Next 10 Years
Your risk WITHOUT exercise
DIABETES
COLON CANCER
STROKE
HEART DISEASE
VERY HIGH
400 in 1000
350 in 1000
HIGH
300 in 1000
250 in 1000
MODERATE
200 in 1000
150 in 1000
LOW
100 in 1000
50 in 1000
VERY LOW
1 in 1000
less than 1 in 1000
Your risk WITH exercise
DIABETES
COLON CANCER
STROKE
HEART DISEASE
VERY HIGH
400 in 1000
350 in 1000
HIGH
300 in 1000
250 in 1000
MODERATE
200 in 1000
150 in 1000
LOW
100 in 1000
50 in 1000
VERY LOW
1 in 1000
less than 1 in 1000
Average person's risk
DIABETES
HEART DISEASE
STROKE
COLON CANCER
There is no such thing as Zero risk!

Supplementary materials for Medical Decision Making

# Using the Short Graph Literacy scale to predict precursors of health behavior change

Yasmina Okan, [1] Eva Janssen, [2] Mirta Galesic, [3,4] Erika A. Waters, [5]

[1] Centre for Decision Research, Leeds University Business School, University of Leeds

[2] Department of Work and Social Psychology, Faculty of Psychology and Neuroscience, Maastricht University

[3] Santa Fe Institute

[4] Harding Center for Risk Literacy, Max Planck Institute for Human Development

[5] Washington University School of Medicine, Division of Public Health Sciences

Corresponding author: Yasmina Okan, Centre for Decision Research, Leeds University Business School, University of Leeds. Charles Thackrah Building, Leeds, LS2 9LB, United Kingdom; E-mail: y.okan@leeds.ac.uk.

**1) Full results for validation of SGL scale**

As described in the section Aim 1 Results in the main text, we validated the SGL scale by reanalyzing the data from an experiment conducted by Garcia-Retamero and Galesic [9] in which participants received numerical information about risks without or with additional visual aids. It was found that the benefit of visual aids is reliably higher for participants with higher levels of graph literacy, as reflected in an ANOVA on accuracy of risk understanding, with presence vs. absence of visual aids, graph literacy, numeracy, and country as between-participant factors. Below we present the descriptive results using the 13-item scale vs. the SGL scale (Table S1), and ANOVA results using each scale (Table S2). As can be seen, the main patterns of results obtained using the 13-item scale are reproduced well when the SGL scale is used instead.

Table S1. Descriptive results, with graph literacy measured using long 13-item scale and SGL scale

| | | Long 13-item scale | | SGL scale | |
|---|---|---|---|---|---|
| Visual aids | Graph literacy | Accuracy | | Accuracy | |
| | | Incorrect | Correct | Incorrect | Correct |
| No visual aids | Low | 70.0% | 30.0% | 70.3% | 29.7% |
| | High | 58.0% | 42.0% | 57.3% | 42.7% |
| Visual aids | Low | 60.3% | 39.7% | 59.6% | 40.4% |
| | High | 26.3% | 73.8% | 26.5% | 73.5% |
| Total | Low | 62.5% | 37.5% | 61.9% | 38.1% |
| | High | 32.7% | 67.3% | 33.0% | 67.0% |

Table S2. Results of ANOVA, with graph literacy measured using long 13-item scale and SGL scale

| | Long 13-item scale | | | SGL scale | | |
|---|---|---|---|---|---|---|
| | F | partial $\eta^2$ | p | F | partial $\eta^2$ | p |
| Visual aids | 29.64 | .029 | .000 | 33.30 | .033 | .000 |
| Numeracy | 75.86 | .071 | .000 | 89.63 | .083 | .000 |
| Graph literacy | 1.25 | .001 | .264 | 2.07 | .002 | .150 |
| Country | .17 | .000 | .684 | .01 | .000 | .941 |
| Visual aids * Numeracy | .67 | .001 | .413 | .28 | .000 | .599 |
| Visual aids * Graph literacy | 8.99 | .009 | .003 | 7.74 | .008 | .005 |
| Numeracy * Graph literacy | 5.45 | .005 | .020 | .85 | .001 | .358 |
| Visual aids * Numeracy * Graph literacy | .01 | .000 | .949 | .003 | .000 | .954 |

Note. For all variables and interactions, df=1, error df=978, n=987.

**2) Survey materials used for Aim 2 Methods**

Table S3. Survey materials

| | |
|---|---|
| **Cognitive precursors** | |
| Risk comprehension | According to the picture you saw, how high is the risk of getting colon cancer? [1=very low risk; 5=very high risk; The picture didn't say]. Responses were dichotomized (correct [High] vs. incorrect [All others]). |
| Message acceptance (α=0.92) | The information in the picture is [easy to understand/ written clearly/ seems like it could be true/ is believable] [1=do not agree; 4=strongly agree]; |
| Response efficacy (α=0.89) | Getting regular physical activity will reduce my chances of getting [colon cancer/ sick from the diseases shown in the picture] [1=do not agree; 4=strongly agree];<br><br>Getting regular physical activity is a good way for me to prevent [colon cancer/ getting sick from the diseases shown in the picture] [1=do not agree; 4=strongly agree]. |
| Cognitive risk perception (α=0.80) / Uncertainty about cognitive risk perception (α=0.77) | How likely do you think it is that you will get [colon cancer/ sick from ANY of the diseases shown in the picture] in the next 10 years, if you do not get regular physical activity? [1=not likely; 4=very likely; I don't know];<br><br>Compared to other people your age and sex, how likely do you think it is that you will get [colon cancer/ sick from ANY of the diseases shown in the picture] in the next 10 years, if you do not get regular physical activity? [1=much less likely; 5=much more likely; I don't know]. |
| Perceived severity (α=0.82) | Think about 100 people with [colon cancer/ ANY of the diseases shown in the picture]. Out of those 100 people, about how many do you think will survive at least 5 years? If you are not sure, take your best guess |
| **Affective precursors** | |
| Feelings of risk (α=0.85) / Uncertainty about feelings of risk (α=0.82) | How much do you agree with the following statement: "I feel like I could easily get [colon cancer/ sick from ANY of the diseases shown in the picture] in the next 10 years if I do not get regular physical activity" [1=do not agree; 4=strongly agree; I don't know];<br><br>Compared to other people your age and sex, how easily do you feel you could get [colon cancer/ sick from ANY of the diseases shown in the picture] in the next 10 years if you do not get regular physical activity? [1=much less easily; 5=much more easily; I don't know]. |
| Worry (α=0.77) | How worried are you about getting [colon cancer/ sick from ANY of the diseases shown in the picture?] [1=not worried; 4=very worried]. |

| | |
|---|---|
| Anticipated regret (α=0.95) | I would regret it if I got [colon cancer/ sick from the diseases shown in the picture] because I did not get regular physical activity [1=do not agree; 4=strongly agree];<br><br>I would be mad at myself if I got [colon cancer/ sick from the diseases shown in the picture] because I did not get regular physical activity [1=do not agree; 4=strongly agree]. |
| **Conative precursors** | |
| Behavioral intentions (α=0.91) | I [intend to/ want to/ am likely to] get regular physical activity in the next 3 months [1=do not agree; 4=strongly agree] |
| Defensive processing (α=0.78) | Personally, I do not need to get regular physical activity because I take good care of myself in other ways<br><br>Personally, I do not need to get regular physical activity because I eat healthy foods<br><br>I will get more regular physical activity in the future, but I have other health priorities right now<br><br>I will get more regular physical activity in the future until I am not as busy<br><br>I can't do EVERYTHING I'm supposed to do for my health. It would be a full time job<br><br>Getting regular physical activity can't be that important because my doctor has never told me I had to do it<br><br>Getting regular physical activity can't be that important because I know people who never exercise and their health is fine<br><br>Response options: [1=do not agree; 4=strongly agree] |
| Self-efficacy (α=0.91) | I am confident I can get regular physical activity even if it is difficult for me [1=do not agree; 4=strongly agree]<br><br>I am certain I can live a physically active lifestyle even if it is difficult for me [1=do not agree; 4=strongly agree] |
| **Numeracy and graph literacy** | |
| Numeracy | 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? _____ times;<br><br>Imagine that the chance of getting a disease is 1%. If there were 1,000 people, about how many would be expected to get the disease? _____ people.<br><br>All correct answers were summed for a possible range of 0-2. |
| Graph literacy | The graph below shows the percentage of people who die from different types of cancer. About what percentage of people who die from cancer die from cancer B, cancer C, and cancer D combined? _____%;<br><br>The graph below shows the number of men and women with |

| | |
|---|---|
| | disease X. The total number of circles is 100. How many more men than women are there among 100 patients with disease X? _____ men;<br><br>You see two magazine advertisements on separate pages. Each advertisement is for a different drug for treating heart disease. Each advertisement has a graph showing the effectiveness of the drug compared to a placebo (sugar pill). Compared to the placebo, which treatment leads to a larger decrease in the percentage of patients who die? [1=Crosicol, 2=Hertinol, 3=They are equal, 4=Can't say];<br><br>You see two newspaper advertisements on separate pages. Each advertisement is for a different treatment of a skin disease. Each advertisement has a graph showing the effectiveness of the treatment over time. Which of the treatments shows a larger decrease in the percentage of sick patients? [1=Apsoriatin, 2=Nopsorian, 3=They are equal, 4=Can't say].<br><br>All correct answers were summed for a possible range of 0-4. |

**3) Descriptive statistics of outcome variables assessed for Aim 2 and full regression results.**

Table S4. Descriptive statistics of outcome variables (n=835)

| Outcome Variable | Mean or n correct | SD or % correct | Range |
|---|---|---|---|
| **Cognitive precursors** | | | |
| Risk comprehension (n correct and % correct) | 465 | 55.7 | n/a |
| Message acceptance | 2.96 | 0.69 | 1-4 |
| Response efficacy | 2.82 | 0.70 | 1-4 |
| Cognitive risk perception (n=554)[a] | 0.03 | 0.78 | -1.87-1.78 |
| Uncertainty about cognitive risk perception (n uncertain=281) | 1.17 | 0.29 | 1-2 |
| Perceived severity | 45.03 | 24.19 | 1-100 |
| **Affective precursors** | | | |
| Feelings of risk (n=632)[a] | 0.02 | 0.82 | -1.87-1.78 |
| Worry | 1.97 | 0.80 | 1-4 |
| Uncertainty about feelings of risk (n uncertain=203) | 1.13 | 0.27 | 1-2 |
| Anticipated regret | 2.84 | 0.89 | 1-4 |
| **Conative precursors** | | | |
| Behavioral intentions | 2.83 | 0.77 | 1-4 |
| Defensive processing | 1.49 | 0.47 | 1-4 |
| Self-efficacy | 2.53 | 0.85 | 1-4 |

[a] Due to scale differences, standardized cognitive risk perception and feelings of risk scores were used in regression analyses (Tables 3 and 4 in the main text).

Table S5a. Regression analyses for cognitive factors (Part 1)

| | Risk comprehension (n=835) | | Message acceptance (n =835) | | Response efficacy (n =835) | |
|---|---|---|---|---|---|---|
| Variable[a] | OR | $R^2$ ($X^2$)[b] | $\beta$ | $R^2$ (F)[b] | $\beta$ | $R^2$ (F)[b] |
| **Step 1** | | | | | | |
| Graph literacy | 1.29*** | 0.03[c] ($X^2$=16.02***) | 0.11** | 0.01 (F=9.59**) | 0.11** | 0.01 (F=9.31**) |
| **Step 2** | | | | | | |
| Graph literacy | 1.15* | 0.05[c] ($X^2$=16.06***) | 0.07† | 0.02 (F=5.25*) | 0.10* | 0.01 (F=0.42) |
| Numeracy | 1.50*** | | 0.09* | | 0.03 | |
| **Step 3** | | | | | | |
| Graph literacy | 1.11 | 0.06[c] ($X^2$=4.33) | 0.09* | 0.02 (F=1.40) | 0.09* | 0.03 (F=2.91**) |
| Numeracy | 1.43** | | 0.11** | | 0.02 | |
| Education (1=Vocational-technical or less; 2=More than vocational-technical training) | 1.09 | | -0.05 | | 0.09* | |
| Race/ethnicity | | | | | | |
| White, Non-Hispanic vs. Black, Non-Hispanic | 0.86 | | 0.02 | | 0.04 | |
| White, Non-Hispanic vs. Other, Non-Hispanic | 1.03 | | -0.02 | | 0.06 | |
| White, Non-Hispanic vs. Hispanic | 0.98 | | 0.07† | | 0.12** | |
| Income (1=≤$49,999; 2=≥$50.000) | 1.25 | | -0.00 | | 0.01 | |
| Gender (1=male; 2=female) | 1.04 | | 0.06 | | 0.05 | |
| Age | 1.00 | | 0.04 | | 0.00 | |

Note: [a]Graph literacy scores range from 0 (lowest) to 4 (highest), and numeracy scores range from 0 (lowest) to 2 (highest). [b]The significance of adding variables in each step was determined by the $X^2$ statistic (for the logistic regression analysis for risk comprehension) and F change statistic (for linear regression analyses for all other cognitive factors); [c]Nagelkerke R square was used as the $R^2$ estimate in the logistic regression analysis; *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$,†$p < 0.10$.

Table S5b**.** Regression analyses for cognitive factors (Part 2)

| | Cognitive risk perception[d] (n =554) | | Uncertainty about cognitive risk perception (n =835) | | Perceived severity (n =835) | |
|---|---|---|---|---|---|---|
| Variable[a] | $\beta$ | $R^2$ (F)[b] | $\beta$ | $R^2$ (F)[b] | $\beta$ | $R^2$ (F)[b] |
| **Step 1** | | | | | | |
| Graph literacy | -0.11** | 0.01 (F=7.10**) | -0.13*** | 0.02 (F=14.58***) | -0.15*** | 0.02 (F=20.31***) |
| **Step 2** | | | | | | |
| Graph literacy | -0.10* | 0.01 (F=0.96) | -0.09* | 0.02 (F=7.62**) | -0.11** | 0.03 (F=6.49*) |
| Numeracy | -0.05 | | -0.10** | | -0.10* | |
| **Step 3** | | | | | | |
| Graph literacy | -0.07 | 0.02 (F=1.74†) | -0.06 | 0.03 (F=1.94†) | -0.09* | 0.05 (F=3.07**) |
| Numeracy | -0.02 | | -0.07† | | -0.06 | |
| Education (1=Vocational-technical or less; 2=More than vocational-technical training) | -0.01 | | -0.08* | | 0.02 | |
| Race/ethnicity | | | | | | |
| White, Non-Hispanic vs. Black, Non-Hispanic | 0.03 | | 0.02 | | 0.06 | |
| White, Non-Hispanic vs. Other, Non-Hispanic | 0.02 | | 0.01 | | 0.02 | |
| White, Non-Hispanic vs. Hispanic | 0.11* | | 0.02 | | 0.05 | |
| Income (1=≤$49,999; 2=≥$50.000) | -0.07 | | -0.08* | | -0.12** | |
| Gender (1=male; 2=female) | -0.01 | | -0.02 | | -0.02 | |
| Age | 0.08† | | -0.01 | | -0.08* | |

Note: [a,b]See note to Table 2a; [d]Out of the 835 participants in the study, 554 provided a valid response to all four cognitive risk perception questions; 281 reported "don't know" to at least one of the questions

Table S6a. Regression analyses for affective factors (Part 1)

| | Feelings of risk[c] (n =632) | | Worry (n =835) | |
|---|---|---|---|---|
| Variable[a] | $\beta$ | $R^2$ (F)[b] | $\beta$ | $R^2$ (F)[b] |
| **Step 1** | | | | |
| Graph literacy | -0.11** | 0.01 (F=8.17**) | -0.13*** | 0.02 (F=13.50***) |
| **Step 2** | | | | |
| Graph literacy | -0.07 | 0.02 (F=6.97**) | -0.08* | 0.02 (F=8.65**) |
| Numeracy | -0.11** | | -0.11** | |
| **Step 3** | | | | |
| Graph literacy | -0.05 | 0.02 (F=0.83) | -0.05 | 0.04 (F=2.89**) |
| Numeracy | -0.10* | | -0.09* | |
| Education (1=Vocational-technical or less; 2=More than vocational-technical training) | 0.01 | | -0.04 | |
| Race/ethnicity | | | | |
| White, Non-Hispanic vs. Black, Non-Hispanic | 0.04 | | 0.01 | |
| White, Non-Hispanic vs. Other, Non-Hispanic | -0.01 | | 0.02 | |
| White, Non-Hispanic vs. Hispanic | 0.03 | | 0.14*** | |
| Income (1=≤$49,999; 2=≥$50.000) | -0.04 | | -0.04 | |
| Gender (1=male; 2=female) | 0.01 | | -0.01 | |
| Age | 0.08† | | 0.02 | |

Note: [a]Graph literacy scores range from 0 (lowest) to 4 (highest), and numeracy scores range from 0 (lowest) to 2 (highest). [b]The significance of adding additional variables in each step was determined by the F change statistic; [c]Out of the 835 participants in the study, 632 provided a valid response to all four feelings of risk questions; 203 reported "don't know" to at least one of the questions; *p < 0.05, **p < 0.01, ***p < 0.001,†p < 0.10.

Table S6b**.** Regression analyses for affective factors (Part 2)

| | Uncertainty about feelings of risk (n =835) | | Anticipated regret (n =835) | |
|---|---|---|---|---|
| Variable[a] | *β* | $R^2$ (F)[b] | *β* | $R^2$ (F)[b] |
| **Step 1** | | | | |
| Graph literacy | -0.12** | 0.01 (F=11.42**) | 0.06† | 0.00 (F=3.27†) |
| **Step 2** | | | | |
| Graph literacy | -0.08* | 0.02 (F=6.02*) | 0.06 | 0.00 (F=0.03) |
| Numeracy | -0.09* | | 0.01 | |
| **Step 3** | | | | |
| Graph literacy | -0.05 | 0.02 (F=1.33) | 0.06 | 0.02 (F=2.80**) |
| Numeracy | -0.06 | | 0.01 | |
| Education (1=Vocational-technical or less; 2=More than vocational-technical training) | -0.06† | | 0.05 | |
| Race/ethnicity | | | | |
| White, Non-Hispanic vs. Black, Non-Hispanic | 0.05 | | 0.08* | |
| White, Non-Hispanic vs. Other, Non-Hispanic or 2+ races, Non-Hispanic | 0.02 | | 0.02 | |
| White, Non-Hispanic vs. Hispanic | -0.01 | | 0.06† | |
| Income (1=≤$49,999; 2=≥$50.000) | -0.06 | | 0.05 | |
| Gender (1=male; 2=female) | 0.00 | | 0.08* | |
| Age | -0.03 | | -0.05 | |

Note: [a,b]See note to Table 3a

Table S7**.** Regression analyses for conative factors

| | Behavioral intentions (n =835) | | Defensive processing (n =835) | | Self-efficacy (n =835) | |
|---|---|---|---|---|---|---|
| Variable[a] | $\beta$ | $R^2$ (F)[b] | $\beta$ | $R^2$ (F)[b] | $\beta$ | $R^2$ (F)[b] |
| **Step 1** | | | | | | |
| Graph literacy | 0.10** | 0.01 (F=8.10**) | -0.20*** | 0.04 (F=36.17***) | -0.02 | -0.00 (F=0.22) |
| **Step 2** | | | | | | |
| Graph literacy | 0.08* | 0.01 (F=1.09) | -0.20*** | 0.04 (F=0.07) | -0.01 | -0.00 (F=0.02) |
| Numeracy | 0.04 | | -0.01 | | -0.01 | |
| **Step 3** | | | | | | |
| Graph literacy | 0.07† | 0.06 (F=7.24***) | -0.20*** | 0.06 (F=3.87***) | -0.00 | 0.03 (F=5.03***) |
| Numeracy | 0.03 | | -0.01 | | 0.00 | |
| Education (1=Vocational-technical or less; 2=More than vocational-technical training) | 0.15*** | | -0.07† | | 0.09* | |
| Race/ethnicity | | | | | | |
| White, Non-Hispanic vs. Black, Non-Hispanic | 0.12** | | -0.01 | | 0.18*** | |
| White, Non-Hispanic vs. Other, Non-Hispanic or 2+ races, Non-Hispanic | 0.06† | | 0.00 | | 0.07† | |
| White, Non-Hispanic vs. Hispanic | 0.10** | | -0.02 | | 0.08* | |
| Income (1=≤$49,999; 2=≥$50.000) | 0.05 | | -0.03 | | 0.02 | |
| Gender (1=male; 2=female) | 0.10** | | -0.14*** | | -0.00 | |
| Age | 0.01 | | -0.09** | | -0.01 | |

Note: [a]Graph literacy scores range from 0 (lowest) to 4 (highest), and numeracy scores range from 0 (lowest) to 2 (highest). [b]The significance of adding additional variables in each step was determined by the F change statistic; *p < 0.05, **p < 0.01, ***p < 0.001, †p < 0.10.