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Risk Literacy Promotes Representative Understanding: Numerate People are Less Biased, More Knowledgeable, and More Concerned about Climate Change

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Risk literacy skills, as measured by numeracy tests, are robust predictors of objective knowledge and risk understanding. However, for some people with extreme cultural worldviews, research suggests numeracy might slightly increase polarization of subjective perceptions of climate change risks. Here, we report the first integrated tests linking skills, worldviews, objective knowledge, beliefs, and subjective perceptions among diverse adults. Compared to less numerate people, regardless of cultural worldviews, highly numerate people were 5-8 times more likely to have accurate knowledge and beliefs (52% vs. 24% incorrect), and 3 times more likely to have above average risk perceptions. Structural modeling suggests numeracy may typically promote acquisition of accurate climate change knowledge, which then robustly informs beliefs and perceptions (e.g., up to 40 times stronger influence than worldviews). Even among people with extreme worldviews, rather than amplifying polarization, numeracy was associated with more representative understanding of climate change risks (e.g., well-informed and coherent).

Some people have inaccurate beliefs about the strong scientific consensus on anthropogenic global warming (e.g., 97% expert agreement; Cook et al., 2016), which may complicate climate change risk mitigation (Hayhoe et al., 2018; Leiserowitz et al., 2020). Learning objective knowledge about scientific consensus causally reduces some climate change biases (Ding et al., 2011; Lee et al., 2015; Lewandowsky et al., 2012; van der Linden et al., 2015b). However, differences in cultural worldviews can affect people's willingness or ability to learn about climate change (e.g., motivated reasoning biases; Kahan et al., 2017b). Do differences in risk literacy skills (i.e., the ability to evaluate and understand risk) help people overcome objective and subjective climate change biases, independent of diverse cultural worldviews?

Risk Literacy & Statistical Numeracy

Tests of practical probabilistic numeracy skills, like the Berlin Numeracy Test, tend to be the single strongest general predictors of decision making skill and risk literacy, often doubling the

predictive power of other cognitive ability and intelligence tests (see RiskLiteracy.org, Cokely et al., 2012, 2018). However, numerate people do not typically rely on more unemotional and abstract logical reasoning for superior decision making, but instead leverage their risk reading and interpretation skills to develop a more personally meaningful and representative understanding of risks (e.g., well-informed, intuitive, emotionally-nuanced and internally coherent; see Skilled Decision Theory for a review, Cokely et al., 2018; see also Cokely & Kelley, 2009, Garcia-Retamero & Cokely, 2017; Ghazal et al., 2014; Gigerenzer, 2015; Peters, 2020; Petrova et al., 2016; Reyna et al., 2009). As such, numeracy has been found to robustly predict reduced biases and more accurate risk knowledge across thousands of naturalistic and paradigmatic judgments (e.g., health, wealth, advice, relationships), including judgments in climate and weather contexts (e.g., interpreting forecasts, avoiding weather myths, recognizing flood risks; see Allan et al., 2017, 2020; Cokely et al., 2012; Ramasubramanian et al., 2019).

Despite the robust relations between numeracy and accurate (objective) risk knowledge, one influential study suggests that numeracy may ironically be associated with slight increases in polarization of subjective risk perceptions about climate change, among some people with extreme worldviews (e.g., numerate hierarchical individualists might be more, not less biased; Kahan et al., 2012). Theoretically, the research suggests numerate people could use their skills to generate more biased and self-serving risk evaluations when it is required to protect their prior beliefs and values (e.g., motivated reasoning). While suggestive, interpretations of differences in subjective judgments are complicated because climate change may legitimately imply greater subjective risk for people with some worldviews (e.g., failure to address climate change entails greater risks/costs for people who assume more responsibility to protect others, as compared to

those who do not). Moreover, the study did not assess or document any differences in objective non-normative biases or polarization related to knowledge or personal beliefs.

For these and other reasons, we conducted the first two studies to address neglected roles of objective knowledge and beliefs, testing an integrated cognitive model of the relations between numeracy skills and (objective and subjective) climate change judgments. Using a probabilistically representative sample of the U.S. adult population, Study 1 tested a structural equation model mapping the influence of worldviews and numeracy on accurate knowledge, beliefs, and climate change risk perceptions. Using a convenience sample of diverse U.S. adults, Study 2 provided an out-of-sample test of the model from Study 1, adding a novel test of the role of specific, general, and relative risk perceptions (i.e., risk of climate change compared to risk perceptions about other risks to society in general, such as nuclear power and vaccines).

Does Numeracy Predict Objective and Subjective Risk Understanding?

We constructed and tested a structural equation model of the relations between numeracy, worldviews, knowledge, beliefs, and risk perceptions (see Figure 1) based on Skilled Decision Theory (Cokely et al., 2018), which holds that numeracy's influence tends to cascade from acquisition of accurate knowledge through beliefs to attitudes about risks (Hornsey et al., 2016; Lewandowsky et al., 2012; van der Linden et al., 2015a, 2015b, 2017, 2019). Statistical indices indicated good model fit: $\chi 2(2) = .56$, $p = .76$, CFI = 1.00, TLI = 1.00, SRMR = .00, RMSEA = .00 with 90% C.I (0.00-0.08). The model suggests numeracy tended to be an independent (direct) predictor of expert consensus knowledge ($\beta = .20$, $p < .001$), and had a significant indirect effect on belief in anthropogenic global warming (.12, 95% CI [.08, .27]) and climate change risk perceptions (.04, 95% CI [.02, .11]). Consistent with previous findings, the model

further indicated that accurate knowledge about expert consensus was by far the strongest predictor of belief in anthropogenic global warming (AGW; $\beta = .59$, $p < .001$), which exhibited a strong direct effect on global warming risk perceptions ($\beta = .20$, $p < .001$). All indirect effects were estimated using a bootstrapping method (5,000 bootstraps). Tests of relevant and plausible potential interaction effects were all found to be statistically trivial and unreliable.

Knowledge Predicts Climate Change Beliefs and Attitudes

To provide more context on the relative predictive power of knowledge on belief in anthropogenic global warming, we constructed a binary logistic regression model (see Supplementary Table 4). Independent of potential biases related to cultural worldviews and demographic variables, the odds of agreeing with anthropogenic global warming were roughly 16 times larger among individuals who agreed there was expert consensus, as compared to those who did not (OR = 16.08 with 95% CI [7.85, 32.96] where OR represents odds ratio). A second binary logistic regression model (see Supplementary Table 5) indicated that the odds of having above-average global warming risk perceptions were about 10 times larger for individuals who expressed accurate expert consensus knowledge, as compared to those who did not (OR = 9.93, 95% CI [4.85, 20.35]). These estimated effects held independent of observed biases associated with worldviews. The continuous predicted probability of different beliefs and risk perceptions for different worldview groups was also compared with respect to scores on expert consensus knowledge (see Figure 2).

Numeracy Predicts Objective Knowledge

Binary logistic regressions were used to estimate relations between numeracy and (objective and subjective) climate change risk understanding (see Supplementary Table 6). Statistical numeracy was a significant predictor of accurate (objective) knowledge about expert consensus: Independent of cultural worldviews and demographic variables, individuals with the highest numeracy score (i.e., 7 correct) were approximately 8 times more likely to have accurate knowledge about expert consensus as compared to individuals with the lowest numeracy score (i.e., 0 correct; OR = 1.35 with 95% CI [1.16, 1.58]). The relationship between numeracy and predicted probabilities for each of the dichotomized outcome variables across the entire range of numeracy (0-7) was also computed and plotted across numeracy scores for average and extreme cultural worldview groups, based on bootstrapped binary logistic regression model estimates (see Figure 3).

Numeracy Predicts Beliefs and Risk Perceptions

A binary logistic regression predicting belief in anthropogenic global warming indicated that individuals with the highest numeracy score were nearly 5 times more likely to personally agree with anthropogenic global warming, as compared to those with the lowest numeracy score (see Supplementary Table 7; OR = 1.27 with 95% CI [1.11, 1.46]). Although the integrated SEM cognitive model revealed that the relationship between numeracy and global warming risk perception was fully mediated by expert consensus knowledge, we estimated the strength of indirect relations using a binary logistic regression model. The model indicated that the odds of having above-average global warming risk perceptions were approximately 3 times larger for people with the highest as compared to lowest numeracy scores (see Supplementary Table 8; OR = 1.15 with 95% CI [1.01, 1.31]).

Numeracy Predicts Relative Risk Attitudes

All key analyses and models from Study 1 were replicated in Study 2, providing out-of-sample testing and validation of the model. Again, the structural equation model and logistic regression models revealed that numeracy directly predicted accurate knowledge (β = .13, p < .01), and had indirect effects on beliefs and risk perceptions, independent of cultural worldviews and demographic variables. Expert consensus knowledge again emerged as the strongest predictor of climate change beliefs (β = .63, p < .001) (See Supplementary Figure 1 and Supplementary Table 9-13 for details). However, in Study 2, in addition to all measures from Study 1, we also measured differences in general risk perception (e.g., how risky is climate change and how risky are other general risks such as vaccines, nuclear power, etc.). Accordingly, we constructed and tested an extended, integrated model including all previous variables and the novel domain general risk perception assessment (Ramasubramanian, 2020; see Figure 4). The statistical indices revealed good model fit: $\chi^2(4) = 8.04$, p = .09, with CFI = 1.00, TLI = .97, SRMR = .02, RMSEA = .04 with 90% C.I (0.00-0.09). Consistent with recent evidence, the model indicated that numeracy was negatively related to domain general risk perceptions (β = -.20, p < .001), which in turn predicted specific global warming risk perceptions (β = .13, p < .001). The observed relations were independent of cultural worldviews and demographic variables. Results suggest that while numerate people may appear to be no more worried about the overall risks of climate change as compared to less numerate people (e.g., specific climate change risk perceptions), numerate people perceive the risk of climate change to be much more concerning as compared to other risks faced by society (e.g., less numerate people reported that climate change risks were similar to those of most other risks to society).

To provide more context on the relationship between numeracy and general risk perception, a binary logistic regression was constructed (see Supplementary Table 14) focusing on relative risk perception as an outcome variable. The model estimated the probability of people expressing above-average relative risk perceptions (dichotomized perception of the relative risks) by comparing the difference between (i) specific global warming risk perceptions and (ii) general risk perceptions (e.g., relative risk perception calculated as specific climate change risk perceptions minus average ratings on five other general risks previously identified as broadly representative of common risks to society; Ramasubramanian, 2020). Results indicated that statistical numeracy was again a significant predictor of relative risk perceptions independent of cultural worldviews: Highly numerate individuals were about 3.3 times more likely to have above-average relative risk perceptions as compared to less numerate individuals (OR = 1.19 with 95% CI [1.06, 1.32]).

Discussion

The studies presented here are the first to test an integrated cognitive (structural) model of the relations between general risk literacy skills (i.e., statistical numeracy), values (e.g., cultural worldviews), objective knowledge, personal beliefs, and subjective attitudes about climate change risks (i.e., specific, general, and relative climate change risk perceptions). Both studies were conducted with diverse adult residents of the United States who varied widely or representatively with respect to variables including skills, worldviews, age, education, ethnicity, and gender identities. In contrast to previous studies that have neglected the strong influences of objective knowledge and personal beliefs, the current results revealed that numeracy does not commonly polarize or bias objective or subjective judgments, even among individuals with

extreme worldviews (e.g., robust linear effects with no evidence of interactions or extreme group polarization). Model results instead indicate that numeracy may be generally related to independent prior acquisition of accurate knowledge about climate change (e.g., knowledge of strong scientific consensus), which in turn robustly informs people's personal beliefs and subjective judgments about causes and risks of climate change, independent of other relevant views and values of diverse adults.

Specific, General, and Relative Risk Perceptions. This study is one of the first to demonstrate that numerate people may typically be less worried about most risks to society in general, as compared to less numerate people. While they were less worried in general, numerate people were significantly more worried about the relative risks of climate change compared to other risks faced by society (see Figure 5). In theory, differences in general risk perceptions of numerate people may at least partially reflect the fact that numerate people tend to know more about many risks in general. To the extent this finding generalizes, other studies that fail to measure specific, general, and relative risk perceptions (i.e., specific minus general perceptions) are more likely to derive distorted estimates of people's judgment and reasoning biases (e.g., interpreting differences in the perceived risk of a $5,000 repair, without considering whether the person is a college student or a millionaire). The tendency to neglect these base-line priors may help explain emerging findings showing numeracy consistently predicts risk understanding even when it appears inconsistently related to specific risk perceptions (e.g., numeracy is the strongest predictor of COVID-19 mis/understanding, yet is not always related to specific COVID-19 risk perceptions; Pennycook et al., 2020; Roozenbeek et al., 2020). Put simply, *assessing priors matters* whether one is comparing the risks of potential financial losses, the meaning of

differences in specific risk perceptions, or differences in reasoning biases among people with different experiences, values, or knowledge.

Prior Knowledge is Powerful, Yet Often Neglected. Knowledge was by far the strongest predictor of personal beliefs and risk attitudes about climate change, consistent with theory and previous findings. Despite using just one simple self-report item to assess differences in expert consensus knowledge, the overall average predictive power of knowledge far exceeded that of all others, typically explaining 5-10 times more variance than differences in cultural worldviews. While the magnitude of the relations between knowledge, beliefs, and attitudes may seem impressive, it is generally consistent with findings showing that large differences in performance often result from differences in specialized knowledge, acquired skills, and representative risk understanding (see Skilled Decision Theory, Cokely et al., 2018; Ericsson et al., 2007).

Although some members of the public are predictably biased and misinformed about objective climate change, it is worth noting that most are not. In our representative sample of U.S. residents collected in Spring of 2016, 84% of participants agreed about expert consensus on anthropogenic global warming (i.e., answered 6 or more out of 10; $M = 6.75$, $SD = 2.55$), and 61% held beliefs consistent with the expert consensus ($M = 6.01$, $SD = 2.87$). Moreover, our results and others suggest most people are generally concerned about the growing threat of climate change, even if they do not agree about just how concerned they should be. These rates of knowledge and climate change concern may seem surprising given some popular media and high-profile scientific reporting; however, they are consistent with many findings over the last two decades (Leiserowitz et al., 2020; Weber & Stern, 2011).

Ironically, it seems some scientific studies investigating potential biases of people who might ignore climate change science have ignored differences in people's knowledge of climate change science, resulting in biased scientific estimates of people's climate-change biases. This is problematic for many reasons. For example, it would be rational for a well-informed, numerate public to reject the views of experts if the experts were found to be demonstrably wrong or biased. The current findings serve as a powerful example of the risks and interpretive errors that can result from neglecting differences in knowledge, skills, values, and base-line perceptions, which in-turn may potentially confound theory, justifiably threaten credibility, and misdirect practical applications and critically-needed investments.

Risk Literacy Promotes Acquisition of Accurate Knowledge. Even among people with conflicting and extreme cultural worldviews, the current set of studies indicate that numeracy tends to be robustly associated with more accurate acquired prior knowledge about climate change, which in turn is associated with reduced biases in downstream beliefs and risk attitudes. While results suggest that numeracy is unlikely to polarize subjective attitudes (directly or indirectly), it is possible that numerate people with extreme views may be more likely to selectively evaluate and acquire evidence in biased ways, consistent with their cultural worldviews. In one of the first and only studies attempting to document these potential effects, Kahan and colleagues (2017b) examined differences in interpretation of fictitious evidence about gun control versus rash treatments. The study suggested that more numerate people with extreme worldviews may have applied different standards for accepting/rejecting evidence in self-serving ways. Unfortunately, the relationship between numeracy and prior knowledge (gun control vs. rash treatment) was again neglected in that study. As such, it is unclear if the different judgments in the conditions (guns, rashes) reflected differences in the use of evidence or instead

reflected differences in the interpretation of questions about the evidence, which can happen when prior knowledge is neglected (see Gigerenzer et al., 1999; Reyna, 1991). Moreover, the fictional raw pattern depicted a very weak relationship, which may be further complicated by the fact that, rationally, how one should interpret new evidence is at least partially a function of how much one knows about prior knowledge (e.g., the more one knows, the less valuable any new weak and inconsistent evidence is likely to be).

While we think it is possible that numeracy may sometimes promote polarization in some kinds of reasoning, we caution that such differences will not necessarily imply errors but could instead simply involve well-reflected differences in fundamental values and subjective preferences (e.g., people, including experts, often legitimately disagree about moral issues such as religion, free will, personal responsibility, intentionality; Feltz & Cokely, 2018, Schulz et al., 2011). That said, given the observed presence of a robust relationship between numeracy and accurate knowledge in the current studies, and in many others, we find no compelling evidence indicating that numeracy is generally related to objectively non-normative biases or polarization. Even among those who had extreme worldviews, numeracy was found to be robustly related to accurate knowledge, which was by far the strongest factor influencing judgment accuracy and coherence. The estimated independent association between numeracy and knowledge in the current study was almost 20 times larger than the estimated magnitude of the significant polarization reported in the previous climate change study (Kahan et al., 2012). Consistent with Skilled Decision Theory, these results suggest that even when considering controversial issues and complex conflicts of interest, when there is compelling evidence available (e.g., well-founded expert consensus), numeracy and risk literacy skills are likely to promote independent

297 acquisition of more accurate and representative risk understanding, independent of people's

298 diverse worldviews and values.

299

Methods

Study 1

Data Collection. The representative sample of the U.S. population was collected in Spring of 2016, using a probability-based sampling panel (KnowledgePanel® from GfK). A total of 305 cases were reported for the analysis (see Supplementary Table 3 for demographic characteristics).

Measures.

Statistical Numeracy. The Berlin Numeracy Test (Cokely et al., 2012) and a three-item scale created by Schwartz et al. (1997) were used to assess numeracy and risk literacy (e.g., *In a forest, 20% of the mushrooms are red, 50% are brown, and 30% are white. A red mushroom is poisonous with a probability of 20%. A mushroom that is not red is poisonous with a probability of 5%. What is the probability that a poisonous mushroom in the forest is red?*). Using the two tests together increases sensitivity of the measurement, allowing for a wider range of skill assessment.

Expert Consensus Knowledge. Knowledge in expert consensus about anthropogenic global warming was assessed by asking the extent to which participants agreed with the statement that most experts believe that greenhouse gases cause increases in global temperature (i.e., *According to most experts, are greenhouse gases, such as those resulting from the combustion of coal, oil, natural gas, and other materials, causing average global temperatures to rise?*). The scale ranged from 0 (Strongly disagree) to 10 (Strongly agree).

Belief in Anthropogenic Global Warming (AGW). Belief in anthropogenic global warming (AGW) was measured with an item asking the degree to which participants agreed with the statement that they personally believe that greenhouse gases cause an increase in global

temperature (i.e., *In your view, are greenhouse gases, such as those resulting from the combustion of coal, oil, natural gas, and other materials, causing average global temperatures to rise?*). The scale ranged from 0 (Strongly disagree) to 10 (Strongly agree).

Global Warming Risk Perception. Perceived risk about global warming was measured with one item: *How much risk do you think global warming poses for people and the environment?* The scale ranged from 0 (No Risk) to 10 (Extreme Risk).

Cultural Theory. The 12-item scale from previous studies (e.g., Jones, 2011; Ripberger et al., 2012; Song et al., 2014; Wildavsky & Dake, 1990) was used to measure four indices of cultural theory: individualism (Cronbach's $\alpha = .54$), egalitarianism (Cronbach's $\alpha = .76$), hierarchy (Cronbach's $\alpha = .67$), and fatalism (Cronbach's $\alpha = .58$). Each index was composed of three statements. Respondents rated the degree to which they agree with each statement, from a scale of 1 (Strongly disagree) to 6 (Strongly agree). As one of the items for fatalism was negatively correlated with the other two, the item was excluded. The reported Cronbach's α is after the exclusion. The mean rating for the three statements was used as a score for each cultural theory index.

Demographic Variables. The demographic variables used for the analyses included age (18-99) and gender (male and female). Descriptive statistics of the aforementioned variables are available in Supplementary Table 1.

Study 2

Data Collection. The data was collected via Amazon Mechanical Turk in 2020 late March, during the early phases of the COVID-19 pandemic in America. Out of 1,043 cases, 537 were used for the analyses after excluding the respondents who took too little time, did not pay

attention to the survey (as assessed by attention checks), or completed less than 90% of the survey elements (see Supplementary Table 3 for demographic characteristics).

Measures. All of the same measures from Study 1 were included in Study 2. This includes: (i) statistical numeracy, (ii) expert consensus knowledge (iii) belief in anthropogenic global warming, (iv) global warming risk perceptions, and (v) cultural theory. As in Study 1, only the two of the three items for fatalism were used in analyses for consistency. In addition to the aforementioned measures, domain-general risk perception was included. Descriptive statistics are available in Supplementary Table 2.

Domain-general Risk Perception. Domain-general risk perception items were assessed using the format developed by Kahan et al., (2017a) "How much risk do the following pose for human health, safety and prosperity?". Questions used a scale from 0 (No Risk at All) to 7 (Extremely High Risk). The five risks included (i) motor vehicles, (ii) skiing, (iii) alcohol, (iv) nuclear power, and (v) vaccination (Fischhoff et al., 1978). The proportional mean of the five items was compared to proportional mean of global warming risk perception, which ranged from 0 to 10. The Cronbach's α was .69.

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Author Contributions

Contribution of the first two authors is equal. All authors contributed to conceptualization and interpretation of the research. E.C., M.R., J.A, and J.C. contributed to data collection. J.C. took the lead in data analyses with inputs from E.C.. E.C. and J.C prepared the manuscript. M.R. aided editing the manuscript. A.F. and R.G. provided detailed comments throughout the study. All authors discussed the results and commented on the manuscript.

Competing Interest Statement

The authors declare no competing interests.

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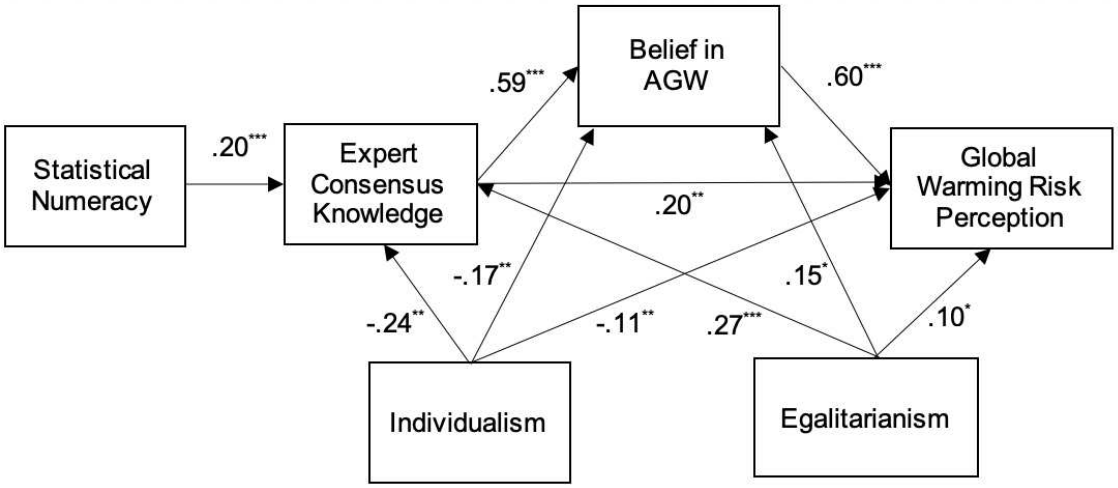
491 **Figure 1**

492 *An Integrated Model of Numeracy, Knowledge, Belief, and Risk Perception*



Note. Reported are standardized coefficients after adjusting for age and gender. The representation does not include paths from hierarchy and fatalism, which were as follows: Hierarchy → Knowledge (β = .01, p = .91), Hierarchy → Belief (β = .01, p = .94), Hierarchy → Risk Perception (β = .07, p = .09), Fatalism → Knowledge (β = .04, p = .61), Fatalism → Belief (β = .12, p < .05), Fatalism → Risk Perception (β = .05, p = .69). *p < .05, **p < .01, ***p < .001

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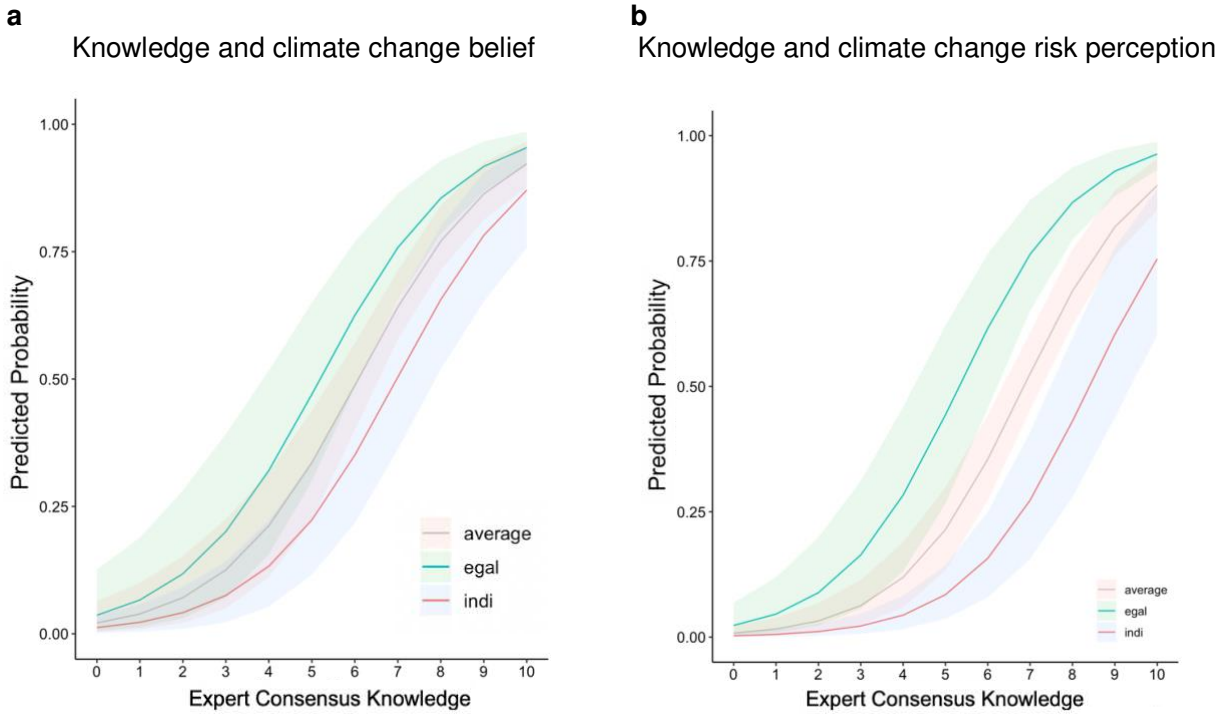
494 **Figure 2**



Note. Results depict the predicted probability for belief in anthropogenic global warming (**a**) and having above-average global warming risk perception (**b**) at different levels of knowledge and cultural worldviews. Individualists (egalitarians) were defined as having individualism (egalitarianism) ratings 1 standard deviation above mean, and egalitarianism (individualism) ratings 1 standard deviation below the mean, while the other worldview indices were held at their mean. The shaded area represents 90% confidence intervals from 1,000 bootstrap iterations.

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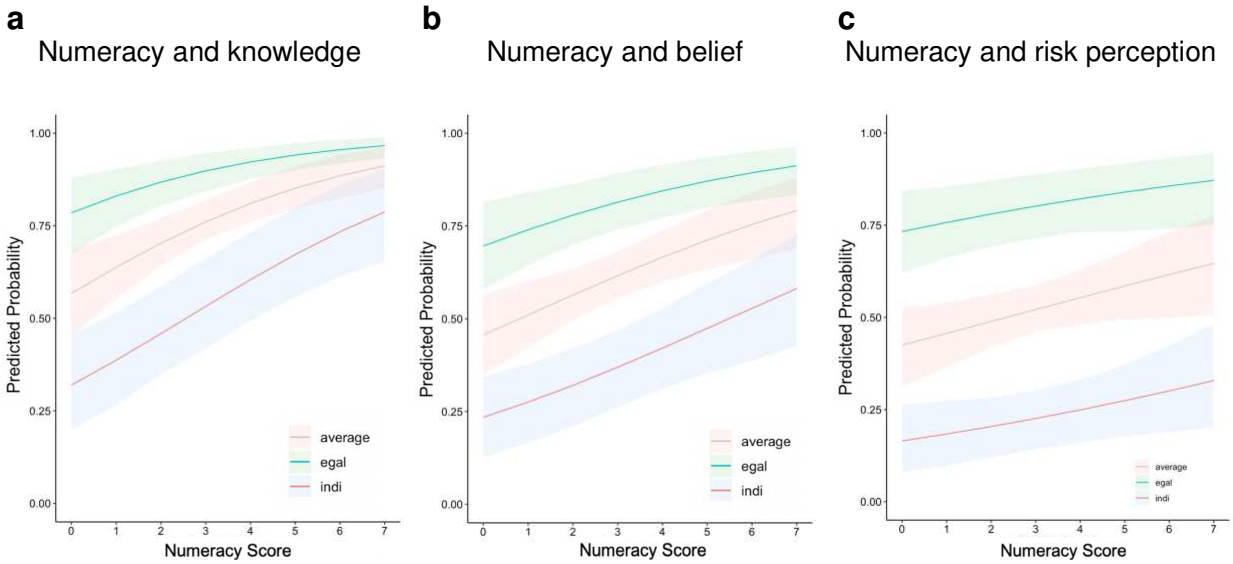
496 **Figure 3**



Note. Results depict the predicted probability of indicating that there is an expert consensus about anthropogenic global warming (**a**), belief in anthropogenic global warming (**b**), and having above-average global warming risk perception (**c**) at different levels of numeracy and cultural worldviews. Individualists (egalitarians) were defined as having individualism (egalitarianism) 1 standard deviation above mean, and egalitarianism (individualism) 1 standard deviation below the mean, while the other worldview indices were held at their mean. The shaded area represents 90% confidence intervals from 1,000 bootstrap iterations.

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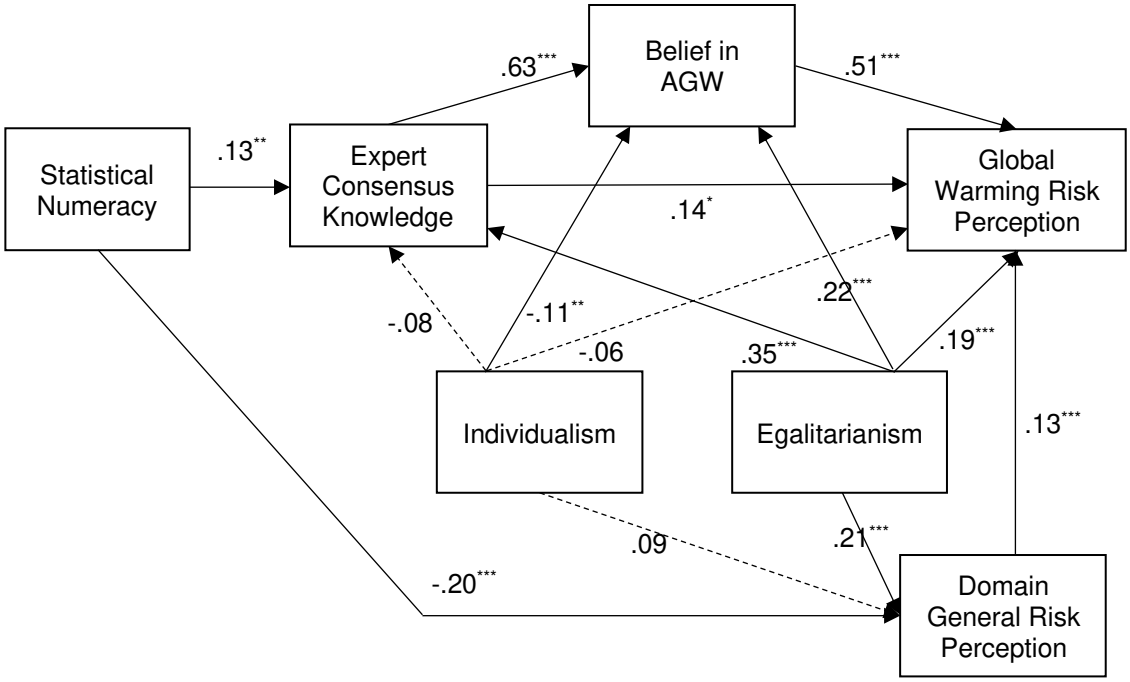
Figure 4

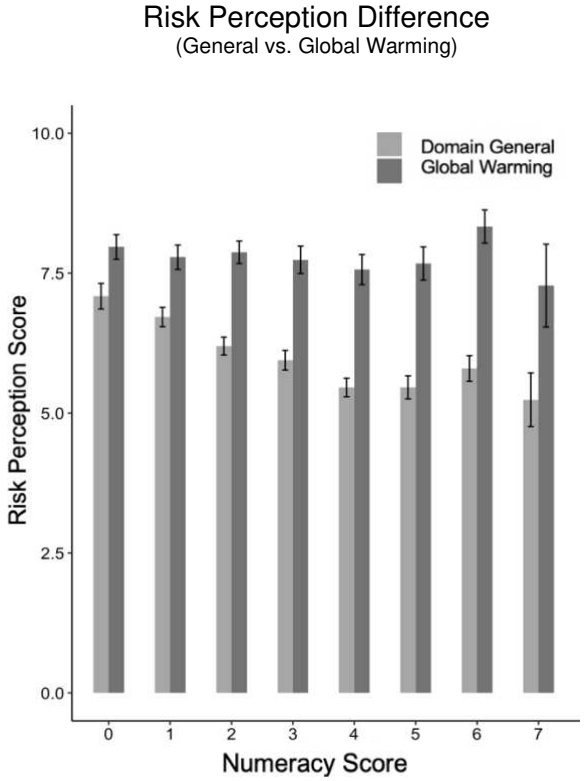
A Structural Equation Model with Domain General Risk Perception



Note. Reported are standardized coefficients after adjusting for age and gender. The representation does not include paths from hierarchy and fatalism, which were as follows: Hierarchy → knowledge (β = -.09, p = .09), Hierarchy → Belief (β = .04, p = .30), Hierarchy → Global Warming Risk Perception (β = .02, p = .54), Hierarchy → General Risk Perception (β = .13, p < .05), Fatalism → Knowledge (β = .04, p = .37), Fatalism → Belief (β = .04, p = .22), Fatalism → Global Warming Risk Perception (β = .03, p = .33), Fatalism → General Risk Perception β =.08, p = .06). *p < .05, **p < .01, ***p < .001

502 **Figure 5**

503 *Numeracy and Differences in Risk Perception (Global warming vs. General)*



Note. Average score of general and global warming risk perception by numeracy score was plotted. Error bars represent standard errors.

504

Figures

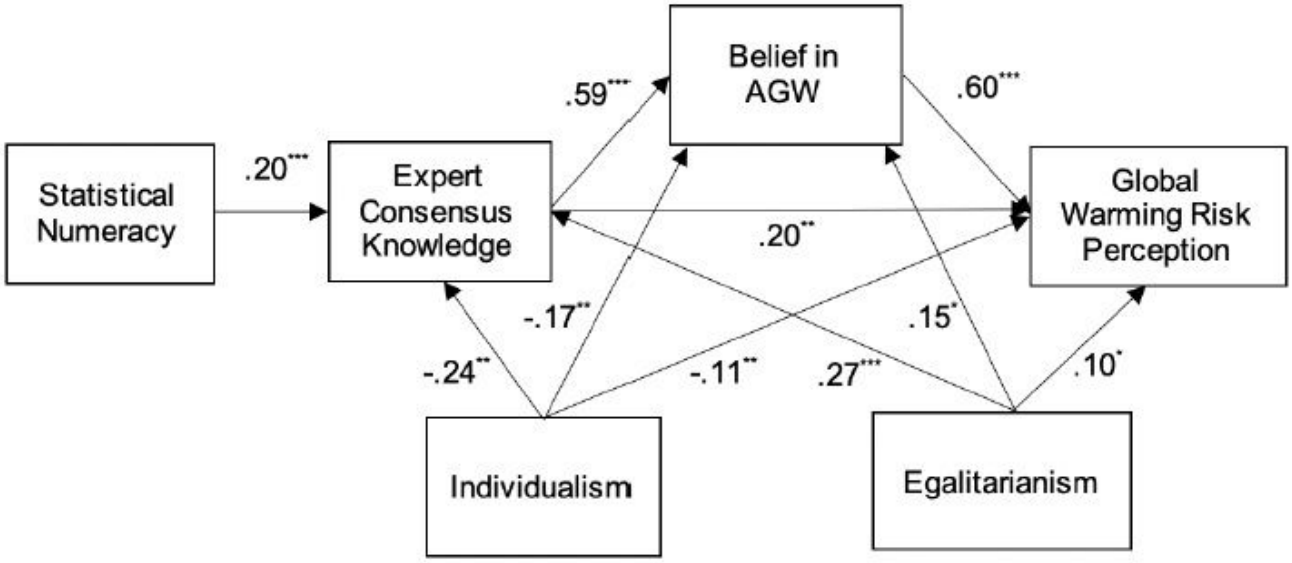


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Figure 1

An Integrated Model of Numeracy, Knowledge, Belief, and Risk Perception

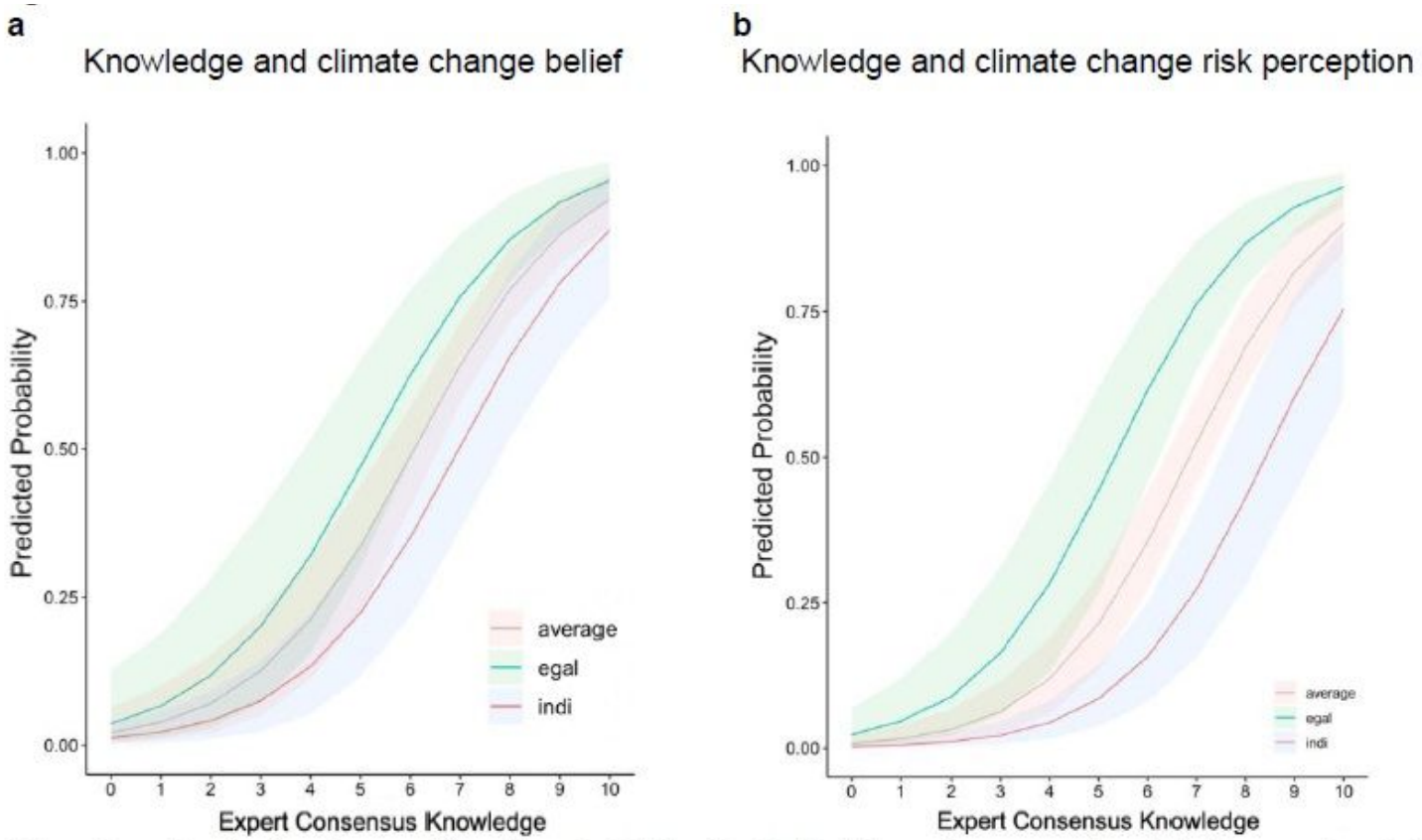

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Figure 2

Expert consensus knowledge

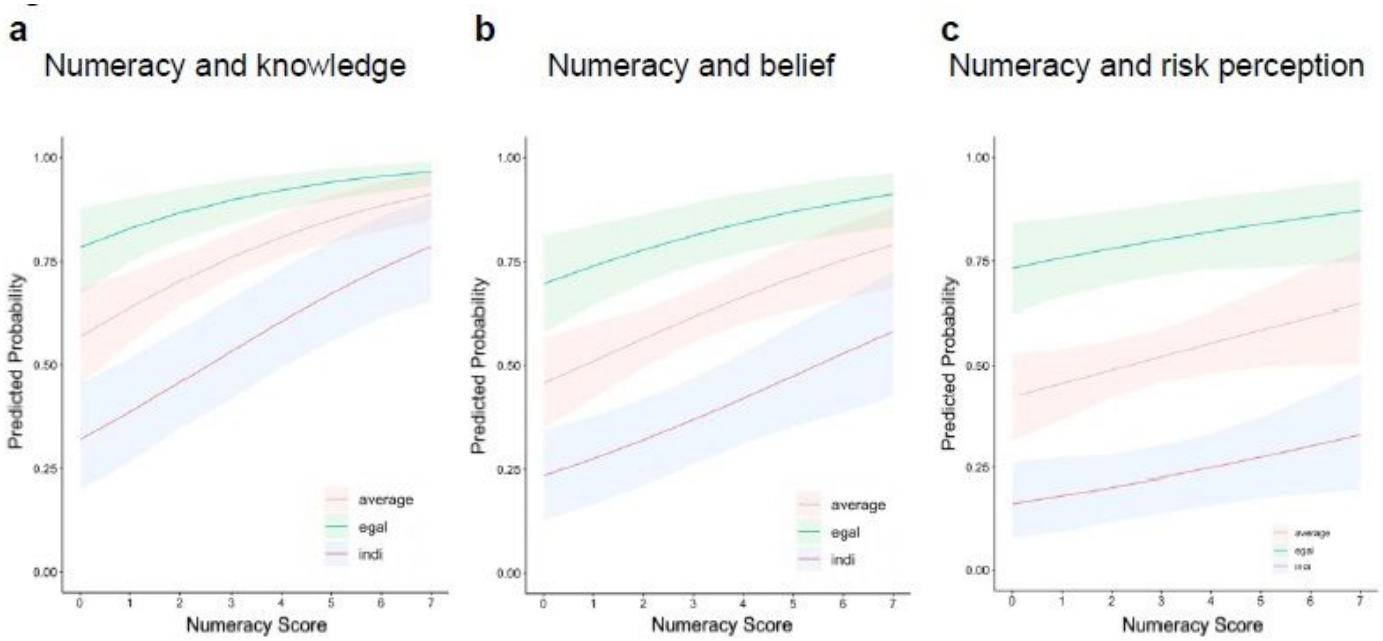

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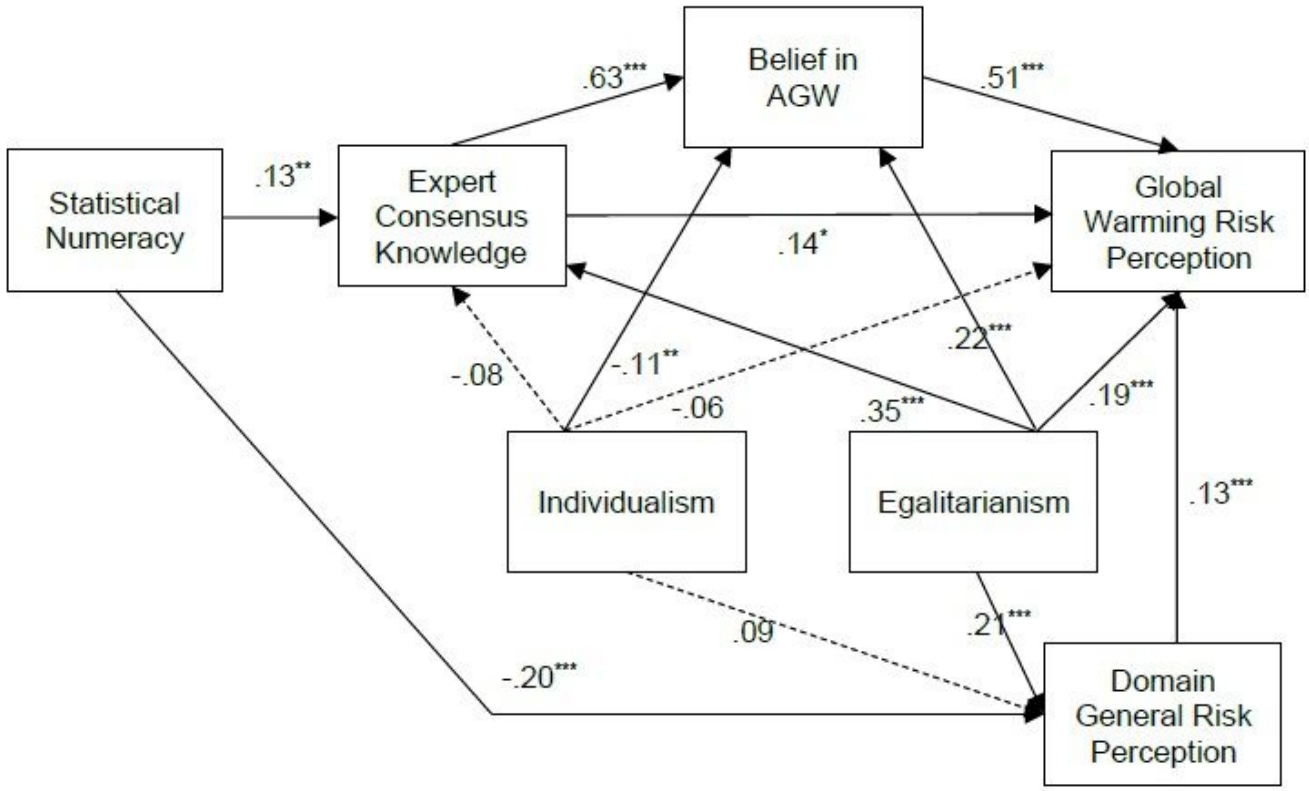
Figure 3

Numeracy score



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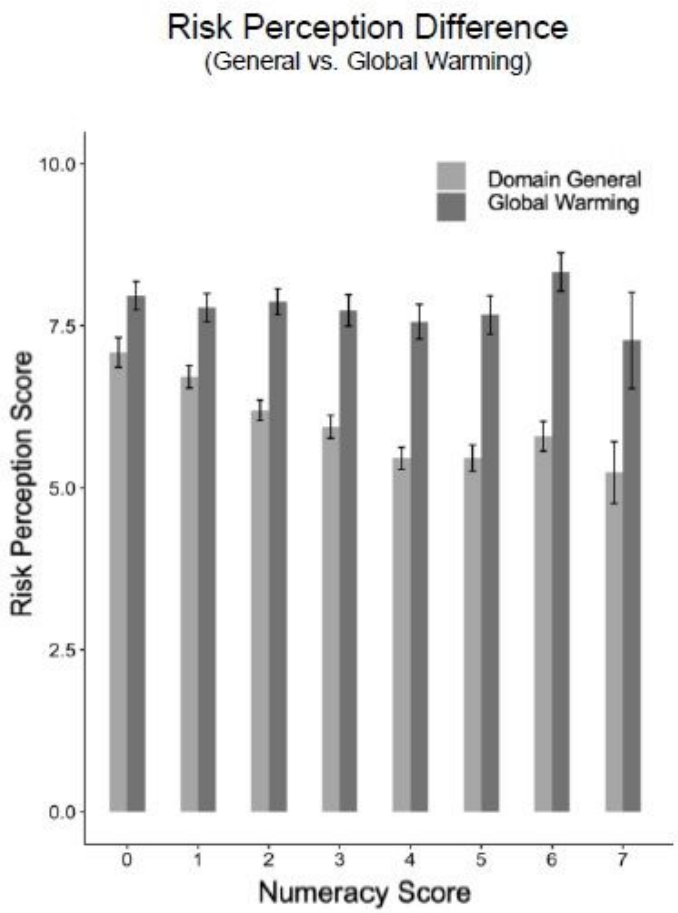

Note. Average score of general and global warming risk perception by numeracy score was plotted. Error bars represent standard errors.

Figure 5

Numeracy and Differences in Risk Perception (Global warming vs. General)

Supplementary Files

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