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Understanding Health Risk Comprehension: The Role of Math Anxiety, Subjective Numeracy, and Objective Numeracy

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1 Running head: Understanding health risk comprehension

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

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6 Jonathan J Rolison, PhD¹

7 Kinga Morsanyi, PhD²

8 Ellen Peters, PhD³

9

10 ²Department of Psychology

11 University of Essex, Essex, UK

12

13 ²School of Psychology

14 Queen's University Belfast, Belfast, UK

15

16 ³School of Journalism and Communication

17 University of Oregon, Eugene, OR, USA

18

19 Address for correspondence: Jonathan J. Rolison, Department of Psychology,

20 University of Essex, Essex, CO4 3SG, Telephone: +44 (0)1206 874882

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Abstract

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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.

53 People face important decisions about their health care and treatment that often re-
54 quire an understanding of statistical concepts, including percentages, frequencies, and proba-
55 bilities.¹⁻⁴ Health authorities recommend patient involvement in decisions about their health
56 care and treatment and encourage the provision of statistical information to inform patient de-
57 cision making.^{5,6} A wealth of research has shown, however, that comprehension of health-re-
58 lated statistical concepts (e.g., lifetime risk, relative risk reduction) is poor among the general
59 public.^{1,3,7,8} Low objective numeracy—assessed with a math test—has been identified as a
60 key factor underlying poor risk comprehension.^{3,4,6,7} Higher math anxiety,^{8,9} which is charac-
61 terized by negative emotions about performing numerical tasks,¹⁰ and lower subjective nu-
62 meracy (self-evaluations of numerical competence) are also associated with poor risk com-
63 prehension.¹¹ We investigated whether math anxiety, subjective numeracy, and objective nu-
64 meracy have independent associations with health risk comprehension. Our goal is to shed
65 light on the various pathways to poor risk comprehension to help inform policies aimed at
66 improving patient decision making by targeting the barriers to risk comprehension.

67 Basic numeracy skills are poor among the general public.^{7,13,14} In one study, only 57%
68 of a nationally representative sample of adult Americans correctly reported a person’s risk of
69 disease in the next 10 years when the risk was double that of another person, whose risk was
70 1 in 100.¹³ Individuals with poorer numerical ability are more likely to fail risk comprehen-
71 sion tests, such as by misunderstanding lifetime risks of prostate cancer following genetic
72 testing³ or by misinterpreting risk of death from breast cancer with and without mammogra-
73 phy⁴. Subjective numeracy scales, measuring self-reported numerical abilities (e.g., “How
74 good are you at working with percentages?”) have been developed as proxies for objective
75 numeracy, circumventing the need to administer a math test.^{11,14} Fagerlin et al.¹¹ proposed
76 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

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

110 A relationship also exists between math anxiety and other forms of anxiety, including
111 test anxiety and generalized anxiety.^{22,28} Nevertheless, math anxiety remains correlated with
112 math performance after controlling for test anxiety and generalized anxiety,²² confirming its
113 distinct association with math performance. Health anxiety, which is characterized by unreal-
114 istic concerns about one's health, is correlated with various other anxiety disorders.²⁹ In the
115 Rolison et al.⁸ study, the association between math anxiety and comprehension of statistical
116 health risks may have been confounded by comorbid anxieties, namely health anxiety, pro-
117 voked by the narrative content of the health risk comprehension problems. We investigated
118 whether math anxiety is associated with risk comprehension even after controlling for health
119 anxiety and generalized anxiety.

120 Less well known is the relation of math anxiety with subjective numeracy. However,
121 in Rolison et al.,⁸ math anxiety was more strongly associated with confidence in comprehen-
122 sion than with correct comprehension, such that math anxious individuals were less confident
123 in their comprehension. Investigations of math anxiety in educational contexts have also
124 found strong correlations between measures of math anxiety and confidence.²² As confidence
125 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

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

155 **EXPERIMENT 1**

156 **Method**

157 *Participants*

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

166 *Materials and Procedure*

167 *Objective numeracy:* Objective numeracy was assessed with the 11-item Lipkus et al.⁷
168 scale and three cognitive reflection items (see Appendix A).³³ The Lipkus et al. scale includes
169 3 items that assess general understanding of chance and probability and 8 items that assess
170 understanding of disease risk, such as converting percentages to frequencies.⁷ The cognitive
171 reflection items assess the ability to produce a numerically correct response by applying a
172 normative rule and resisting an intuitively appealing response.³³ We combined the Lipkus et
173 al.⁷ scale items and cognitive reflection items to extend the scale's range of difficulty as total
174 scores tend to be negatively skewed toward the high end of the scale for the Lipkus et al.⁷

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

182 *Subjective numeracy:* Subjective numeracy was assessed with an 8-item scale devel-
183 oped by Fagerlin et al.¹¹ The scale assesses self-reported ability to work with numerical infor-
184 mation (e.g., ‘how good are you at working with percentages?’) on a 6-point scale, ranging
185 from ‘not at all good’ (value of 1) to ‘extremely good’ (value of 6), and preferences for nu-
186 merical formats of information (e.g., ‘how often do you find numerical information to be use-
187 ful? [1 = ‘never’, 6 = ‘very often’]) on a 6-point scale. Overall subjective numeracy was cal-
188 culated as the mean score across the 8 items (Cronbach $\alpha = .87$).

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

196 *Generalized anxiety:* Generalized anxiety was assessed with the 7-item generalized
197 anxiety disorder scale (GAD),³⁹ which assesses mild to severe levels of generalized anxiety
198 based on self-reported frequency of anxiety symptoms over the last 2 weeks (e.g., ‘feeling
199 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 $\alpha = .92$).

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 $\alpha = .93$).

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*

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

227 *Option 1: The patient will not require further treatment*

228 *Option 2: The patient will require further treatment*

229 *Option 3: The patient has equal chances that they will or will not require fur-*
230 *ther treatment*

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

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

239 **Results**

240 Participants responded correctly to a mean of 8.61 ($s = 2.20$) of the 12 risk compre-
241 hension items. Table 2 provides the intercorrelations among variables. Higher risk compre-
242 hension scores were associated with higher objective and subjective numeracy and lower
243 math anxiety, health anxiety, and generalized anxiety. Higher objective numeracy was associ-
244 ated with higher subjective numeracy and lower math anxiety, health anxiety, and generalized
245 anxiety. Math anxiety was positively associated with health anxiety and generalized anxiety.

246 ***Multiple linear regression analysis on risk comprehension***

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

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

264 *Mediation analysis on risk comprehension*

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

¹The 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 ($b = .16, t = 2.70, p = .007$).

²This 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.

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

283 The total effect of math anxiety on risk comprehension was significant ($c = -.939$, 95%
284 CIs = -1.122 : -0.756 ; $p < .001$). Nevertheless, once the mediators were entered into the re-
285 gression, the direct association between math anxiety and risk comprehension was no longer
286 significant ($p = .995$). Additionally, our mediation analysis revealed that all three indirect
287 pathways were significant. Specifically, there was a significant indirect association of math
288 anxiety with risk comprehension via objective numeracy (i.e., indirect pathway 1; $b = -0.669$,
289 95% CIs = -0.816 : -0.537), objective and subjective numeracy in serial (indirect pathway 2; b
290 = -0.521 , 95% CIs = -0.081 : -0.031), and via subjective numeracy (indirect pathway 3; $b = -$
291 0.217 , 95% CIs = -0.313 : -0.129 ; Figure 1). The ratio of the indirect to the total effect can be
292 used as an effect size statistic for the mediation effects.⁴³ These results indicated that the me-
293 diational effect of objective numeracy for math anxiety was large (.71), whereas the media-
294 tional effects of objective and subjective numeracy in serial (.06) and subjective numeracy

295 (.23) were small. Regarding the covariates, education was a significant covariate ($p < .0001$;
296 95% CIs = 0.267: 0.549); the effect of generalized anxiety ($p = .055$; 95% CIs = -0.005:
297 0.396) approached significance, whereas gender ($p = .212$) and health anxiety ($p = .230$) were
298 non-significant covariates.³ In sum, our mediation analysis supported our mediation hypothe-
299 ses, demonstrating that objective and subjective numeracy mediated the association between
300 math anxiety and risk comprehension and that subjective numeracy partially mediated the as-
301 sociation between objective numeracy and risk comprehension.

302 **EXPERIMENT 2**

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

312 **Method**

313 *Participants*

314 One thousand four hundred twenty-three participants were invited to participate in a
315 study of their understanding of statistical health risks using online public and private recruit-
316 ment platforms. Of these, 1,261 consented to participate and 940 participants completed the
317 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.

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

322 *Materials and Procedure*

323 As in Experiment 1, participants completed the objective numeracy, subjective nu-
324 meracy, math anxiety, and health anxiety scales. Experiment 1 demonstrated that math anxi-
325 ety was a significant predictor of risk comprehension after controlling for the effects of gen-
326 eralized anxiety and health anxiety. Nevertheless, we included the health anxiety scale as a
327 covariate in Experiment 2, as we were interested in potential differences in the effects of
328 math anxiety on risk comprehension between the health and non-health domains after con-
329 trolling for potential effects of health anxiety.

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

339 Participants first completed the health anxiety scale, followed by the subjective nu-
340 meracy scale, math anxiety scale, risk comprehension items, and finally, the objective numer-
341 acy scale. Participants were randomly assigned to complete either the health ($n = 476$; 50%)
342 or non-health version of the risk comprehension items.

343 **Results**

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

351 ***Multiple linear regression analysis on risk comprehension***

352 Provided in Table 3 are the results of our linear regression analysis on total risk
353 comprehension scores. Age, gender, education, objective numeracy, math anxiety, health
354 anxiety, and domain were included in Model 1b. Subjective numeracy was included in Model
355 2b to assess effects of math anxiety after controlling for subjective numeracy. Interaction
356 terms involving domain were included in Model 3b to test for moderating effects of domain
357 on objective numeracy, math anxiety, health anxiety, and subjective numeracy. Higher objective
358 numeracy was associated with higher risk comprehension scores (Model 1b; Table 3).
359 Controlling for objective numeracy, higher math anxiety was associated with lower risk com-
360 prehension scores (Model 1b; Table 3). Controlling for math anxiety, health anxiety was not
361 significantly associated with risk comprehension (Model 1b; Table 3). Moreover, risk com-
362 prehension did not differ depending on whether the scenarios related to the health or non-
363 health domain (Model 1b; Table 3). In a second model, higher subjective numeracy was asso-
364 ciated with higher risk comprehension scores and, controlling for subjective numeracy, math
365 anxiety was no longer significantly associated with risk comprehension (Model 2b; Table 3).
366 In our final model (Model 3b; Table 3), domain (i.e., health vs. non-health) did not moderate
367 effects of objective numeracy, math anxiety, health anxiety, or subjective numeracy on risk

368 comprehension scores.⁴ In sum, our multiple linear regression analysis replicated Experiment
369 1's findings and revealed no effects of risk-comprehension domain.

370 *Mediation analysis on risk comprehension*

371 In our mediation model (Figure 2), we followed the procedure introduced in Experi-
372 ment 1 to test the indirect effect of math anxiety on risk comprehension via objective numer-
373 acy (indirect pathway 1), objective and subjective numeracy in serial (indirect pathway 2),
374 and via subjective numeracy (indirect pathway 3). Gender, education, and health anxiety
375 were included as covariates. The total effect of math anxiety on risk comprehension was sig-
376 nificant ($c = -.868$, 95% CIs = -1.039: -0.696; $p < .0001$). Nevertheless, once the mediators
377 were entered into the regression, the direct effect of math anxiety was no longer significant (p
378 = .108). Our mediation analysis confirmed that all three indirect effects were significant. Spe-
379 cifically, there was a significant indirect effect of math anxiety on risk comprehension via ob-
380 jective numeracy (i.e., indirect pathway 1; $b = -0.581$, 95% CIs = -0.702: -0.473), objective
381 and subjective numeracy in serial (indirect pathway 2; $b = -0.025$, 95% CIs = -0.045: -0.010),
382 and via subjective numeracy (indirect pathway 3; $b = -0.122$, 95% CIs = -0.208: -0.049).⁵ The
383 ratios of the indirect to the total effect indicated that the mediational effect of objective nu-
384 meracy for math anxiety was large (.67), whereas the mediational effects of objective and
385 subjective numeracy in serial (.03) and subjective numeracy (.14) were small. Regarding the
386 covariates, health anxiety was the only significant covariate ($p = .027$; 95% CIs = -0.551: -

⁴The 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.

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

387 .033), whereas the effect of education approached significance ($p = .078$).⁶ In sum, our medi-
388 ation analysis replicated Experiment 1's findings regarding the indirect effects of math anxi-
389 ety and objective numeracy on risk comprehension.

390 **GENERAL DISCUSSION**

391 What are the barriers to comprehension of statistical health risks? Previous research
392 has identified objective numeracy,⁴ subjective numeracy,¹¹ and math anxiety⁸ as predictors of
393 risk comprehension. Yet, no previous study has explored whether these constructs have inde-
394 pendent associations with risk comprehension. In the current investigation, we explored the
395 effects of math anxiety, subjective numeracy, and objective numeracy together to shed light
396 on the determinants of poor risk comprehension. We found that subjective and objective nu-
397 meracy were directly associated with risk comprehension. Math anxiety was directly associ-
398 ated with risk comprehension when controlling for objective numeracy, but not when control-
399 ling for both objective and subjective numeracy. We discovered three indirect pathways of
400 math anxiety to risk comprehension, including via objective numeracy, subjective numeracy,
401 and via objective and subjective numeracy in serial, whereby subjective numeracy mediated
402 effects of objective numeracy after controlling for effects of math anxiety on objective nu-
403 meracy.

404 Rolison et al.⁸ reported that higher math anxiety was associated with poorer compre-
405 hension of absolute and relative risk reductions associated with medical treatments, but not
406 after controlling for objective numeracy. Our current findings replicate the previously re-
407 ported mediating effect of objective numeracy, even after controlling for individual differ-

⁶The 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.

408 ences in health and generalized anxiety. This finding implies that the effect of anxiety on ob-
409 jective numeracy is specific to anxiety about math problems. The indirect effect of math anxi-
410 ety is likely to be a consequence of the tendency for math anxious individuals to rate their
411 skills as lower, have less confidence, and avoid opportunities to respond to current math-re-
412 lated problems or to take advantage of earlier math education, limiting their development of
413 numeracy skills.^{21,22}

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

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

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

442 The current findings imply a multifaceted nature of numerical competencies under-
443 lying risk comprehension. Subjective numeracy scales have often been used as a proxy for
444 actual numerical abilities,^{11,14} despite offering a poor diagnostic tool for assessing objective
445 numeracy.¹⁵ In the current experiments, objective numeracy had a direct effect on risk com-
446 prehension and an indirect effect via subjective numeracy, implying that objective and sub-
447 jective numeracy have independent associations with risk comprehension even though they
448 are related. The serial pathway from objective numeracy to risk comprehension via subjective
449 numeracy has been supported in other studies by structural equation model analysis in which
450 reversing the path between objective numeracy and subjective numeracy results in a poorer
451 model fit.¹⁹ Similarly, in an intervention study designed to improve numeracy with a statistics
452 course combined with values affirmation, the alternative model with a pathway leading from
453 subjective numeracy to risk comprehension via objective numeracy fitted the data less well
454 than a pathway leading from objective numeracy to risk comprehension via subjective numer-
455 acy.²⁰ A clinical implication of our findings is that subjective numeracy may be an inadequate
456 proxy for numerical ability as it does not fully account for the association between objective

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

466 Levy et al.³² reported that performance on math problems posed in the health domain
467 was poorer than for problems that had a financial or purer math content. Their finding reso-
468 nates with a view that health numeracy is a separate construct to general numerical ability.³⁰⁻
469 ³² A possible interpretation of their finding is that health-related information provokes anxiety
470 that interferes with performance. However, using a larger battery of risk comprehension prob-
471 lems (i.e., 12 items) than Levy et al. (4 items),³² we did not find differences in risk compre-
472 hension between problems posed in health and non-health domains. Moreover, effects of math
473 anxiety, subjective numeracy, and objective numeracy did not depend on domain, suggesting
474 that they each have domain-general effects on risk comprehension. As discussed below, par-
475 ticipants in the current experiments reported relatively low symptoms of health anxiety. If fu-
476 ture research were to assess individuals of higher health anxiety (e.g., with an illness anxiety
477 disorder), domain differences in health comprehension may occur due to impairing effects of
478 anxiety.

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

481 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.

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

506 objective numeracy, and better risk comprehension. Thus, the high educational attainment of
507 our samples may have suppressed an even stronger association between math anxiety, subjective
508 and objective numeracy, and risk comprehension. Future research could target individuals
509 with low educational attainment where math anxiety is likely to be higher and subjective
510 and objective numeracy lower, addressing a sample of the population who are likely to misunderstand
511 numerical health risks. The percentage of participants who failed to complete Experiments
512 1 and 2 (15% & 25%, respectively) was considerable, and thus, effort should be
513 made to maximize participant completion rates if specialist samples are sought in future
514 search.

515 Finally, we measured objective numeracy with the 11-item Lipkus scale and three
516 additional Cognitive Reflection Test (CRT) items in a manner similar to a well-validated
517 Rasch-based measure.³⁷ The Lipkus scale is perhaps the most widely used scale to assess objective
518 numeracy in the context of health risk comprehension and scores on the scale have
519 been shown to correlate highly with subjective numeracy^{11,14}, math anxiety⁸, and risk comprehension.^{3,4}
520 However, studies have reported that scores on the scale are negatively skewed
521 toward the high end of the scale.^{13,34} We included three additional CRT items in our objective
522 numeracy measure, on which performance is typically poorer³³, to address the scale's skewed
523 scores and to capture a broader range of numerical ability. While alternative measures exist,
524 such as the Berlin Numeracy Test⁵¹, designed to overcome the psychometric problems with
525 the Lipkus scale, studies nevertheless have shown stronger positive associations between subjective
526 numeracy and objective numeracy measured using the Lipkus scale than the Berlin
527 Numeracy Test.⁵² Some researchers have questioned the inclusion of CRT items with items
528 of numeracy scales.⁵³ However, previous studies have shown that CRT items load on the
529 same factor as the Lipkus scale items and improve scale structure and reliability when
530 combined.^{35-38, 36,37} Moreover, our pattern of results for both experiments was similar when we

531 excluded the CRT items and our objective numeracy scale included only the Lipkus scale
532 items. The Lipkus scale comprises a mixture of health and non-health related items.⁷ A previ-
533 ous study reported poorer performance on math problems presented in the health domain
534 compared to other domains.³² Using a larger battery of items, in Experiment 2, we did not
535 find any differences in risk comprehension for health and non-health related items and the as-
536 sociations between math anxiety, objective numeracy, subjective numeracy, and risk compre-
537 hension did not differ with domain. Thus, it is unlikely that our findings, or those of other
538 studies, were affected by the Lipkus scale containing a mixture of health and non-health re-
539 lated items.

540 In conclusion, the current findings suggest that math anxiety, objective numeracy,
541 and subjective numeracy are independent constructs that each relate to comprehension of sta-
542 tistical health risks via unique pathways. These findings indicate a multifaceted nature of nu-
543 merical competencies in the health context and highlight a need to move beyond singular pre-
544 dictors (e.g., objective numeracy) to investigate indirect pathways to risk comprehension. We
545 discovered pathways to poor risk comprehension that were independent of numeracy skills.
546 This finding implies that government policies and education initiatives may be most effective
547 if targeted at math emotions and self-evaluations, in addition to training math skills, recogniz-
548 ing the multifaceted nature of numerical competence.

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Table 1. Participant demographics

	Experiment 1 (<i>n</i> = 1,011)	Experiment 2 (<i>n</i> = 940)
	\bar{x} (<i>s</i>) or Per- centage	\bar{x} (<i>s</i>) or Per- centage
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 ($n = 1,194$)

	<i>M (SD)</i>	(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

Included	Experiment 1 (<i>n</i> = 1,194)		Included	Experiment 2 (<i>n</i> = 940)		
	Unstandardized beta			Unstandardized beta		
	Model 1a	Model 2a		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 × Do- main			0.02
			Health anxiety × Do- main			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 ($n = 940$)

	<i>M (SD)</i>	(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.

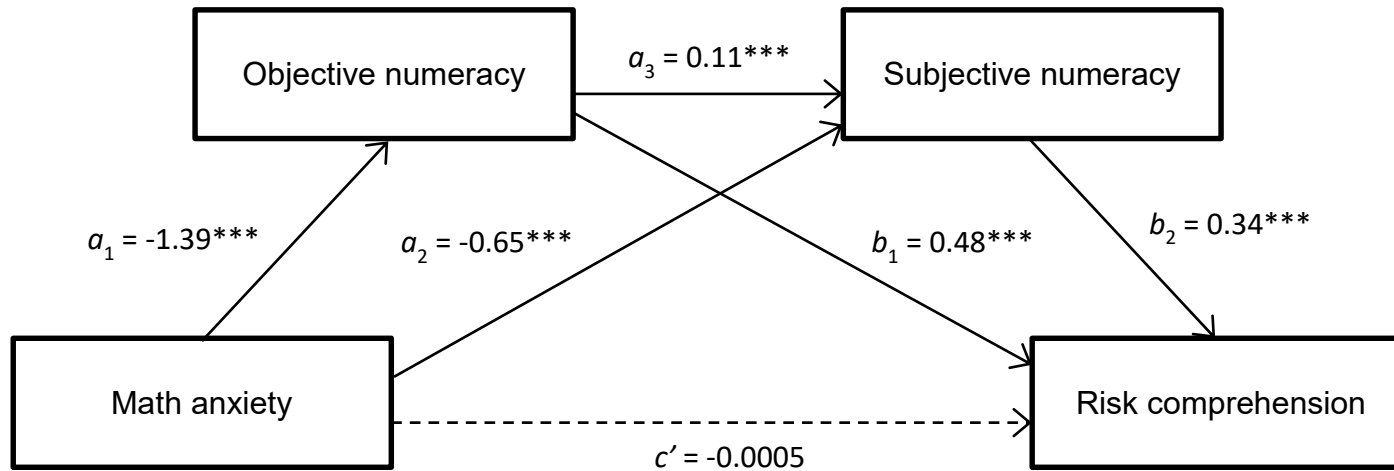


Figure 1. Mediation analysis. The model assessed effects of math anxiety on risk comprehension via objective numeracy ($a_1 * b_1 =$ indirect pathway 1), subjective numeracy ($a_2 * b_2 =$ indirect pathway 2), and objective and subjective numeracy ($a_1 * a_3 * b_2 =$ indirect pathway 3), as well as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

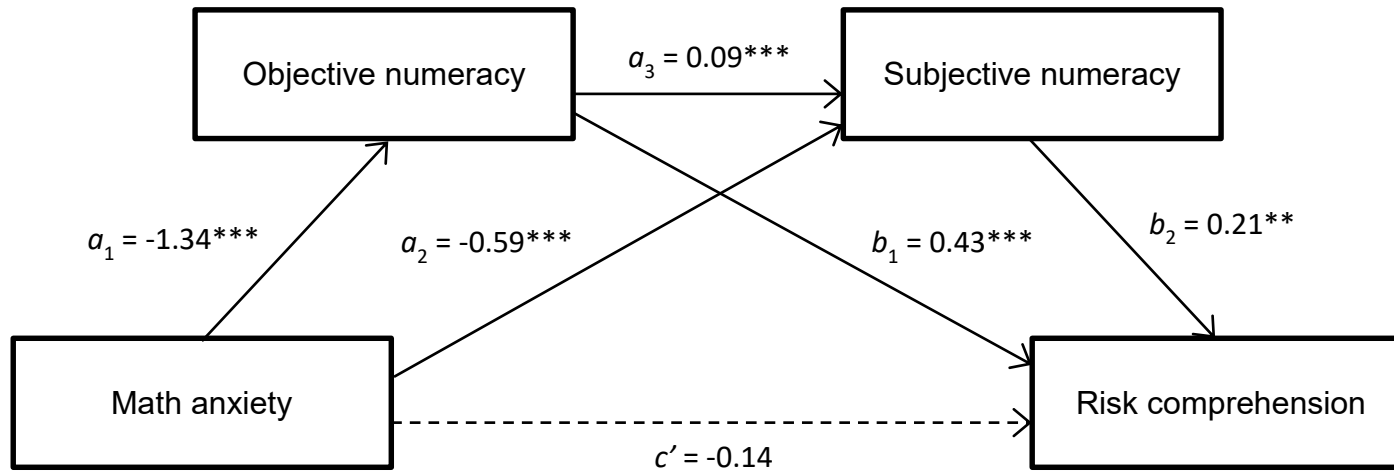


Figure 2. Mediation analysis. The model assessed effects of math anxiety on risk comprehension via objective numeracy ($a_1 * b_1 =$ indirect pathway 1), subjective numeracy ($a_2 * b_2 =$ indirect pathway 2), and objective and subjective numeracy ($a_1 * a_3 * b_2 =$ indirect pathway 3), as well as 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.