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Understanding health risk comprehension: The role of math anxiety, subjective numeracy, and objective numeracy

Jonathan J Rolison, PhD[1]

Kinga Morsanyi, PhD[2]

Ellen Peters, PhD[3]

[2]Department of Psychology

University of Essex, Essex, UK

[2]School of Psychology

Queen's University Belfast, Belfast, UK

[3]School of Journalism and Communication

University of Oregon, Eugene, OR, USA

Address for correspondence:

Jonathan J. Rolison

Department of Psychology

University of Essex

Essex, CO4 3SG

Telephone: +44 (0)1206 874882

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Abstract

Background. Numeracy skills are important for medical decision making as lower numeracy is associated with misinterpreting statistical health risks. Math anxiety, characterized by negative emotions about numerical tasks, and lower subjective numeracy (i.e., self-assessments of numerical competence) are also associated with poor risk comprehension. **Objective.** To explore independent and mediated associations of math anxiety, numerical ability, and subjective numeracy with risk comprehension and to ascertain whether their associations are specific to the health domain. **Methods.** Objective numeracy was measured with a 14-item test. Math anxiety and subjective numeracy were assessed with self-report scales. Risk comprehension was measured with a 12-item test. In Experiment 1, risk comprehension items were limited to scenarios in the health domain. In Experiment 2, participants were randomly assigned to receive numerically-equivalent risk comprehension items in either a health or non-health domain. **Results.** Linear regression analyses revealed that individuals with higher objective numeracy were more likely to respond correctly to the risk comprehension items, as were individuals with higher subjective numeracy. Higher math anxiety was associated with a lower likelihood of correct responding when controlling for objective numeracy, but not when controlling for subjective numeracy. Mediation analyses indicated that math anxiety may undermine risk comprehension in three ways, including through: (1) objective numeracy; (2) subjective numeracy; and (3) objective and subjective numeracy in serial, with subjective numeracy mediating the association between objective numeracy and risk comprehension. Findings did not differ by domain. **Conclusions.** Math anxiety, objective numeracy, and subjective numeracy are associated with risk comprehension through unique pathways. Education initiatives for improving health risk comprehension may be most effective if jointly aimed at tackling numerical ability as well as negative emotions and self-evaluations related to numeracy.

People face important decisions about their health care and treatment that often require an understanding of statistical concepts, including percentages, frequencies, and probabilities.[1-4] Health authorities recommend patient involvement in decisions about their health care and treatment and encourage the provision of statistical information to inform patient decision making.[5,6] A wealth of research has shown, however, that comprehension of health-related statistical concepts (e.g., lifetime risk, relative risk reduction) is poor among the general public.[1,3,7,8] Low objective numeracy—assessed with a math test—has been identified as a key factor underlying poor risk comprehension.[3,4,6,7] Higher math anxiety,[8,9] which is characterized by negative emotions about performing numerical tasks,[10] and lower subjective numeracy (self-evaluations of numerical competence) are also associated with poor risk comprehension.[11] We investigated whether math anxiety, subjective numeracy, and objective numeracy have independent associations with health risk comprehension. Our goal is to shed light on the various pathways to poor risk comprehension to help inform policies aimed at improving patient decision making by targeting the barriers to risk comprehension.

Basic numeracy skills are poor among the general public.[7,13,14] In one study, only 57% of a nationally representative sample of adult Americans correctly reported a person's risk of disease in the next 10 years when the risk was double that of another person, whose risk was 1 in 100.[13] Individuals with poorer numerical ability are more likely to fail risk comprehension tests, such as by misunderstanding lifetime risks of prostate cancer following genetic testing[3] or by misinterpreting risk of death from breast cancer with and without mammography[4]. Subjective numeracy scales, measuring self-reported numerical abilities (e.g., "How good are you at working with percentages?") have been developed as proxies for objective numeracy, circumventing the need to administer a math test.[11,14] Fagerlin et al.[11] proposed that self-assessments of numerical competence could be used to replace objective numeracy

77 measures on the basis of a strong association (r = .68) between subjective and objective nu-
78 meracy measures. However, while objective and subjective numeracy are highly corre-
79 lated,[11,14] subjective numeracy scales exhibit low sensitivity and specificity as diagnostic
80 measures of objective numeracy.[15] As a result, many participants can be identified as either
81 overconfident or underconfident with respect to their numerical abilities.[15]

82 The findings above suggest that objective and subjective numeracy are independent
83 constructs. Whereas objective numeracy measures ability to perform math tasks, subjective
84 numeracy concerns self-judgments and expectations about one's ability to perform math
85 tasks. They are linked, of course. Successful performance on a task demonstrates skills and
86 abilities to perform similar tasks in the future, which in turn, increases self-efficacy (self-as-
87 sessments of one's ability to perform similar tasks).[16,17] Self-efficacy is a strong predictor of
88 task performance, in part owing to effects of self-efficacy on investment of effort and persis-
89 tence with challenging tasks.[16,18] Therefore, higher objective numerical ability may increase
90 subjective numerical ability, and in turn, improve performance on risk comprehension tasks
91 through greater effort and persistence. Indeed, the association between objective numeracy
92 and decision outcomes has been shown to be mediated by subjective numeracy.[19,20] There-
93 fore, we hypothesized that direct associations of each numeracy would exist with risk com-
94 prehension and that higher subjective numeracy would partially mediate the association be-
95 tween objective numeracy and risk comprehension.

96 Math anxiety refers to feelings of tension, fear, or apprehension that affect perfor-
97 mance on math tasks.[10] It is associated with poorer comprehension of statistical health
98 risks.[8,9] Individuals who are higher in math anxiety typically attain lower scores on tests of
99 numerical ability,[21] which may be due partially to avoidance of opportunities for math educa-
100 tion.[22] Anxiety experienced during engagement with math tasks may also interfere with per-
101 formance by distracting or occupying limited working memory resources that are necessary

for good performance.[23-25] Rolison et al.[8] found that higher math anxiety was associated with poorer interpretation of absolute and relative risk reductions, but not after controlling for objective numeracy, indicating that objective numeracy mediated an association between math anxiety and risk comprehension. Other studies have found evidence of objective numeracy partially mediating the association between math anxiety and performance with numerical reasoning tasks (e.g., the cognitive reflection test), with a significant direct link between math anxiety and performance.[26,27] This finding suggests a possible direct association between math anxiety and performance independent of numerical ability.

A relationship also exists between math anxiety and other forms of anxiety, including test anxiety and generalized anxiety.[22,28] Nevertheless, math anxiety remains correlated with math performance after controlling for test anxiety and generalized anxiety,[22] confirming its distinct association with math performance. Health anxiety, which is characterized by unrealistic concerns about one's health, is correlated with various other anxiety disorders.[29] In the Rolison et al.[8] study, the association between math anxiety and comprehension of statistical health risks may have been confounded by comorbid anxieties, namely health anxiety, provoked by the narrative content of the health risk comprehension problems. We investigated whether math anxiety is associated with risk comprehension even after controlling for health anxiety and generalized anxiety.

Less well known is the relation of math anxiety with subjective numeracy. However, in Rolison et al.,[8] math anxiety was more strongly associated with confidence in comprehension than with correct comprehension, such that math anxious individuals were less confident in their comprehension. Investigations of math anxiety in educational contexts have also found strong correlations between measures of math anxiety and confidence.[22] As confidence in one's performance is closely related to self-assessments of one's ability to perform a task,

126 subjective numeracy may mediate the association between math anxiety and risk comprehen-
127 sion. That is, anxiety, tension, and fear associated with math anxiety may have detrimental
128 effects on self-evaluations of math ability, reducing subjective numeracy, and in turn, wors-
129 ening persistence on numeric tasks and risk comprehension. We hypothesized a direct associ-
130 ation between math anxiety and subjective numeracy on risk comprehension and a mediating
131 role of subjective numeracy on the association between math anxiety and risk comprehension
132 in Experiments 1 and 2.

133 Finally, we question whether the pathways to poor risk comprehension are specific to
134 the health domain. Some theorists have proposed that health numeracy is a separate compe-
135 tency to general numerical ability.[30-32] Levy et al.,[32] for example, found that participants were
136 less likely to respond correctly to math problems presented in the health domain (e.g., per-
137 centage of people who get a disease) compared to a financial (e.g., percentage of customers
138 who get a discount) or pure math (i.e., no risk context) domain. One possible explanation for
139 this finding is that due to its importance, health-related information provokes anxiety that in-
140 terferes with risk comprehension. Adverse effects of health-related content on risk compre-
141 hension should be stronger among health anxious individuals who are likely to be more sensi-
142 tive to health-related information, and among individuals who are high in math anxiety as any
143 anxiety provoked by the verbal content of a problem would exacerbate anxiety caused by its
144 numerical content. Therefore, in Experiment 2, we further explored whether associations be-
145 tween math anxiety, subjective numeracy, and objective numeracy differ depending on the
146 domain of risk comprehension problems.

147 In sum, the current investigation was designed to test for independent associations be-
148 tween math anxiety, subjective numeracy, and objective numeracy with risk comprehension.
149 We hypothesized that the association between math anxiety and risk comprehension would be

mediated by: (1) objective numeracy; (2) subjective numeracy; and (3) objective and subjective numeracy in serial, whereby subjective numeracy mediates the association between objective numeracy and risk comprehension. Additionally, we explored whether the associations between objective numeracy, math anxiety, and subjective numeracy depend on the domain of risk comprehension problems.

EXPERIMENT 1

Method

Participants

One thousand two hundred fifty-seven participants were invited to participate in a study of their understanding of statistical health risks using online public and private recruitment platforms. Of these, 1,194 consented to participate and 1,011 participants competed the study. Only complete data were used in all analyses. Of those who completed the study, 660 were recruited via Amazon's Mechanical Turk and the remaining 351 were recruited either on a voluntary basis or in exchange for course credit. The majority (n = 705) were from the USA or Canada, 244 were from the UK or Ireland, and a minority (n = 59) were from another country. Table 1 provides the sample characteristics.

Materials and Procedure

Objective numeracy: Objective numeracy was assessed with the 11-item Lipkus et al.[7] scale and three cognitive reflection items (see Appendix A).[33] The Lipkus et al. scale includes 3 items that assess general understanding of chance and probability and 8 items that assess understanding of disease risk, such as converting percentages to frequencies.[7] The cognitive reflection items assess the ability to produce a numerically correct response by applying a normative rule and resisting an intuitively appealing response.[33] We combined the Lipkus et al.[7] scale items and cognitive reflection items to extend the scale's range of difficulty as total scores tend to be negatively skewed toward the high end of the scale for the Lipkus et al.[7]

scale items.[13,34] Confirmatory and exploratory factor analysis has shown that cognitive reflection items are appropriate to use with standard numeracy questions as they load on the same numerical ability factor as the Lipkus scale items.[35-38] Previous studies have included CRT items with the Lipkus scale items due to improvements in the scale structure and reliability.[36,37] Items were scored as either correct (value of 1) or incorrect (value of 0). Total scores were summed across the 11 Lipkus et al.[7] scale items and the three cognitive reflection items (Cronbach $\alpha = .80$).

Subjective numeracy: Subjective numeracy was assessed with an 8-item scale developed by Fagerlin et al.[11] The scale assesses self-reported ability to work with numerical information (e.g., 'how good are you at working with percentages?') on a 6-point scale, ranging from 'not at all good' (value of 1) to 'extremely good' (value of 6), and preferences for numerical formats of information (e.g., 'how often do you find numerical information to be useful? [1 = 'never', 6 = 'very often']) on a 6-point scale. Overall subjective numeracy was calculated as the mean score across the 8 items (Cronbach $\alpha = .87$).

Math anxiety: Math anxiety was assessed with the 13-item Adult Everyday Math Anxiety Scale (AEMAS),[8] which evaluates self-reported anxiety with numerical information in general (e.g., 'having to work with percentages'), in everyday tasks (e.g., 'having to work out prices in a foreign currency'), and in the workplace (e.g., 'having to present numerical information at a work meeting'). Participants responded on a 5-point scale, ranging from 'low anxiety' (value of 1) to 'high anxiety' (value of 5). Overall math anxiety was calculated as the mean score across the 13 items (Cronbach $\alpha = .93$).

Generalized anxiety: Generalized anxiety was assessed with the 7-item generalized anxiety disorder scale (GAD),[39] which assesses mild to severe levels of generalized anxiety based on self-reported frequency of anxiety symptoms over the last 2 weeks (e.g., 'feeling nervous, anxious, or on the edge') on a 3-point scale, ranging 'not at all' (value of 1) to

200 'nearly every day' (value of 4). Overall generalized anxiety was calculated as the mean score
201 across the 7 items (Cronbach α = .92).
202 *Health anxiety*: Health anxiety was assessed with the 15-item Health Anxiety Ques-
203 tionnaire,[40] which measures health concerns, preoccupation with health issues, attention to
204 aches and pains and bodily sensations, and fear of serious illness, on a 4-point scale (e.g., 'not
205 at all or rarely' [value of 1], 'sometimes' [value of 2], 'often' [value of 3], 'most of the time'
206 [value of 4]). Overall health anxiety was calculated as the mean score across the 15 items
207 (Cronbach α = .93).
208 *Risk comprehension*: We constructed a battery of 12 risk comprehension items in the
209 health domain based on novel items and items drawn from the existing literature (see Appen-
210 dix A for full list of items). Items assessed comprehension of absolute risk ('the patient's
211 chance of surviving … is increased to 70%'; Question 1),[8] relative risk ('the patient's chance
212 of surviving … is increased by 25%'; Question 2),[8] and lifetime risk of cancer informed by
213 genetic testing (Question 3)[3]. Novel items assessed comprehension of ratios in the context of
214 communicating the health benefits of a vitamin supplement (Question 4), misconceptions re-
215 lating to random event sequences in the context of the most likely outcome for a patient in a
216 hospital who follows a sequence of prior patients (Question 5), and proportions in terms of
217 the percentage of people who are at increased risk of developing a serious health condition
218 (Question 6). We also included items that assessed comprehension of comparative infor-
219 mation in the context of multiple performance indicators of hospitals (Questions 7-12).[41]
220 For example, the item that assessed comprehension of event sequences (Question 5)
221 asked participants:
222 *In a hospital, 10 in every 30 patients who undergo a medical procedure require*
223 *further treatment and the remaining 20 do not require any further treatment. The*
224 *last 5 medical procedures carried out in the hospital did not require any further*

treatment. What do you think is the most likely outcome for the next patient who undergoes a medical procedure in the hospital?

Option 1: The patient will not require further treatment

Option 2: The patient will require further treatment

Option 3: The patient has equal chances that they will or will not require further treatment

The risk comprehension items were scored as either correct (value of 1) or incorrect (value of 0). Total scores were summed across all 12 items (Cronbach $\alpha = .69$).

Participants first completed the generalized anxiety scale. They then completed the health anxiety scale, followed by the subjective numeracy scale, then the math anxiety scale, followed by the risk comprehension items, and finally, the objective numeracy scale. The risk comprehension and objective numeracy items were presented after the math anxiety scale and subjective numeracy scale to avoid influencing participants' self-reported math anxiety and subjective numeracy.

Results

Participants responded correctly to a mean of 8.61 ($s = 2.20$) of the 12 risk comprehension items. Table 2 provides the intercorrelations among variables. Higher risk comprehension scores were associated with higher objective and subjective numeracy and lower math anxiety, health anxiety, and generalized anxiety. Higher objective numeracy was associated with higher subjective numeracy and lower math anxiety, health anxiety, and generalized anxiety. Math anxiety was positively associated with health anxiety and generalized anxiety.

Multiple linear regression analysis on risk comprehension

Provided in Table 3 are the results of our linear regression analysis on total risk comprehension scores. Age, gender, education, objective numeracy, math anxiety, health anxiety, and generalized anxiety were included in Model 1a. Subjective numeracy was included in

Model 2a to assess effects of math anxiety after controlling for subjective numeracy. Higher objective numeracy was associated with higher risk comprehension scores (Model 1a; Table 3). Controlling for objective numeracy, higher math anxiety was associated with lower risk comprehension scores (Model 1a; Table 3). Controlling for health anxiety and generalized anxiety, math anxiety remained a significant predictor, while health anxiety and generalized anxiety were not (Model 1a; Table 3). Higher subjective numeracy was associated with higher risk comprehension scores when included in a second model (Model 2a; Table 3). Controlling for subjective numeracy, math anxiety was no longer significantly associated with risk comprehension (Model 2a; Table 3).[1] In sum, as hypothesized, objective and subjective numeracy each had direct associations with risk comprehension. Math anxiety was associated with risk comprehension independent of objective numeracy, health anxiety, and generalized anxiety, but its association with risk comprehension appeared to be mediated by subjective numeracy. Health anxiety and generalized anxiety were not associated with risk comprehension independent of math anxiety.

Mediation analysis on risk comprehension

We hypothesized that the association between math anxiety and risk comprehension would be mediated by: (1) objective numeracy; (2) objective and subjective numeracy in serial; and (3) subjective numeracy. To test our mediation hypotheses, we employed Preacher and Hayes' INDIRECT regression procedure with 10,000 bootstrapped samples to estimate the 95% confidence intervals (CI) for the direct and indirect pathways[2].[41]

[1]The pattern of results was similar when the objective numeracy measure included only the 11 Lipkus scale items, with the exception that education was positively associated with risk comprehension in Model 1a (b = .15, t = 2.52, p = .012) and Model 2a (b = .16, t = 2.70, p = .007).

[2]This procedure makes it possible to test the potential effects of a number of mediators (as well as potential serial mediation effects) in a single analysis, without the need to conduct separate analyses to statistically compare the adequacy of competing models.

In our mediation model (Figure 1), we estimated the indirect pathway between math anxiety and risk comprehension via objective numeracy (indirect pathway 1), objective and subjective numeracy in serial (indirect pathway 2), and via subjective numeracy (indirect pathway 3). In our analysis, we controlled for health anxiety and generalized anxiety in order to confirm the specific associations of math anxiety (as opposed to a more general anxious predisposition) with risk comprehension. We controlled for gender, as math anxiety is often more prevalent in women, whereas men are often characterized by higher levels of subjective numeracy, which was also the case in the current sample (Table 2). We also controlled for education as higher education was associated with lower math anxiety, and higher objective and subjective numeracy (Table 2). In the INDIRECT regression procedure, a bias-corrected bootstrapped CI of the product of the paths within each indirect route that does not include zero indicates a significant indirect association of math anxiety with risk comprehension through the mediating variables.[42]

The total effect of math anxiety on risk comprehension was significant (c = -.939, 95% CIs = -1.122: -0.756; $p < .001$). Nevertheless, once the mediators were entered into the regression, the direct association between math anxiety and risk comprehension was no longer significant (p = .995). Additionally, our mediation analysis revealed that all three indirect pathways were significant. Specifically, there was a significant indirect association of math anxiety with risk comprehension via objective numeracy (i.e., indirect pathway 1; b = -0.669, 95% CIs = -0.816: -0.537), objective and subjective numeracy in serial (indirect pathway 2; b = -0.521, 95% CIs = -0.081: -0.031), and via subjective numeracy (indirect pathway 3; b = -0.217, 95% CIs = -0.313: -0.129; Figure 1). The ratio of the indirect to the total effect can be used as an effect size statistic for the mediation effects.[43] These results indicated that the mediational effect of objective numeracy for math anxiety was large (.71), whereas the mediational effects of objective and subjective numeracy in serial (.06) and subjective numeracy

(.23) were small. Regarding the covariates, education was a significant covariate ($p < .0001$; 95% CIs = 0.267: 0.549); the effect of generalized anxiety ($p = .055$; 95% CIs = -0.005: 0.396) approached significance, whereas gender ($p = .212$) and health anxiety ($p = .230$) were non-significant covariates.[3] In sum, our mediation analysis supported our mediation hypotheses, demonstrating that objective and subjective numeracy mediated the association between math anxiety and risk comprehension and that subjective numeracy partially mediated the association between objective numeracy and risk comprehension.

EXPERIMENT 2

In Experiment 2, we aimed to replicate the findings of Experiment 1, indicating that objective and subjective numeracy mediate an association between math anxiety on risk comprehension in the health domain. Previous research has indicated that people perform more poorly on math problems when presented in the health domain compared to other domains.[32] A further aim of Experiment 2 was to explore whether the associations between objective numeracy, math anxiety, subjective numeracy, and risk comprehension differ depending on the domain of risk comprehension problems. In Experiment 2, participants were randomly assigned to receive risk comprehension problems with identical numerical content in either the health domain, as in Experiment 1, or in a non-health domain.

Method

Participants

One thousand four hundred twenty-three participants were invited to participate in a study of their understanding of statistical health risks using online public and private recruitment platforms. Of these, 1,261 consented to participate and 940 participants competed the study. Only complete data were used in all analyses. Of those who completed the study, 225

[3] The pattern of results was the same when the objective numeracy measure included only the 11 Lipkus scale items.

were recruited via Amazon's Mechanical Turk and the remaining 715 were recruited either on a voluntary basis or in exchange for course credit. The majority (n = 463) were from the USA or Canada, 244 were from the UK or Ireland, and the remaining 233 were from another country. Table 1 provides the sample characteristics.

Materials and Procedure

As in Experiment 1, participants completed the objective numeracy, subjective numeracy, math anxiety, and health anxiety scales. Experiment 1 demonstrated that math anxiety was a significant predictor of risk comprehension after controlling for the effects of generalized anxiety and health anxiety. Nevertheless, we included the health anxiety scale as a covariate in Experiment 2, as we were interested in potential differences in the effects of math anxiety on risk comprehension between the health and non-health domains after controlling for potential effects of health anxiety.

Risk comprehension: We constructed an alternative format of the 12 health-related risk comprehension items used in Experiment 1. In our alternative format, the scenarios were altered such that they no longer referred to health. For example, rather than refer to a patient's chance of survival one year after a cancer diagnosis (health domain), the equivalent scenario in the non-health domain referred to a toy shop's chance of making a profit one year after the sale of a new product (see Appendix A). Importantly, the non-health version of each item maintained an identical structure, similar length, and presented identical numerical information. Hence, the items in the health domain and non-health domain were identical in all aspects other than their reference to health or non-health related scenarios.

Participants first completed the health anxiety scale, followed by the subjective numeracy scale, math anxiety scale, risk comprehension items, and finally, the objective numeracy scale. Participants were randomly assigned to complete either the health (n = 476; 50%) or non-health version of the risk comprehension items.

Results

Participants responded correctly to a similar number of risk comprehension items in the health ($\bar{x}$ = 8.16, s = 2.18) and non-health ($\bar{x}$ = 7.98, s = 2.25) domains (p = .203). Across domains, higher risk comprehension scores were associated with higher objective and subjective numeracy and lower math anxiety and health anxiety (Table 4). Higher objective numeracy was associated with higher subjective numeracy and lower math and health anxiety. Math anxiety was positively associated with health anxiety (Table 4). Thus, the intercorrelations among the variables replicated the findings of Experiment 1.

Multiple linear regression analysis on risk comprehension

Provided in Table 3 are the results of our linear regression analysis on total risk comprehension scores. Age, gender, education, objective numeracy, math anxiety, health anxiety, and domain were included in Model 1b. Subjective numeracy was included in Model 2b to assess effects of math anxiety after controlling for subjective numeracy. Interaction terms involving domain were included in Model 3b to test for moderating effects of domain on objective numeracy, math anxiety, health anxiety, and subjective numeracy. Higher objective numeracy was associated with higher risk comprehension scores (Model 1b; Table 3). Controlling for objective numeracy, higher math anxiety was associated with lower risk comprehension scores (Model 1b; Table 3). Controlling for math anxiety, health anxiety was not significantly associated with risk comprehension (Model 1b; Table 3). Moreover, risk comprehension did not differ depending on whether the scenarios related to the health or non-health domain (Model 1b; Table 3). In a second model, higher subjective numeracy was associated with higher risk comprehension scores and, controlling for subjective numeracy, math anxiety was no longer significantly associated with risk comprehension (Model 2b; Table 3). In our final model (Model 3b; Table 3), domain (i.e., health vs. non-health) did not moderate effects of objective numeracy, math anxiety, health anxiety, or subjective numeracy on risk

comprehension scores.[4] In sum, our multiple linear regression analysis replicated Experiment 1's findings and revealed no effects of risk-comprehension domain.

Mediation analysis on risk comprehension

In our mediation model (Figure 2), we followed the procedure introduced in Experiment 1 to test the indirect effect of math anxiety on risk comprehension via objective numeracy (indirect pathway 1), objective and subjective numeracy in serial (indirect pathway 2), and via subjective numeracy (indirect pathway 3). Gender, education, and health anxiety were included as covariates. The total effect of math anxiety on risk comprehension was significant (c = -.868, 95% CIs = -1.039: -0.696; p < .0001). Nevertheless, once the mediators were entered into the regression, the direct effect of math anxiety was no longer significant (p = .108). Our mediation analysis confirmed that all three indirect effects were significant. Specifically, there was a significant indirect effect of math anxiety on risk comprehension via objective numeracy (i.e., indirect pathway 1; b = -0.581, 95% CIs = -0.702: -0.473), objective and subjective numeracy in serial (indirect pathway 2; b = -0.025, 95% CIs = -0.045: -0.010), and via subjective numeracy (indirect pathway 3; b = -0.122, 95% CIs = -0.208: -0.049).[5] The ratios of the indirect to the total effect indicated that the mediational effect of objective numeracy for math anxiety was large (.67), whereas the mediational effects of objective and subjective numeracy in serial (.03) and subjective numeracy (.14) were small. Regarding the covariates, health anxiety was the only significant covariate (p = .027; 95% CIs = -0.551: -

[4]The pattern of results was similar when the objective numeracy measure included only the 11 Lipkus scale items, with the exceptions that education was positively associated with risk comprehension (b = .14, t = 2.13, p = .034) in Model 1b and that math anxiety (b = -.21, t = 2.31, p = .021) and health anxiety (b = -.23, t = 2.00, p = .045) were associated with poorer risk comprehension in Model 2b.

[5]We additionally tested for moderating effects of domain (health vs. non-health) on the indirect pathways, which yielded no moderating effects.

.033), whereas the effect of education approached significance (p = .078).[6] In sum, our mediation analysis replicated Experiment 1's findings regarding the indirect effects of math anxiety and objective numeracy on risk comprehension.

GENERAL DISCUSSION

What are the barriers to comprehension of statistical health risks? Previous research has identified objective numeracy,[4] subjective numeracy,[11] and math anxiety[8] as predictors of risk comprehension. Yet, no previous study has explored whether these constructs have independent associations with risk comprehension. In the current investigation, we explored the effects of math anxiety, subjective numeracy, and objective numeracy together to shed light on the determinants of poor risk comprehension. We found that subjective and objective numeracy were directly associated with risk comprehension. Math anxiety was directly associated with risk comprehension when controlling for objective numeracy, but not when controlling for both objective and subjective numeracy. We discovered three indirect pathways of math anxiety to risk comprehension, including via objective numeracy, subjective numeracy, and via objective and subjective numeracy in serial, whereby subjective numeracy mediated effects of objective numeracy after controlling for effects of math anxiety on objective numeracy.

Rolison et al.[8] reported that higher math anxiety was associated with poorer comprehension of absolute and relative risk reductions associated with medical treatments, but not after controlling for objective numeracy. Our current findings replicate the previously reported mediating effect of objective numeracy, even after controlling for individual differ-

[6]The pattern of results was similar when the objective numeracy measure included only the 11 Lipkus scale items, with the exception that the direct effect of math anxiety on risk comprehension remained significant after including the mediators and covariates in the model (b = -0.201, 95% CIs = -0.375: -0.027). That is, when only the easier numeracy items were included in the numeracy scale, the effect of math anxiety was only partially mediated.

ences in health and generalized anxiety. This finding implies that the effect of anxiety on objective numeracy is specific to anxiety about math problems. The indirect effect of math anxiety is likely to be a consequence of the tendency for math anxious individuals to rate their skills as lower, have less confidence, and avoid opportunities to respond to current math-related problems or to take advantage of earlier math education, limiting their development of numeracy skills.[21,22]

We also found an effect of math anxiety on risk comprehension after controlling for objective numeracy and health and generalized anxiety. We speculate that the effect of math anxiety on risk comprehension after controlling for objective numeracy may not have been detected in the Rolison et al.[8] study because the present study used a much larger battery of risk comprehension items, increasing statistical power and reducing the extent to which our findings depend on a single risk comprehension problem. Moreover, our findings show that effects of math anxiety remain even after controlling for health and generalized anxiety, indicating that anxiety is specific to the numerical content of risk comprehension problems.

The effects of math anxiety on risk comprehension, however, were mediated by subjective numeracy. This novel finding suggests a pathway to misinterpretation of statistical health risks that is independent of numeracy skills or abilities. We speculate that anxiety about numerical content negatively affects self-evaluations of math ability (i.e., subjective numeracy), which in turn, worsens performance on risk comprehension tasks through reduced effort or persistence. Education initiatives targeted at improving numeracy skills may be undermined if they fail also to address people's anxieties about math and negative self-evaluations. Hence, an important implication of our findings is that education programs may be most effective if they stretch beyond training basic numeracy skills and address emotions and self-evaluations of abilities. Successful performance on a task improves self-evaluations of

one's ability to perform related tasks.[16] University undergraduates who received an intervention designed to increase math-related self-efficacy, which included basic numerical problem solving tasks, subsequently reported greater confidence in their ability to perform math-related tasks and expressed greater interest in studying math- or science-related courses.[44] Moreover, among young children, modifying math problems to enable high student success rates increases subsequent math performance by motivating more practice.[45] One initiative could involve using similar techniques in high school and university level math education to improve self-evaluations and alleviate math anxiety through performance accomplishment. Such efforts may be particularly important to health when good outcomes depend on numeric ability but also persistence over time.[46]

The current findings imply a multifaceted nature of numerical competencies underlying risk comprehension. Subjective numeracy scales have often been used as a proxy for actual numerical abilities,[11,14] despite offering a poor diagnostic tool for assessing objective numeracy.[15] In the current experiments, objective numeracy had a direct effect on risk comprehension and an indirect effect via subjective numeracy, implying that objective and subjective numeracy have independent associations with risk comprehension even though they are related. The serial pathway from objective numeracy to risk comprehension via subjective numeracy has been supported in other studies by structural equation model analysis in which reversing the path between objective numeracy and subjective numeracy results in a poorer model fit.[19] Similarly, in an intervention study designed to improve numeracy with a statistics course combined with values affirmation, the alternative model with a pathway leading from subjective numeracy to risk comprehension via objective numeracy fitted the data less well than a pathway leading from objective numeracy to risk comprehension via subjective numeracy.[20] A clinical implication of our findings is that subjective numeracy may be an inadequate proxy for numerical ability as it does not fully account for the association between objective

numeracy and risk comprehension. The direct effect of subjective numeracy on risk comprehension (even after controlling for effects of math anxiety and numeracy) also has potential clinical importance. Higher self-efficacy (i.e., self-judgments of ability) leads to better task performance as a consequence of greater persistence and investment of effort.[16,18] If subjective numeracy levels were enhanced with an intervention designed to reduce negative self-evaluations, this could lead to better risk comprehension, improving patient decision-making in health contexts. Care needs to be taken, however, as such efforts could increase overconfidence. A fruitful avenue for future research would be to explore how interventions designed to enhance subjective numeracy affect performance on risk comprehension tasks.

Levy et al.[32] reported that performance on math problems posed in the health domain was poorer than for problems that had a financial or purer math content. Their finding resonates with a view that health numeracy is a separate construct to general numerical ability.[30-32] A possible interpretation of their finding is that health-related information provokes anxiety that interferes with performance. However, using a larger battery of risk comprehension problems (i.e., 12 items) than Levy et al. (4 items),[32] we did not find differences in risk comprehension between problems posed in health and non-heath domains. Moreover, effects of math anxiety, subjective numeracy, and objective numeracy did not depend on domain, suggesting that they each have domain-general effects on risk comprehension. As discussed below, participants in the current experiments reported relatively low symptoms of health anxiety. If future research were to assess individuals of higher health anxiety (e.g., with an illness anxiety disorder), domain differences in health comprehension may occur due to impairing effects of anxiety.

The current research has potential limitations. Our mediation analysis was correlational in nature, which precludes strong claims about the directionality of some pathways

within our mediation model. As discussed earlier, the serial pathway from objective numeracy to risk comprehension via subjective numeracy has been supported by previous research.[19,20] Thus, we took a confirmatory approach to test this pathway in our experiments. However, our approach does not rule out alternative models, such as a pathway leading from subjective numeracy to risk comprehension via objective numeracy, which would imply that negative self-assessments of math ability undermine performance on math problems, leading to poor risk comprehension. Further research could seek to manipulate subjective numeracy (e.g., by presenting easy or difficult math problems) in order to unpick its causal links with objective numeracy, math anxiety, and risk comprehension. We focused our investigation on individuals in the general population. On average, participants reported experiencing relatively low symptoms of health anxiety in Experiment 1 ($\bar{x}$ = 1.72; Table 2) and Experiment 2 ($\bar{x}$ = 1.84; Table 4) where 1 = 'not at all or rarely' and 2 = 'sometimes.' However, patients with a health-related anxiety disorder (e.g., illness anxiety disorder) exhibit considerably higher health anxiety scores than the general public.[47,48] High levels of health anxiety, as exhibited by patients who suffer illness anxiety disorder, may have negative effects on comprehension of statistical health risks missed by the relatively low levels of health anxiety we observed presently. A valuable direction for future research would be to explore whether anxiety experienced by illness anxiety disorder patients influences health risk comprehension independent of the effects of math anxiety. Patients who score high in health anxiety visit their physician more frequently than other patients,[49,50] and people with illness anxiety disorder search more online for health-related information.[50] Thus, individuals suffering from this disorder are much more exposed to health statistics than others and their potentially poor comprehension of such information may exacerbate their health anxieties.

A third of participants had completed a university degree. In both experiments, higher educational attainment was associated with lower math anxiety, higher subjective and

objective numeracy, and better risk comprehension. Thus, the high educational attainment of our samples may have suppressed an even stronger association between math anxiety, subjective and objective numeracy, and risk comprehension. Future research could target individuals with low educational attainment where math anxiety is likely to be higher and subjective and objective numeracy lower, addressing a sample of the population who are likely to misunderstand numerical health risks. The percentage of participants who failed to complete Experiments 1 and 2 (15% & 25%, respectively) was considerable, and thus, effort should be made to maximize participant completion rates if specialist samples are sought in future research.

Finally, we measured objective numeracy with the 11-item Lipkus scale and three additional Cognitive Reflection Test (CRT) items in a manner similar to a well-validated Rasch-based measure.[37] The Lipkus scale is perhaps the most widely used scale to assess objective numeracy in the context of health risk comprehension and scores on the scale have been shown to correlate highly with subjective numeracy[11,14], math anxiety[8], and risk comprehension.[3,4] However, studies have reported that scores on the scale are negatively skewed toward the high end of the scale.[13,34] We included three additional CRT items in our objective numeracy measure, on which performance is typically poorer[33], to address the scale's skewed scores and to capture a broader range of numerical ability. While alternative measures exist, such as the Berlin Numeracy Test[51], designed to overcome the psychometric problems with the Lipkus scale, studies nevertheless have shown stronger positive associations between subjective numeracy and objective numeracy measured using the Lipkus scale than the Berlin Numeracy Test.[52] Some researchers have questioned the inclusion of CRT items with items of numeracy scales.[53] However, previous studies have shown that CRT items load on the same factor as the Lipkus scale items and improve scale structure and reliability when combined.[35-38, 36,37] Moreover, our pattern of results for both experiments was similar when we

excluded the CRT items and our objective numeracy scale included only the Lipkus scale items. The Lipkus scale comprises a mixture of health and non-health related items.[7] A previous study reported poorer performance on math problems presented in the health domain compared to other domains.[32] Using a larger battery of items, in Experiment 2, we did not find any differences in risk comprehension for health and non-health related items and the associations between math anxiety, objective numeracy, subjective numeracy, and risk comprehension did not differ with domain. Thus, it is unlikely that our findings, or those of other studies, were affected by the Lipkus scale containing a mixture of health and non-health related items.

In conclusion, the current findings suggest that math anxiety, objective numeracy, and subjective numeracy are independent constructs that each relate to comprehension of statistical health risks via unique pathways. These findings indicate a multifaceted nature of numerical competencies in the health context and highlight a need to move beyond singular predictors (e.g., objective numeracy) to investigate indirect pathways to risk comprehension. We discovered pathways to poor risk comprehension that were independent of numeracy skills. This finding implies that government policies and education initiatives may be most effective if targeted at math emotions and self-evaluations, in addition to training math skills, recognizing the multifaceted nature of numerical competence.

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Table 1. Participant demographics

	Experiment 1 (n = 1,011)	Experiment 2 (n = 940)
	$\bar{x}$ (s) or Percentage	$\bar{x}$ (s) or Percentage
Age	33.77 (11.77)	30.42 (11.76)
Age range	18-74	18-70
Female gender	61%	71%
Highest educational attainment		
High school	11%	12%
Some college	41%	41%
University degree	31%	33%
Postgraduate course	18%	12%
Employment		
Full-time	50%	38%
Part-time	21%	25%
Unemployed	10%	17%
Other occupation (e.g., homemaker)	20%	20%
Place of birth		
United States or Canada	70%	49%
UK or Republic of Ireland	24%	26%
Other	6%	25%

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Table 2. Experiment 1: Descriptive statistics and Pearson correlations (n = 1,194)

	M (*SD*)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	
Age (1)	33.76 (11.77)	—								
Male gender (2)	n=398 (39%)	-.01	—							
Education (3)	1.56 (0.90)	.04	-.10*	—						
Objective numeracy (4)	10.54 (2.83)	-.01	-.12**	.25**	(.80)					
Subjective numeracy (5)	4.40 (1.01)	.07*	.24**	.11**	.52**	(.87)				
Math anxiety (6)	1.97 (0.79)	-.09*	-.20**	-.15**	-.44**	-.62**	(.93)			
Health anxiety (7)	1.72 (0.54)	-.10**	-.05	-.13**	-.23**	-.19**	.43**	(.93)		
Generalized anxiety (8)	1.83 (0.75)	-.22**	-.14**	-.07*	-.16**	-.21**	.40**	.52**	(.92)	
Risk comprehension (9)	8.60 (5.05)	.02	.01	.23**	.70**	.45**	-.35**	-.17**	-.09*	(.69)

Note. *$p \leq .05$, **$p \leq .001$, 2-tailed significance. Cronbach α values are shown in parenthesis. Education was coded as: 0 = high school; 1 = some college; 2 = university degree; and 3 = postgraduate degree.

Table 3. Linear regression models used to predict risk comprehension scores

	Experiment 1 (n = 1,194)			Experiment 2 (n = 940)		
	Unstandardized beta			Unstandardized beta		
Included	Model 1a	Model 2a	Included	Model 1b	Model 2b	Model 3b
Age	0.01	0.00	Age	-0.01	-0.01	-0.01
Male gender	-0.35*	-0.42**	Male gender	-0.12	-0.17	-0.17
Objective numeracy	0.52**	0.48**	Objective numeracy	0.45**	0.43**	0.47**
Education	.10	.11	Education	.12	.10	.10
Math anxiety	-0.22*	0.00	Math anxiety	-0.27**	-0.14	-0.15
Health anxiety	-0.01	-0.07	Health anxiety	-0.15	-0.21	-0.23
Generalized anxiety	0.12	0.12	Domain	-0.01	0.00	0.22
Subjective numeracy		0.33**	Subjective numeracy		0.21**	0.17
			Objective numeracy × Domain			-0.07
			Math anxiety × Domain			0.02
			Health anxiety × Domain			0.03
			Subjective numeracy × Domain			0.08

Note. *$p \leq .05$, **$p \leq .001$. Education was coded as: 0 = high school; 1 = some college; 2 = university degree; and 3 = postgraduate degree.

Table 4. Experiment 2: Descriptive statistics and Pearson correlations (n = 940)

	M (*SD*)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	
Age (1)	30.42 (11.76)	—							
Male gender (2)	n=277 (29%)	.05	—						
Education (3)	1.46 (0.86)	.13**	-.07*	—					
Objective numeracy (4)	9.33 (2.85)	-.02	.05	.07*	(.75)				
Subjective numeracy (5)	4.11 (1.07)	.06	.21**	.14**	.42**	(.84)			
Math anxiety (6)	2.16 (0.86)	-.09*	-.19**	-.10*	-.44**	-.54**	(.93)		
Health anxiety (7)	1.84 (0.56)	-.12**	-.04	-.05	-.26**	-.11**	.43**	(.93)	
Risk comprehension (8)	8.07 (2.12)	-.04	.02	.10*	.65**	.37**	-.38**	-.21**	(.67)

Note. *$p \leq .05$, **$p \leq .001$, 2-tailed significance. Cronbach α values are shown in parenthesis. Education was coded as: 0 = high school; 1 = some college; 2 = university degree; and 3 = postgraduate degree.

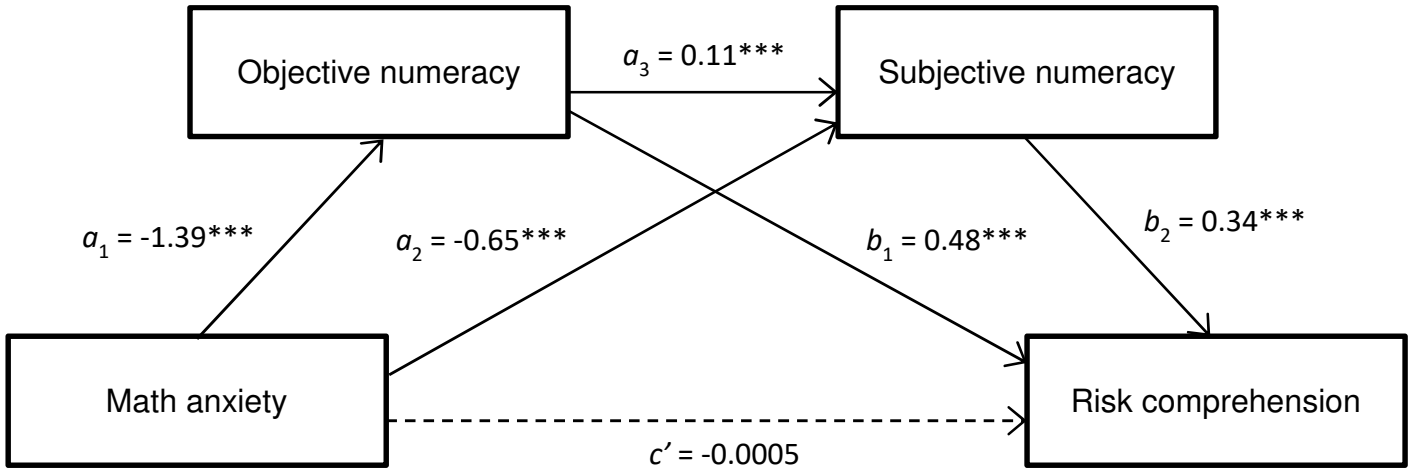

Figure 1. Mediation analysis. The model assessed effects of math anxiety on risk comprehension via objective numeracy ($a_1 * b_1$ = indirect pathway 1), subjective numeracy ($a_2 * b_2$ = indirect pathway 2), and objective and subjective numeracy ($a_1 * a_3 * b_2$ = indirect pathway 3), as well as the unmediated direct effect (c') of math anxiety on risk comprehension. Gender, education, generalized anxiety, and health anxiety were included as covariates.

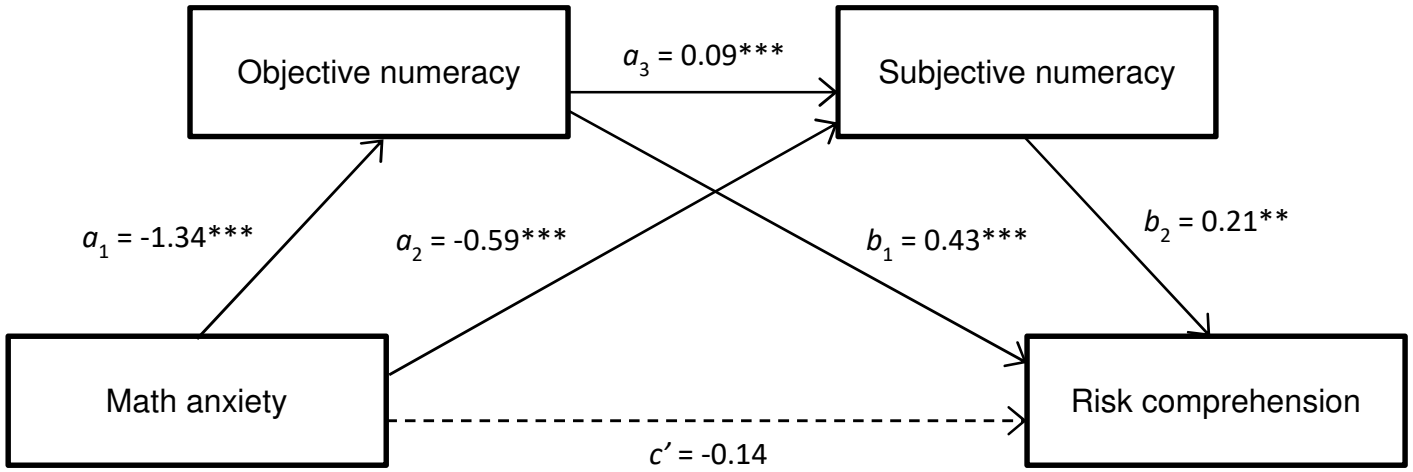

Figure 2. Mediation analysis. The model assessed effects of math anxiety on risk comprehension via objective numeracy ($a_1 * b_1$ = indirect pathway 1), subjective numeracy ($a_2 * b_2$ = indirect pathway 2), and objective and subjective numeracy ($a_1 * a_3 * b_2$ = indirect pathway 3), as well as the unmediated direct effect (c') of math anxiety on risk comprehension. Gender, education, and health anxiety were included as covariates. Generalized anxiety was removed from the model vis a vis Figure 1.