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Using the Short Graph Literacy Scale to Predict Precursors of Health Behavior Change

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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 with 47% participants belonging to 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). Patterns 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). Graph literacy had predictive value for most cognitive and affective precursors beyond numeracy. In addition, 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
graph literacy, health behavior, individual differences, risk communication, risk perception, visual aids

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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.[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] and 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]

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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.[7,24] This may discourage their use in research and medical practice,[12] as well as 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 measure 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] with 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 cognitive, affective, and conative precursors of behavior change while controlling for numeracy and sociodemographic 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 United States.[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 2 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 3 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 toward 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 6 cognitive precursors of behavior change. Three originate from the health action process approach (HAPA) model,[20] which includes factors common to several key health behavior

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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 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 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 risks 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). In addition, 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 to 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 his or her 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 precursors.

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 Galesic and Garcia-Retamero[7] for further details). Participants

Table 1 Scores of All Items from the 13-Item Scale on the 4 Criteria Used to Select Items for the Short Graph Literacy (SGL) Scale, Obtained in the Initial Construction Sample ($n = 51$)[a]

		Correlation with				
Item No. in the 13-Item Scale (and Short Scale)	**Type of Graph**	**Total Score on the 13-Item Scale[b]**	**Score on 16 Complex Visual Displays[c]**	**Basic Numeracy[d]**	**Advanced Numeracy[e]**	**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

[a]Items selected for the SGL scale are in bold.
[b]Galesic and Garcia-Retamero.[7]
[c]Okan et al.[15]
[d]Lipkus et al., 2001 and Schwartz et al.[29]
[e]Cokely et al., 2012.

with a variety of graph literacy scores were invited 1 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 Short Graph Literacy (SGL) scale, we used 4 criteria: correlations of each item with 1) the total score on the 13-item scale, 2) comprehension of the 16 complex visual displays, 3) numeracy (low to medium correlations), and 4) discrimination rate of each item (percentage correct answers). We 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 in a total of 4 items.

Validation

The selected items were used in a second study to predict accuracy of understanding health risk information presented numerically v. 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 United States and 2.0 (SD = 1.10) in Germany.

Aim 1 Results

Psychometric Properties

Scores of all items from the 13-item scale on the 4 criteria outlined above are shown in Table 1. Figure 1 shows the 4 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 4 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 the 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: $r = −.04$).

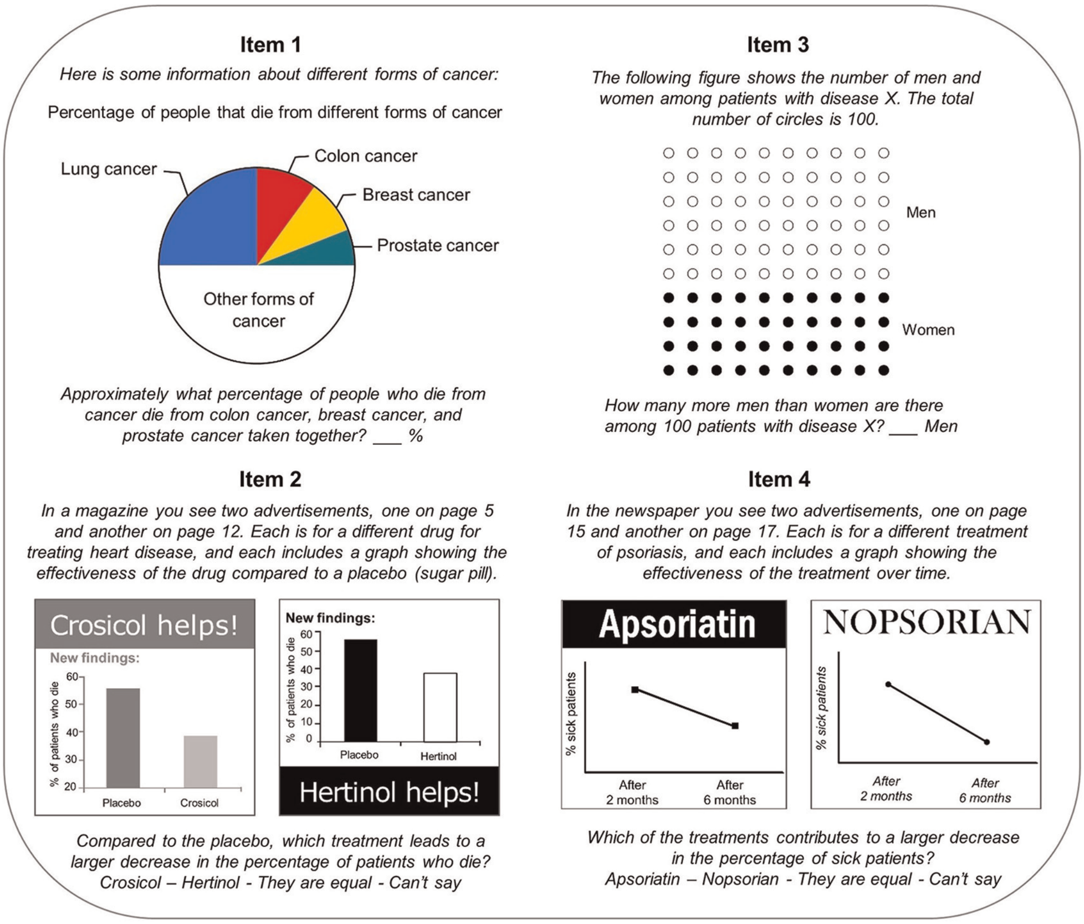

Figure 1 Short Graph Literacy (SGL) scale. Partial reproduction with permission from SAGE. Galesic M, Garcia-Retamero R. Graph literacy: a cross-cultural comparison. *Med Decis Making*. 2011;31:444–57. The SGL scale items can be downloaded from the Open Science Framework at https://doi.org/10.17605/OSF.IO/FRJBQ.

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 4-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 3 studies reported in this article are shown in Table 2.

Predictive Validity of the SGL v. 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 analysis of variance (ANOVA) with presence v. 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, $F(1, 978) = 8.99$, $P = 0.003$, and the SGL scale, $F(1, 978) = 7.74$, $P = 0.005$ (see full results in Suppl. Tables S1–S2), suggesting that participants with high graph literacy benefited more from visual aids. These results indicate that the SGL scale was able to recover the same patterns as the long scale, while taking substantially less time to complete.

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			
Item	**Initial Construction: Lab Germany (n = 51)**	**Validation Sample: National Germany (n = 495)**	**Validation Sample: National United States (n = 492)**	**Aim 2 Sample: National United States (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

Aim 2 Methods

Detailed information about the parent study's methods and results can be found in Janssen et al.[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 (institutional review board 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 US population. GFK emailed an invitation to a randomly selected subsample of individuals from its English-language database who were 30 to 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 US national physical activity guidelines.[53] Stratified recruitment was used to ensure sufficiently large samples of people with no college experience and 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. Of the sample, 53.3% 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 1 of 12 conditions in which risk ladders displayed hypothetical risk calculator results. The risk ladders varied orthogonally according to whether 1) the risk information was presented as words or words and numbers, 2) risk reduction information was or was not present, and 3) 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 Janssen et al.[30]

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 Janssen et al.[56]), worry,[55] perceived severity, response efficacy,[24] anticipated regret (adapted from Weinstein et al.[57]), behavioral intentions,[58] and defensive processing (adapted from McQueen et al.[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 not included in the present analyses because they were outside the scope of the research question. Finally, participants completed the SGL scale, 2 numeracy items adapted from the scale

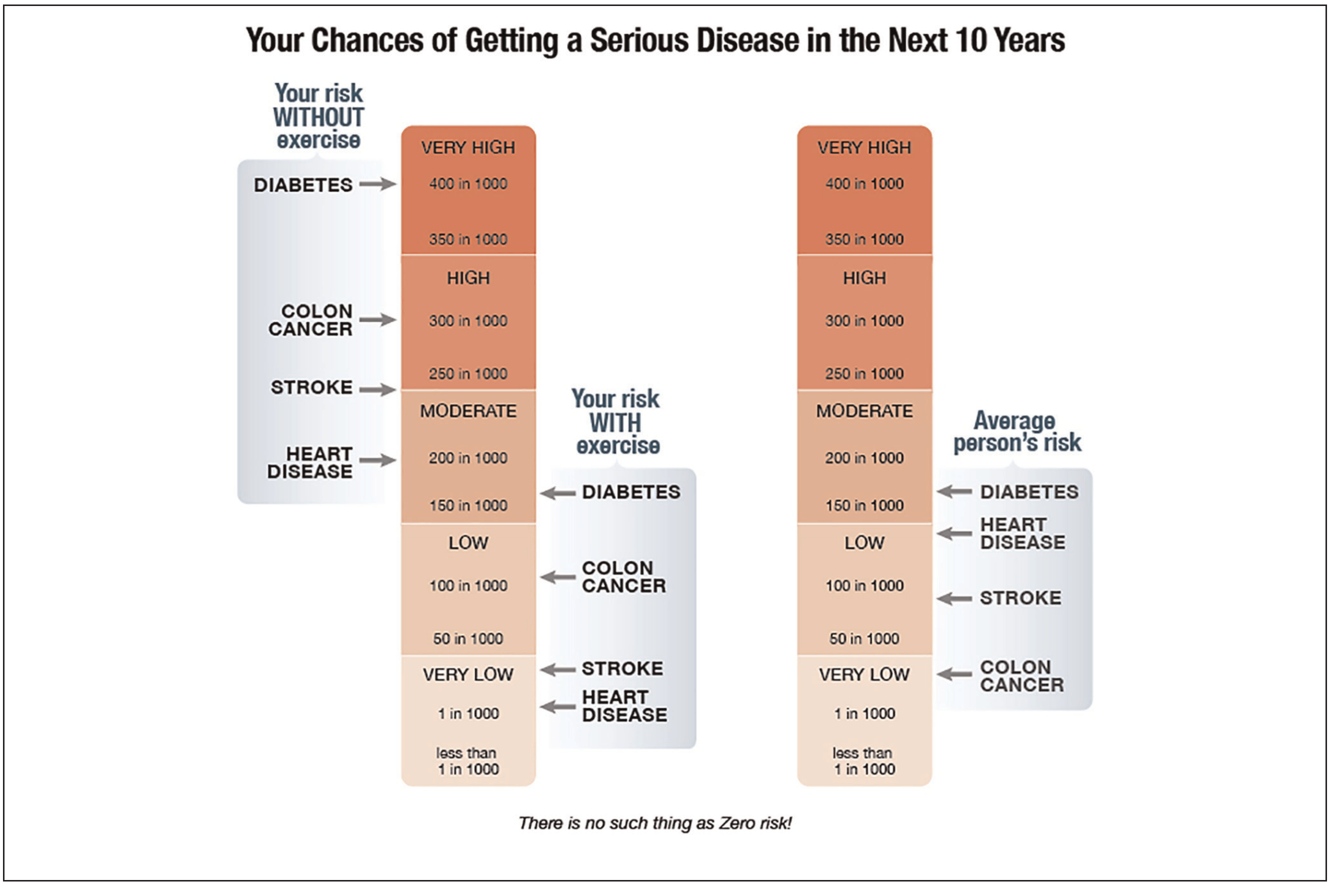

Figure 2 Risk ladder including words + numbers, risk reduction information, and social comparison information stating that participants' risk was much higher than average. Reprinted with permission from Springer Nature. Janssen E, Ruiter RA, Waters EA. Combining risk communication strategies to simultaneously convey the risks of four diseases associated with physical inactivity to socio-demographically diverse populations. *J Behav Med*. 2018;41(3):318–32.

by Schwartz et al.,[29] and demographic questions (gender, age, education, income, and racial and ethnic background). Two of the 3 numeracy items included in the scale developed by Schwartz and colleagues[29] 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 Supplemental 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. Sociodemographics (gender, age, education, racial/ethnic background, and income) were entered in the third block. Graph literacy scores did not vary across the 3 experimental manipulations tested in Janssen et al.[30] (all *F*s < 1, all *P*s > 0.5), 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 (SPSS, Inc., an IBM Company, Chicago, IL).

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

Table 3 Graph Literacy by Sociodemographic Characteristics (n = 835)[a]

Sociodemographic Characteristic	n	Graph Literacy, Mean (SD)	Test Result	P Value
Education				
Vocational-technical training or less	387	1.9 (1.10)	$t(833) = -7.97$	<0.001
More than vocational-technical training	448	2.4 (1.03)		
Race/ethnicity				
White, non-Hispanic	445	2.4 (1.06)*	$F(3, 831) = 18.38$	<0.001
Black, non-Hispanic	144	1.7 (1.05)*		
Hispanic	141	2.0 (1.12)*		
Other, non-Hispanic	105	2.4 (1.05)*		
Income			$t(833) = -7.59$	
≤ $49,999	340	1.8 (1.10)		<0.001
≥$50,000	495	2.4 (1.04)		
Gender				
Male	356	2.3 (1.08)	$t(833) = 3.41$	<0.01
Female	479	2.1 (1.10)		
Age	835	—	Pearson's $r = -0.05$	0.15

[a]Post hoc comparisons were used to examine differences in graph literacy among racial groups. *indicates significant differences between groups (all Ps < 0.02).

(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 supplemental materials include descriptive statistics for all outcomes (Suppl. Table S4) and full regression results (Suppl. Tables S5–S7).

Cognitive Precursors

The first step of the linear regression showed that, as expected, graph literacy was positively associated with risk comprehension, message acceptance, and response efficacy (see Table 4). Also as expected, graph literacy was negatively associated with cognitive risk perception, uncertainty about cognitive risk perception. There was also a negative association between graph literacy 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 (Suppl. Table S5a,b). Adding sociodemographic 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 v. absence of risk reduction information was added following the first step of the regression, $\beta = .19$, $t = 1.44$, $P = 0.15$.

Affective Precursors

As anticipated, graph literacy was negatively associated with feelings of risk, worry, and uncertainty about feelings of risk. 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 sociodemographic 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.

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	+	+	+[a]	NS
Message acceptance	+	+	NS[a]	+
Response efficacy	+	+	+	+[a]
Cognitive risk perception	–	–	–	NS
Uncertainty about cognitive risk perception	–	–	–[a]	NS
Perceived severity	?	–	–[a]	–[a]
Affective precursors				
Feelings of risk	–	–	NS[a]	NS
Worry	–	–	–[a]	NS[a]
Uncertainty about feelings of risk	–	–	–[a]	NS
Anticipated regret	?	NS	NS	NS[a]
Conative precursors				
Behavioral intentions	?	+	+	NS[a]
Defensive processing	?	–	–	–[a]
Self-efficacy	?	NS	NS	NS[a]

NS, nonsignificant relationship; +, the hypothesized/observed relationship was positive (i.e., higher graph literacy associated with higher levels of the construct); –, the hypothesized/observed relationship was negative; ?, no hypothesis was developed.
[a]The variables added in this step significantly improved predictions, as determined by F change (χ^2 for risk comprehension).
Full regression results are available in the online supplemental materials (Suppl. Tables S5–S7).

Numeracy did not improve predictions of any of the conative precursors, whereas sociodemographic factors improved predictions of all conative precursors (Table 4). After adding sociodemographics, the independent contribution of graph literacy still existed for defensiveness, and the effect size remained unchanged (Suppl. Table S7). However, the relation between graph literacy and behavioral intentions no longer reached conventional levels of significance after adding sociodemographics.

Discussion

The first 2 studies in this article indicated 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 demonstrated 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 affective and conative precursors. It also showed that graph literacy has predictive value for most cognitive and affective precursors beyond numeracy and that graph literacy (but not numeracy) is 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 Lipkus[4] for a review of custom-tailored graphical risk communications). In addition, 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 2 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 help more graph-literate participants not only to understand the information objectively better but also to perceive it as more compelling. Previous studies, however, 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] In addition, 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 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,[64,65] 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 sociodemographic 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 2 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 v. graph literacy 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[50] but not always recommended by experts.[66] 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.

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Supplementary Material

Supplementary material for this article is available on the *Medical Decision Making* Web site at http://journals.sagepub.com/home/mdm.

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