What if I'm the one? Measuring individual differences in emotional sensitivity to probability and emotional reactivity to possibility

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Abstract

Current theories of risk perception point to the powerful role of emotion and the neglect of probabilistic information in the face of risk, but these tendencies differ across individuals. We propose a method for measuring individuals' emotional sensitivity to probability to assess how feelings about probabilities, rather than the probabilities themselves, influence decisions. Participants gave affective ratings (worry or excitement) to 14 risky events, each with a specified probability ranging from 1 in 10 to 1 in 10,000,000. For each participant, we regressed these emotional responses against item probabilities, estimating a slope (the degree to which emotional responses change with probability) and an intercept (the emotional reaction to an event with a fixed probability). These two parameters were treated as individual difference scores and included in models predicting reactions to several health risk scenarios. Both emotional sensitivity to probability (slope) and emotional reactivity to possibility (intercept) significantly predicted responses to these scenarios, above and beyond the predictive power of other well-established individual difference measures.

What if I'm the one? Measuring individual differences in emotional sensitivity to probability and emotional reactivity to possibility

Imagine two patients, each deciding whether to go ahead with a surgery for a chronic health problem, and each provided with information about possible complications and the probabilities associated with them. Patient A might comprehend and attend to that information, recognize that the probability of a major complication is remote, and agree to the surgery, unworried. However, Patient B may have a solid comprehension of the probabilities, but may nevertheless "tune out" or ignore that information and fearfully fixate on the mere possibility of being that one person out of x people who will die in surgery or experience life-altering complications. For Patient A, the probabilities are informative and help guide decisions. But for Patient B, the statistical information has little impact; the possibilities are simply more salient than the probabilities.

Ideally, risk response should incorporate analysis of probabilities, and economic theories traditionally assumed that such analysis occurred in the absence of emotion. However, current theories emphasize that emotion is neither absent from nor antithetical to rational decision making. Emotion rapidly signals past experiences of danger or pleasure, success or failure, and efficiently guides decisions to approach or avoid (Bechara & Damasio, 2005; Damasio, 1994). Peters and Slovic (2000; Slovic & Peters, 2004) identified what they referred to as the Affect Heuristic, in which risk response is governed largely by global evaluation of the desirability or undesirability of some outcome as an efficient shortcut for making decisions. Loewenstein, Weber, Hsee, and Welch's (2001) Risk As Feelings hypothesis similarly argues that excitement or worry about an event may be more closely tied to the emotional impact of that event than the probability of its occurrence, as illustrated by a hypothetical lottery player whose excitement is scaled to the size of the possible jackpot rather than the vanishingly low probability of actually winning.

Insensitivity to probabilities has been well-documented. Specifically, an inverted S-shaped weighting function demonstrates that people generally overweight small probabilities and underweight medium and large probabilities (Gonzalez & Wu, 1999; Prelec, 1998; Tverky & Kahneman, 1992; Wu & Gonzalez, 1996). This insensitivity is often treated, explicitly or implicitly, as resulting from interference from emotions. Affect-rich outcomes have been shown to further decrease sensitivity to probability compared to affect-poor outcomes (Pachur, Hertwig, & Wolkewitz (2014); Rottenstreich & Hsee, 2001; Suter, Pachur, & Hertwig, 2016). Sunstein and Zeckhauser (2011) state that "emotional activity dampens cognitive activity" (p. 439), causing overreactions to vivid fearsome risks and insensitivity to large differences in probability. Rottenstreich and Hsee (2001) argue that it is affective processes that account for the relative insensitivity to intermediate probabilities between 0 (impossibility) and 1 (certainty). Pachur, et al. (2014) argued that affect-rich prospects are evaluated heuristically, whereas probabilities are incorporated into expected value analysis for affect-poor prospects. The tendency to overlook probability information is often treated as a direct consequence of emotion though some models more explicitly emphasize the complex interaction of the analytical and emotional processing without assuming such a tradeoff (Loewenstein, O'Donoghue, & Bhatia, 2015, Mukherjee 2010). Ferrer and Klein (2015) point out that current models of risk perception generally fail to effectively explain the integration of deliberative and affective processes.

It may be possible to better integrate deliberative and affective processes by mapping probabilities onto an affective scale, allowing for individual differences in that mapping process. We argue that processing probability information is not an alternative to emotional processes in risk evaluation but is interconnected with it. Probabilities serve as a warning about whether something will happen and are translated into emotionally meaningful scales that fuel anticipatory worry or excitement. The rate at which these anticipatory emotions change with respect to changes in probabilities provides a basis for integrating probabilities into decisions that are heavily influenced by emotional processing. In this framework, it is the affective sensitivity to changes in probability alongside of, but nevertheless distinct from, the numeric sensitivity to changes in probability that guides decision making.

As illustrated by our two hypothetical patients, there is good reason to expect meaningful individual differences in the extent to which probability information influences emotional reactions to risk. Some people line up to buy lottery tickets, but others are unwilling to waste even a dollar on a virtually unwinnable gamble. Some people go to great effort to avoid very low-probability dangers or fret about extremely rare diseases, while others barely give these a thought, knowing they will likely never face them. Much of the literature on probability neglect describes the expected response, or what is observed on average for the population as a whole, though a few studies have addressed variability among individuals. An early example comes from Levy & Baron (2005), who measured sensitivity to probability among doctors and laypeople and found significant variability, particularly among laypeople. The superior sensitivity to probabilities among physicians was attributed to some combination of education and daily experience interpreting probabilities. More recently, Pachur, Suter, Hertwig (2017) found domain specificity in sensitivity to probability, with more probability neglect in medical choices than in monetary choices. Petrova and colleagues (Petrova, Traczyk, & Garcia-Retamero, 2018; Petrova, van der Pligt, & Garcia-Retamero, 2014) have mapped probability weighting functions across individuals and have found that more numerate individuals show less distortion (i.e., more linearity, less S-curvature). Traczyk & Fulawka (2016) found that probability weighting functions were affected by negative affect, but only in less numerate individuals.

The relationship between numeracy and risk perception is not surprising (Pachur & Galesic, 2013; Peters, 2012; Peters, Hibbard, Slovic, & Dieckmann, 2007; Traczyk & Fulawka, 2016). It would be impossible to effectively apply probabilistic information without some basic comprehension of it. Those with little educational exposure to math and statistics should be less able to appreciate differences between, say, a 1 in 100 event and a 1 in 10,000 event. However, we argue that the tendency to incorporate probabilistic information into decision making goes beyond numeracy. In other words, even those individuals with the ability to comprehend and interpret probabilistic information may differ in how they respond emotionally to those probabilities. As with our hypothetical Patient B, some individuals may simply focus on the possibility of being “the one” who experiences some outcome, regardless of how likely or unlikely it may be. A measure that captures not only interest in or aptitude for numerical input but the emotional reaction to it may improve our understanding of risk assessments of the individual decision maker.

For this study, we have developed a method to operationalize and measure emotional sensitivity to the probabilities of different risks and emotional reactivity to the possibility of different outcomes. We presented participants with a series of hypothetical events, each with a specified probability of some outcome and asked them to rate their emotional worry or excitement to the possibility of each. For example, participants rated how worried they would be about a 1 in 10,000 risk of a serious side effect from a heart medication or how excited they would be about a 1 in 10,000,000 chance of winning a multimillion dollar lottery. The 14 items included both positive (e.g., lottery win) and negative (e.g., stroke) events in different life domains (e.g., health, finance, travel) and covered the lower range of probabilities from extremely unlikely (1 in 10,000,000) to somewhat unlikely (1 in 10).

The scoring of this measure differs from traditional individual difference measures for which scale scores are typically computed by summing across a series of items. For each participant, we modeled the relationship between emotional responses (worry or excitement) and the probabilities specified in each item, computing a unique intercept and slope across the 14 items for each person. The intercept is the baseline emotional reactivity (excitement or worry) to the possibility of an event with a fixed probability of 0.001.[1] For example, people who tend to worry a lot may report more worry than others for a given event regardless of its probability. In contrast, the slope describes how people update their affective response as the probability of events change. As probability changes, the slope codes how much change in affective response is expected. Some people might update their affective responses very little, barely differentiating between high and low probability events, others very much. Consistent with these two dimensions, we named this measure the Possibility Probability Questionnaire (PPQ).

Operationalizing these constructs as the intercept and slope results in a fairly unconstrained two dimensional space in which to categorize individuals, at least with respect to the measurement tool itself. The PPQ does not enforce a strong tradeoff between affect and deliberation or between emotional sensitivity to probability and emotional reactivity, allowing for nuanced predictions about responses to risk. For example, among individuals with relatively flat slopes (i.e., those who are less sensitive to probability), some may have higher intercepts, showing strong emotional reactions to all events, while others with lower intercepts will show little emotional reactivity to any event. We might expect the low-slope/high-intercept person to show substantial worry for any risk without discriminating between rare and more probable outcomes, responding intensely even to minute risks, while the low-slope/low-intercept person would be emotionally indifferent to all risks, even for high risk situations. Likewise, for a fixed intercept, some individuals may substantially update their affective response to an event as the probability of the event changes, whereas for others their affective response may change very little.

Our conceptualization of sensitivity to probability bears resemblance to past approaches that modelled disutility as a function of probability but with some important distinctions. Gonzalez and Wu (1999) solicited certainty equivalents for gambles at 11 probabilities ranging from 1% to 99%, and Petrova, et al. (2014) measured willingness to pay to insure a possession with risk of loss specified at nine probabilities ranging from 1% to 99%. Levy, and Baron (2005) solicited "badness" judgments from each participant at seven probabilities ranging from .1% to 100% for each of eight health conditions. In each of these cases, the same target was evaluated at different probabilities within-subjects, a systematic approach that is valuable for establishing that individuals do vary in their capacity to respond differently to probabilities when asked to. However, these approaches introduce heavy demand characteristics. A participant who is asked to repeatedly evaluate the same circumstance with everything held constant but the probability will likely detect that they are supposed to respond to probability. We aim to reduce these demands, at least to some degree. Our measure varies probability within-subjects as well, but not for any single condition, arguably reducing these demand characteristics to some extent. Moreover, our measure was developed not only to demonstrate variability but with the interest of predicting responses to risky situations, so it was designed to be substantially shorter than these previous tasks, reducing respondent burden. We also differ in our analysis and interpretation, extracting not only the slope as a measure of sensitivity to probability, but the intercept as a distinct measure of emotional reactivity to possibility. Others have not aimed to capture this specific construct, though the intercept is conceptually similar to Gonzalez and Wu's (1999) elevation parameter, which they attributed to the attractiveness of the gamble.

Apart from measurement issues, The PPQ differs conceptually from previous approaches in that the PPQ items are fundamentally affective. The PPQ maps changes in probability onto a psychological representation, but unlike the probability weighting function which maps stated probability onto another set of weights ranging from 0 to 1, the PPQ maps probability directly onto affect. We measured worry and excitement, the kind of anticipatory emotions that people readily discuss when facing risks and which are central to affect-based theories of risk. The parameters estimated from the PPQ items describe not how decision weights change with respect to changes in stated probabilities but how affect changes with respect to changes in stated probabilities.

To assess the utility of the PPQ for understanding risk perceptions of individual decision-makers, we regressed responses to three short vignettes describing health risks on the PPQ's two dimensions and other established individual difference measures. The health scenarios described risky events with potential for harm such as a pregnant woman drinking alcohol, discovery of asbestos in a home, and a choice between cancer surgeries, allowing us to assess the role of emotional sensitivity to probability and emotional reactivity to possibility in the individual decision-maker's perceptions of risk.

We hypothesize the following: 1) Insensitivity to probability is neither ubiquitous nor absolute. We expect heterogeneity in emotional sensitivity to probability (PPQ-Slope) and expect few respondents to ignore it altogether. 2) Risky events will elicit emotional reactions, even when the probability of those events is fixed and very low, and this emotional reactivity (PPQ-Intercept), will vary among individuals. 3) Emotional sensitivity to probability (PPQ-Slope) and emotional reactivity (PPQ-Intercept) will be negatively related. Emotional responses to risky events may be mitigated to some extent by awareness that an event is unlikely to occur, but this does not imply a direct tradeoff between emotional sensitivity to probability and emotional reactivity. In other words, even after conditioning on a given emotional sensitivity to probability, we expect a wide range of emotional responses to extremely rare events. 4) The PPQ-Slope and Intercept will correlate modestly with other individual difference measures including, among others, the Subjective Numeracy Scale (Fagerlin, et al., 2007) and the Rational Experiential Inventory (Norris, Pacini, & Epstein, 1998), a frequently used measure of thinking style preference. These scales, while conceptually related, lack the specificity of the PPQ to explicitly assess processing of probabilities. 5) Emotional sensitivity to probability and emotional reactivity to possibility will each predict responses to our risk scenarios not captured by existing individual difference measures. We predict that emotional reactivity should generally predict more worry in risky situations, whereas emotional sensitivity to probability should calibrate to the risk, causing more worry when the probability of harm is high and less worry when that probability is low.

Experiment 1

Methods

Participants. Participants were recruited to complete an online survey administered by Qualtrics during April and May 2014 using Amazon's Mechanical Turk. Participants were 2523 members of MTurk who opted to participate in this study based upon a brief description in exchange for a small monetary reward. Several studies have demonstrated that MTurk is a source of high-quality data (Buhrmester, Kwang & Gosling, 2011; Casler, Bickel, & Hackett, 2013; Paolacci, & Chandler, 2014), particularly for a novel task not previously seen by MTurk participants. Mullinex, Leeper, Druckman, and Freese, (2015) demonstrated high agreement between findings of a nationally representative study and those from an MTurk study.

Of the 2523 participants who finished the survey, 600 were omitted from analysis for missing data leaving a sample of 1923 with completed surveys (ages 18 to 79, *M*=35.44, *SD*=12.20; 63.9% female, 36.1% male; 82.3% white, 12.9% non-white, 4.7% unreported; 47.9% at least a bachelor's degree, 51.9% less than a bachelor's degree, 0.2% unreported). To be included in regression models, participants had to have non-missing data for 72 items including all individual difference measures and age (for the categorical variables gender, race, and education, we allowed participants with missing data, classifying them as unreported). The missing data rate for any individual item was between 2% and 5% indicating a fairly random distribution of missed items, and 94% of participants had no more than two items missing, suggesting that inattention was not a substantial problem in spite of the length of the survey. For each regression model, additional participants were excluded if the outcome item was missing; for each of these items, missing data rate was between 1 and 3%. For estimation of the PPQ-Slope and PPQ-Intercept, we included all 2229 participants with a complete set of PPQ responses, but the demographic characteristics of this subsample did not differ from those included in other analyses.

Sample size was based on an a priori power analysis for the 2 x 2 x 3 interaction of one of our health scenarios indicating that 200 participants per cell provides 79% power to pick up a medium sized effect using an alpha of 0.05.

Possibility/Probability Questionnaire. We developed 14 questions (summarized in Table 1) in which people imagined facing a risky situation that is well-defined but out of their personal control. Each question included statistical information about the probability of an event presented in 1-in-x format (e.g., a 1 in 10,000 risk of experiencing a stroke from a heart medication or a 1 in 10,000,000 chance of winning a lottery). For each question, participants rated how worried (for negative events) or excited (for positive events) they would be "about the possibility that you might be that 1 person out of x" who would have the event happen, using a 5-point scale (1= "Not at all worried/excited" to 5 = "Extremely worried/excited").

Both the phrasing of the question and the 1-in-x probability format were selected to highlight the sense of possibility that the event could happen, which was central to our emotional reactivity construct. The 1-in-x format has well-documented limitations, most notably a tendency to evoke stronger risk responses than other formats such as frequencies or rates (Cuite, Weinstein, Emmons & Colditz, 2008; Grimes & Snively, 1999; Pighin, et al., 2011; Zikmund-Fisher, 2011), but its emphasis on possibility is important in this context. Zikmund-Fisher (2011) argued that the "1" as numerator emphasizes the very existence of a risk. While that emphasis can be counterproductive in risk communication efforts, for our purposes, a format that accentuates possibility should engage the emotional reactivity to possibility that we seek to measure while still allowing us to detect sensitivity to the varied probabilities across the items.

Event probability and emotional valence (positive/negative) of the outcomes varied across questions. We selected risk contexts and plausible probabilities for types of events that people commonly consider in day-to-day life across different domains such as health and finance and determined in a pilot test that these items generated adequate variability in affective responses across items and across individuals.

Prenatal Alcohol Scenario. Participants were asked to imagine that they went into a local restaurant and saw a pregnant acquaintance from work drinking wine. We varied (between-subjects) three elements of the description of the coworker that we hypothesized would influence beliefs about the riskiness of alcohol use in pregnancy. Additional information about these variables are available as Supplementary Materials. In a full factorial design, we randomly assigned participants to receive one of the 12 scenarios.

All participants then provided ratings of their perceptions of risk associated with the coworker's alcohol consumption on several items. They first rated to what degree they believed "the woman in the scenario has harmed her fetus through drinking" on a 4-point scale (1= "definitely harmed her fetus," 2 = "probably harmed her fetus," 3 = "probably has not harmed her fetus," and 4 = "definitely has not harmed her fetus." For ease of reporting, we reverse score this item for analysis such that higher numbers indicate greater perceived harm). Next, participants were asked "how risky is it for the woman in the scenario to be drinking alcohol the way she is," rating riskiness on a 10-point scale (1 = "not at all risky" to 10 = "extremely risky"). Finally, participants were asked "regardless of whether you think this woman's drinking behavior is risky or not, how uncomfortable would you feel watching her drink alcohol," rating discomfort on a 10-point scale (1 = "not at all uncomfortable" to 10 = "extremely uncomfortable"). The survey also included additional items not relevant to the current hypothesis (i.e., items measuring moral judgment of the pregnant women, such as whether she is selfish and whether she is acting responsibly).

Asbestos Scenario. Participants were asked to imagine a young, healthy, married couple without children who own their own home and discover during a routine maintenance call that their basement insulation contains asbestos. The scenario goes on to describe asbestos as a mineral fiber previously used to insulate homes but banned in recent decades because it can cause lung cancer. We varied, between-subjects, the text of this scenario to include either a rigid statement of risk or one that was more nuanced. This manipulation is discussed in Supplementary Materials. Finally, participants read that, depending on the condition of the asbestos material, it can be managed either by professionally abating it under carefully air-controlled conditions at a cost of several thousand dollars, professionally containing it with heavy-grade plastic at a cost of several hundred dollars, or by leaving it alone and avoiding disturbing the material.

Participants then provided ratings on a series of questions in which they were asked to imagine being in the homeowner's position. Using 5-point rating scales, participants rated "how worried would you be about the safety of your home" (1 = "not at all worried" to 5 = "extremely worried"), "how severe would you feel this problem is" (1 = "not at all severe" to 5 = "extremely severe"), and "how much would you feel like the situation is hopeless, and will continue to cause problems no matter what you do" (1 = "not at all hopeless" to 5 = "entirely hopeless"). This was followed by an additional scenario segment and additional response items not relevant to the current hypothesis (i.e., items related to the participants' willingness to follow expert advice about asbestos).

Cancer Surgery Scenario. We included a scenario taken from Amsterlaw, Zikmund-Fisher, Fagerlin, and Ubel (2006), in which participants were asked to imagine receiving a colon cancer diagnosis and must consider two possible surgeries. Outcomes for Surgery 1, the *complicated surgery*, include an 80% chance of cure with no further complications, a 16% chance of failure to cure the cancer resulting in death within two years, a 1% chance of cure with a subsequent colostomy, a 1% chance of cure with chronic diarrhea, a 1% chance of cure with intermittent bowel obstruction, and a 1% chance of cure with a wound infection. Outcomes for Surgery 2, the *uncomplicated surgery*, include an 80% chance of cure with no further complications and a 20% chance of failure to cure the cancer resulting in death within 2 years. Thus, the complicated surgery offers a 4% greater chance of survival, albeit with unpleasant complications. Amsterlaw, et al., (2006) found that approximately half of participants chose Surgery 2 in spite of its elevated probability of death. We included this scenario and asked participants to make a binary choice between Surgery 1 and Surgery 2.

Additional Measures. In addition to the PPQ, participants completed a series of individual difference measures to explore the correlations between these measures and the PPQ and to demonstrate that the PPQ is distinct from these constructs. Specifically participants completed the 10-item Aversion to Ambiguity in Medicine scale (AA-Med; Han, Reeve, Moser, & Klein, 2009), the 5-item regret scale from the Maximizing/Satisficing Scale (MSS-R; Schwartz, et al., 2002), the 14-item Personal Fear of Invalidity scale (PFI; Thompson, et al., 2001), the 10-item Rational-Experiential Inventory (REI; Norris, et al., 1998), the 15-item Extended Life Orientation Test (ELOT; Chang, Maydeau-Olivares, D'Zurilla, 1997), and the 8-item Subjective Numeracy Scale (SNS; Fagerlin, et al., 2007).

Procedures. Participants who responded to our MTurk posting were directed to a website and read a brief introduction to the experiment. Participants were randomly assigned to read one version of the prenatal alcohol scenario and completed the related questions, then randomly assigned to read one version of the asbestos scenario and completed the related questions, then read the cancer surgery scenario and completed the related question. Participants then completed the PPQ, AA-Med, MMS-R, PFI, REI, ELOT and SNS scales, in that order. Finally, participants were asked a series of demographic questions, including age, gender, race and ethnicity, education, general health rating, and whether they had any experience working in a health related field, whether they had ever been pregnant, and whether they had ever made any decisions related to asbestos.

Results and Discussion

All analyses were completed using *R* statistical software (R Core Team, 2019), particularly the LME4 package. All continuous dependent and independent variables were standardized to have a mean of 0 and a variance of 1.[2]

Computing PPQ Scores. A review of Table 1, the right-most column in particular, demonstrates that worry and excitement ratings were related to item probabilities. A Spearman's rank-correlation rho test shows a strong positive correlation between item probability and ranked response, $r_s(0.90) = 0.85$, $p < .001$. Notably, the least probable item, a 1 in 10,000,000 chance of winning a lottery, ranked lowest in mean excitement or worry (*M=1.91, SD=1.21)*, in spite of the dramatically positive outcome of a winning a multimillion dollar jackpot.

Figure 1 further demonstrates that item probability predicts affective responses (excitement or worry) to PPQ items. As probability of an event increases, respondents report greater affective response, but this change is not linear. The affective response increases rapidly with each small change in probability near the very low end of the probability scale, and much more gradually after a probability of about 1%. This non-linear response to changes in probability is well documented; people react strongly to small changes in probability at the extreme end of the probability scale (e.g. Gonzalez & Wu, 1999). Figure 1 also illustrates that the curvature is similar for the positive and negative items, but affective responses to items with negative outcomes are stronger than those with positive outcomes, consistent with the asymmetry of gains and losses in Prospect Theory (Kahneman & Tversky, 1979). To fit the data with a linear model, we apply a natural logarithm transformation of the item probability, similar to Prelec (1998), resulting is an approximately linear relationship between the natural logarithm of probability and the average affective response for each item (see Figure A).[3] A simple linear regression fits well with over 70% of the variance in the affective response explained by the natural logarithm transform of probability, $t(10) = 5.01$, $p < .001$. Further discussion of this transformation is available in Supplementary Materials.

To estimate the PPQ-Intercept and PPQ-Slope parameters for individual respondents, we fit a linear mixed effect model regressing affective response on the scaled natural logarithm of probability, where the PPQ-Intercept and PPQ-Slope are random effects, allowed to vary across participants, and assumed to follow a multivariate normal distribution. The PPQ-Intercept and PPQ-Slope for each participant are then extracted. The natural log of probability was scaled such that the mean was 0 and variance 1. This has the dual effect of reducing collinearity with the intercept and avoiding scaling differences that can introduce problems in model convergence. The choice to scale the natural logarithm of probability resulted in an intercept that is the expected affective response at the average natural logarithm of probability, which is -6.587, or 0.001 on the probability scale.

Consistent with our first two hypotheses, the expected values of PPQ-Slope (0.45, t = 62.37, p <0.05) and PPQ-Intercept (2.84, t = 197.04, p < 0.01) significantly different from zero using the Satterthwaite's method, and there was variance across participants in both the PPQ-Slope (0.03) and the PPQ-Intercept (0.39). The magnitude of the fixed effects is sizable too. The PPQ-Intercept (with probability of 0.001) sits slightly above the mid-point of our 5-point scale. The expected PPQ-Slope is about 0.4, which corresponds to a 10% change in the range of the 5-point scale. It is noteworthy that the variance of the intercept was more than an order of magnitude larger than that of the slope; emotional reactivity to possibility appears more varied than sensitivity to probability. Nevertheless, a chi-square test on model deviance showed a significantly better fit to PPQ responses when slope was modeled as a random effect than as a fixed effect, $X^2(2) = 156.78$, $p < 0.001$. This suggests that people do in fact respond emotionally to probabilities on average, and they differ in how much they do so.

Distinguishing the PPQ from Other Constructs. Consistent with hypothesis 3, PPQ-Slope and PPQ-Intercept do not show a strong tradeoff. They were significantly negatively correlated but the relationship was modest, $r(1921) = -0.22$, $p < .001$. Most of the variability in each measure is not explained by the other and conditioning on either the PPQ-Slope or the PPQ-Intercept does not uniquely identify the other. This is consistent with the two-parameter model proposed for the PPQ.

Table 2 shows correlations between the PPQ-Slope and the PPQ-Intercept with each of the other individual difference measures. The PPQ-Slope and PPQ-Intercept show only modest relationships with the other measures. Notably, subjective numeracy (SNS) had only a modest, though significant, positive correlation with the PPQ-Slope and a modest negative correlation with the PPQ-Intercept. The PPQ-Slope had a significant positive correlation with the REI's Need for Cognition (REI-NFC) subscale and no correlation with the Faith in Intuition (REI-FI) subscale while the PPQ-Intercept showed a small but significant negative correlation with REI-NFC and a positive correlation with REI-FI. The PPQ-Slope, then, is not simply a proxy for high subjective numeracy, nor for a preference for analytical thought, and the PPQ-Intercept is not simply a proxy for poor numeracy, nor for a preference for intuitive thought. Correlations with all of the additional scales were weak or modest, ranging in magnitude from .01 to .21. Cross-correlations among all individual difference measures are shown in Table 1 of Supplementary Materials.

Predicting Responses to Prenatal Alcohol Risk. Responses to the prenatal alcohol scenario were modeled using linear regression. Predictors in the model included all individual difference measures, age, gender, race, and education, as well as amount of alcohol, frequency of alcohol, stage of pregnancy (see Supplementary Materials). The model accounted for significant variance of perceived harm to the fetus, $F(27, 1894) = 25.11$, $p < .001$, $R^2 = 0.26$, how risky it is for the woman to drink, $F(27, 1893) = 28.56$, $p < .001$, $R^2 = 0.29$, and discomfort watching her drink, $F(27, 1891) = 12.64$, $p < .001$, $R^2 = 0.15$.

Coefficients and significance levels are shown in Table 3. The PPQ-Intercept was a significant predictor in each model, explaining unique variance in all three responses to the prenatal alcohol scenario beyond the contributions of other individual difference variables. People with greater emotional reactivity to possibility (i.e., higher PPQ-Intercept) saw the drinking as more harmful to the fetus and more risky, and felt more uncomfortable seeing the woman drink, responding to what could possibly happen to the fetus, regardless of its probability. The PPQ-Slope was a less consistent predictor. It predicted significantly less perceived harm to the fetus; people who were more emotionally sensitive to probability information (i.e., higher PPQ-Slope) saw the woman's drinking behavior as less harmful, arguably thinking probabilistically about the potential for harm, rather than assuming that drinking always causes harm. However, there were no effects of PPQ-Slope for perceived risk or discomfort.

Predicting Responses to Asbestos Risk. Responses to each of the asbestos-related questions were modeled using linear regression with all individual difference measures, age, gender, race, and education included as predictors. Risk message type was also included in the model (see Supplementary Materials). The models accounted for significant variance in worry about the safety of the home, $F(24, 1895) = 15.26$, $p < .001$, $R^2 = 0.16$, perceived severity of the problem, $F(24, 1881) = 15.15$, $p < .001$, $R^2 = 0.16$ and feeling hopeless about the problem, $F(24, 1888) = 9.25$, $p < .001$, $R^2 = .11$.

Results are shown in Table 3. As predicted, the PPQ-Intercept predicted significantly more worry, greater perceived severity, and more hopelessness about the problem, even when the contributions of other validated measures were accounted for. The PPQ-Slope also predicted significantly more worry and perceived severity of the problem. This suggests that greater emotional sensitivity to probability does not serve to reduce worry across the board, but rather modulates risk perception, resulting in greater concern when one is likely to be affected. This scenario, for example, indicated that the homeowner has indeed found a dangerous carcinogenic substance in the home, but it did not specify the degree of exposure. The scenario indicated that some homes can safely leave asbestos in place (suggesting minimal exposure and minimal risk) but did not specify whether this is a case of minimal or extensive exposure. We speculate that participants interpreted the unspecified amount and condition of asbestos in the home as a high risk situation, so those who are more emotionally sensitive to probabilities expressed more concern about it.

In contrast to the worry and severity responses, the PPQ-Slope predicted less hopelessness about the problem. This distinction provides further insight about the role of probability information in the face of risk. Participants who are more emotionally sensitive to probability are more concerned about what they consider to be a high risk health danger, but responses to hopelessness suggest that they experience greater confidence that appropriate action can reduce the risk.

The coefficients were generally larger for the PPQ-Intercept than the PPQ-Slope, with one exception. For the hopelessness rating, the effect of the PPQ-Intercept and PPQ Slope were comparable. Emotional sensitivity to probability is as strong a predictor of hopelessness as is emotional reactivity to possibility.

Predicting Cancer Surgery Choice. In their original use of the surgery scenario, Amsterlaw, et al. (2006) found that slightly more than half of participants chose a surgery with no risk of complications despite a lower chance of survival. Replicating their findings, we found that 53% of participants in our sample chose the uncomplicated surgery with a lower survival rate, and 47% chose the complicated surgery with a higher survival rate and a small risk of complications.

We modeled this binary choice with logistic regression using all individual difference measures, age, gender, race, and education as predictors. A likelihood ratio test shows that the hypothesized model fits better than the null model overall, $X^2(15) = 76.92$, $p < .001$. Neither PPQ-Slope nor PPQ-Intercept significantly predicted surgery choice, though several other individual difference measures did. Results are shown in Table 3.

Discussion

Experiment 1 provides initial evidence that emotional sensitivity to probability and emotional reactivity to possibility vary across individuals, and that these variables help predict responses to health risk scenarios. However, the correlations between the PPQ and other validated measures were generally weak, providing little convergent validity for our interpretations of the PPQ-Slope and Intercept. In particular, the expected relationship between

PPQ-Slope and numeracy was significant but quite modest. While we expected that subjective numeracy, preference for and comfort with numeric information, would correlate with emotional sensitivity to probability, an objective numeracy measure would provide a better test of our interpretation. Moreover, the 5-point response scale of the PPQ is coarse in comparison to the wide range of probabilities in the items. A more fine-grained response scale should allow more variability in responding, providing better detection of correlations with individual difference items, and may also better capture contributions of the PPQ in our models of health risk responses. Finally, we found no relationship between the two PPQ dimensions and the binary cancer surgery choice. This may reflect the scenario itself (which has been shown to be remarkably resistant to debiasing efforts (Amsterlaw, et al., 2006; Witteman, et al., In Press), or it may reflect the nature of the binary choice question, in contrast to the rating scales used in the other scenarios. In Experiment 2 we address these shortcomings.

Experiment 2

Experiment 2 was designed to replicate and extend the findings of Experiment 1, with several specific goals. First, we included an objective measure of numeracy to more directly test participants' ability to work with numeric and probabilistic information. Second, while our interpretation of the PPQ-Intercept as a measure of emotional reactivity to possibility offers some face validity, we included an existing validated measure of emotional reactivity to provide convergent validity for this interpretation. Third, we increased the PPQ rating scale to nine points to capture smaller shifts in affective responses to changes in probability. Fourth, to address possible order effects in Experiment 1 (the health scenarios and individual difference measures were always presented in static order), we randomly varied the order of the individual difference measures and the order of the health scenarios, though scenarios were always presented prior to the individual difference measures.

Method

Participants. Participants included 1333 people recruited in October 2019 by Dynata, a commercial vendor with 3.5 million members who voluntarily agreed to receive email invitations for surveys to be eligible for cash prizes. Of the 1333 who finished the survey, 342 were omitted from analysis for missing data, using the same criteria used in Experiment 1. Missing data appears to be distributed randomly with fewer than 2% missing for any given item, with the exception of several objective numeracy (BNT-S) items which had missing data rates between 2% and 4%. No more than 2 items were missed by 94% of participants. For any given regression model, additional participants were dropped from analysis if their response to the outcome item was missing, with less than 1% missing from each of these items on average. All 1241 participants with complete data for the PPQ items were included for estimation of the PPQ-Slope and PPQ-Intercept, with no notable demographic differences between this subsample and those included in the regression analyses.

The sample was intended to approximate the demographic characteristics of Experiment 1, however due to a sampling error, we oversampled Asian and Hispanic respondents and under-sampled white respondents resulting in a much more diverse sample (ages 18 to 99, M = 48.23, SD = 16.4; 47.6% female, 52.3% male, 0.1% unreported, 41.8% white, 51.8% non-white, 6.4% unreported; 49.5% at least a bachelor's degree, 50.4% less than a bachelor's degree, 0.1% unreported). While this sample is not proportionally representative of the U.S. population, its diversity allows us to better generalize across ethnic groups.

Scenarios. In consideration of participant burden we used only two of the scenarios from Experiment 1, the asbestos and cancer scenarios, and we did not vary the risk message for the asbestos scenario (using the nuanced version described in Supplementary Materials). For the cancer scenario, we added two additional response items after the binary surgery choice item, "how worried would you be about your health?" (1 = "not at all worried" to 5 = "extremely worried") and "how hopeless would you feel about your health?" (1 = "not hopeless at all" to 5 = "entirely hopeless"). The order of the two scenarios was randomized, though the order of response questions remained fixed for each scenario.

Individual Difference Measures. All of the measures from Experiment 1 were included again in Experiment 2, and two new scales were added. The Berlin Numeracy Test (BNT-S; Cokely, Galesic, Schulz, Ghazal, & Garcia-Retamero, 2012; Schwartz, Woloshin, Black, & Welch, 1997) was included to measure objective numeric ability. We used the 7-item version which has been shown to be more effective at differentiating across a wide range of numeric ability, as opposed to shorter versions which are more appropriate for highly numerate samples. The 6-item arousal/intensity subscale of the Emotional Reactivity Scale (ERS-A; Nock, Wedig, Holmberg, & Hooley, 2008) was also included to provide support for our interpretation of the PPQ-slope as a measure of emotional reactivity to possibility.

For Experiment 2, the PPQ was modified to use a 9-point rating scale (1= "Not at all worried/excited" to 9 = "Extremely worried/excited"). In addition, we corrected an error in the AA-Med scale used in Experiment 1. In that experiment, we inadvertently included a version that had been modified to address attitudes about ambiguity in clinical trials specifically, as opposed to ambiguity in expert opinions (e.g., "I would not have confidence in a medical test or treatment if there were conflicting results from the clinical trials testing it" rather than "I would not have confidence in a medical test or treatment if experts had conflicting opinions about it"). The version focusing on clinical trials was not the version validated by Han, et al. (2009). For Experiment 2, we corrected this error, using the correct wording for the 6 item AA-med scale.

Procedures. Dynata panelists who followed our survey link saw a brief introduction to the study. Participants then read the asbestos and cancer scenarios, each with its response questions, with scenario order randomly assigned. Participants then completed individual difference measures, presented in random order. Finally, participants were asked a series of demographic questions, including age, gender, race and ethnicity, education, general health rating, and whether they had any experience working in a health related field, whether they had ever made any decisions related to asbestos, and whether they had ever made cancer treatment decisions for themselves or a loved one.

Results

Computing PPQ Scores. As in Experiment 1, we applied a natural logarithm transformation of the item probability to fit the data with a linear model. A simple linear regression fit the average PPQ responses well, with 78% of the variance in the affective response accounted for by logged item probability, $t(10) = 5.93$, $p<0.001$). We estimated the PPQ-Intercept and PPQ-Slope parameters for individual respondents as in Experiment 1. The expected values of the PPQ-Slope (0.34, $t = 20.44$, $p < 0.01$) and PPQ-Intercept (4.72, $t = 89.01$, $p < 0.01$) were significantly greater than zero, and while there was greater variance in the PPQ-Intercept (3.27) than the PPQ-Slope (0.13), a chi-square test on model deviance showed a significantly better fit to PPQ responses when slope was modeled as a random effect than as a fixed effect, $X^2(2) = 153.80$, $p < 0.001$. Figure 2 shows the curvilinear function for the untransformed probabilities, and the linear function for the natural logarithm of probability.

Relationships between PPQ and Other Constructs. Table 2 shows correlations between the PPQ-Slope and Intercept and each of the other measures (cross-correlations among all individual difference measures are shown in Table 2 of Supplementary Materials). Consistent with Experiment 1, we found a significant but modest negative correlation between the PPQ-Slope and PPQ-Intercept, $r(989) = -0.27$, $p < 0.001$. For PPQ-Slope, the significant correlations observed in Experiment 1 were generally replicated. The two new measures, objective numeracy (BNT-S) and emotional reactivity arousal/intensity (ERS-A), were both significantly correlated with the PPQ Slope. As expected, emotional sensitivity to probability was associated with higher objective numeracy on the BNT-S. Emotional sensitivity to probability was associated with significantly less emotional reactivity on the ERS-A.

For the PPQ-Intercept, many of the relationships observed here were much stronger than those observed in Experiment 1. For two of the individual difference measures, the correlations actually reversed; here, the PPQ-Intercept was positively correlated with subjective numeracy (SNS) and with need for cognition (REI-NFC) whereas it was negatively correlated with both in Experiment 1, though these correlations were modest for both studies. As expected, we found a strong positive correlation with the measure of emotional reactivity (ERS-A). We also found a modest negative correlation with objective numeracy (BNT-S).

Predicting Responses to Asbestos Scenario. Responses to the asbestos scenario questions were modeled using linear regression with all individual difference measures, age, gender, race, and education included as predictors. The model accounted for significant variance for worry about the safety of the home, $F(27, 961) = 15.44$, $p < .001$, $R^2 = 0.30$, perceived severity of the problem, $F(27, 958) = 16.28$, $p < .001$, $R^2 = 0.31$, and hopelessness about the problem $F(27, 963) = 14.81$, $p < .001$, $R^2 = .29$.

Model coefficients for each of the asbestos outcomes are shown in Table 4. Consistent with Experiment 1, the contributions of the PPQ-Slope and Intercept were significant even when controlling for the contributions of other measures. The PPQ-Intercept was a significant predictor for each of the outcomes, predicting significantly more worry, greater perceived severity, and more hopelessness about asbestos. Those who are more emotionally reactive to possibilities show more concern and less hope about exposure to the carcinogen, asbestos. The PPQ-Slope predicted significantly more worry about and perceived severity of the asbestos problem, however, we did not replicate the relationship between PPQ-Slope and hopelessness observed in Experiment 1. In that study, we found that greater emotional sensitivity to probability resulted in more concern over asbestos exposure (worry and perceived severity) but also provided a sort of buffering effect, protecting against hopeless feelings and arguably making the problem feel more tractable and manageable in spite of its seriousness. Here, we see the same worry, but without the same protection from hopelessness.

Table 4 shows the effects of other individual difference measures. Notably, neither objective nor subjective numeracy were consistent predictors in these models, with only a marginal effect on perceived severity for the BNT-S. There were also no significant effects for ERS-A.

Predicting Responses to Cancer Surgery Scenario. Results for the cancer surgery scenario are shown in Table 4. We again replicated the basic finding of Amsterlaw, et al. (2006), with 51.16% of participants choosing the uncomplicated surgery with a lower chance of survival, and 48.84% choosing the complicated surgery with a higher survival rate. Modelling the binary choice with a logistic regression model using each of our individual difference measures, age, gender, race, and education as predictors fit significantly better than the null model overall, $X^2(12) = 28.86$, $p < .01$.

As in Experiment 1, we found that neither the PPQ-Slope nor the PPQ-Intercept contributed significantly to the surgery decision. However, in addition to the binary choice item, participants in Experiment 2 were asked to rate their emotional responses to the cancer surgery scenario, which were modelled using linear regression with all individual difference measures and demographic variables as predictors. Our models predicted significant variance for both worry, $F(12, 974) = 32.20$, $p < .001$, $R^2 = 0.28$, and feelings of hopelessness, $F(12, 975) = 21.26$, $p < .001$, $R^2 = 0.21$, in response to the cancer surgery scenario. PPQ-Slope predicted significantly more worry and marginally more hopelessness, and PPQ-Intercept predicted significantly more worry and hopelessness. Thus, PPQ-Slope and PPQ-Intercept are indeed relevant for these affective responses to the cancer surgery scenario, if not for the binary decision.

Discussion

The findings from Experiment 1 were largely replicated in Experiment 2, indicating that the methodological changes in Experiment 2 made little difference in the core results. PPQ-Slope and Intercept were again found to contribute to affective responses for our two health scenarios, though not for the binary surgery choice in the cancer scenario. The role of PPQ-Slope and Intercept in these models did not depend on the scaling of the PPQ items (5-point in vs. 9-point response scale), nor on the presentation order of the scenarios or individual difference measures (fixed vs. randomized). This pattern of results also persisted despite sample differences across the two studies. Experiment 1 used a sample drawn from M-Turk that was younger, less racially diverse, and more female than the sample drawn five years later from a Dynata sample in Experiment 2. Nevertheless, the PPQ-Slope and PPQ-Intercept effects were largely consistent.

One exception to our replication is the effect of PPQ-Slope on hopelessness. In Experiment 1, PPQ-Slope was associated with less hopelessness, suggesting that the Slope might serve a protective role, reassuring that the problem can be mitigated even as it predicts greater overall concern about the risk. That effect disappeared in Experiment 2, and in fact, PPQ-Slope had a marginally positive relationship with the new hopelessness item for the cancer scenario. Thus, while the role of the PPQ-Slope in worry and perceived severity is consistent, its role in hopelessness (and perhaps other related emotions like despair, or related judgments, like the manageability of the problem) is less clear and warrants future research.

Experiment 3

In Experiments 1 and 2, we aimed to establish the PPQ-Slope and Intercept as measures of emotional sensitivity to probability and emotional reactivity to possibility, respectively, and to demonstrate their predictive value in modelling reactions to health risks. However, neither study addressed whether these individual differences are stable or transient over time. In Experiment 3, we measured test-retest reliability of the PPQ.

Methods

Participants. A convenience sample of 77 participants were recruited from a small university campus and offered extra credit for participation (ages 18 to 22, *M* = 19.73, *SD* = 1.18; 48.1% female, 51.9% male; 80.1% white, 15.6% non-white, 3.9% unreported).

Procedures. Participants were asked to complete the 14 PPQ items, presented in random order, using the original 5-point rating scale. Exactly two weeks later, participants completed it again.

Results

The correlation for PPQ-Intercept scores at Time 1 and Time 2 was acceptable, $r(75) = 0.72$, $p < .001$, though the correlation for PPQ-Slope was weaker, $r(75) = 0.55$, $p < .001$. When the PPQ items are treated like a typical individual difference measure, summing responses to generate an aggregate score, retest correlation is acceptable and quite comparable to the PPQ-Intercept, $r(75) = 0.72$, $p < .001$. In other words, there is temporal consistency in responding to PPQ items, and the low retest correlation in Slope may to some degree reflect the indirect scoring approach. These retest correlations may also reflect a lower bound; In Experiment 2, we generally found stronger correlations using the 9-point scale, and the same is possible for retest correlations.

To better understand the nature of how the PPQ slope changes over time, we constructed Bland-Altman plots (Bland & Altman, 1986), which shows an unusual pattern (see Figure 3). The Bland-Altman plot presents the difference score (Time 1 - Time 2) plotted against their mean. For the PPQ-Intercept, there is a modest positive relationship, suggesting, if anything, regression to the mean, $r(75) = 0.33$, $p = .01$. That is, if your Intercept is low overall, it increases a bit from Time 1 to Time 2, and vice versa. However, for the PPQ-Slope, the relationship is quite different. There is a strong negative relationship $r(75) = -0.87$, $p<.001$, indicating more extreme scores at Time 2. That is, if you are emotionally insensitive to probabilities on average, you are more so at Time 2 than Time 1. This may help to explain why the test-retest correlation is low for the PPQ-Slope. If points following a line closely are pulled apart along the horizontal dimension, a tight linear relationship becomes more cloud like, weakening the correlation.

This also suggests that referring to the PPQ-Slope as a measure of state is an oversimplification because there are strong relationships between Time 1 and Time 2 scores. So while it may not qualify as a stable trait by conventionally accepted standards, it may not be a passing state either. For now, we are agnostic as to whether the PPQ-Slope is a state or trait. In the current work we are not examining its relevance for understanding behavior across time, and we find that it is a reliable and robust predictor of health risk responses in the moment. Future work can better test the extent to which PPQ-Slope is stable over time and the extent to which it responds to transient contextual factors. In particular, it will be it will be important to investigate the impact of emotional state on this measure, given the affective basis of the measure. To the degree that the PPQ measures a stable trait, we would expect little difference in a comparison of affect-rich vs. affect-poor items, and we would expect little impact from a mood manipulation.

General Discussion

Overall, the results from Experiment 1 and 2 support our five hypotheses. Expected values of the PPQ-Slope and PPQ-Intercept are well above zero, suggesting that on average, respondents were both emotionally sensitive to probability when evaluating risky outcomes (hypothesis 1), as well as generally responsive to events with a fixed probability (hypothesis 2), and importantly, participants varied in both. This variability illustrates that respondents did not ignore probabilistic information and yet still responded to events that would likely never occur.

The modest negative correlation between them also indicates that they did not directly trade between PPQ-Slope and PPQ-Intercept (hypothesis 3). This is an important feature of the PPQ: Within the same individual, the PPQ measures two seemingly contradictory components contributing to risk perception. Emotional sensitivity to probability might suggest that a respondent should hardly respond to an extremely unlikely event, and yet, on average, respondents do. This means that while emotional sensitivity to probability may mitigate emotional reactivity to rare events, even those who are grounded in probabilities can become quite emotional about possibilities (e.g., it’s possible to enjoy the excitement of a lottery, even with the full recognition that you almost certainly won't win), and respondents vary quite a bit in how much they do each.

The PPQ gets at both emotional sensitivity to probability and emotional reactivity to possibility and together they provide a richer description of the fragile balance people struggle to hold when evaluating risks. This is a departure from models that imply a direct tradeoff between affective responses and analytical probabilistic responses to risk, emphasizing the dominance of affect over analytical processing and its causal role in insensitivity to probability (Rottenstreich & Hsee, 2001; Sunstein & Zeckhauser, 2001). These theories suggest that emotional arousal is the cause of probability neglect, and that to be emotionally aroused is to be insensitive to probabilities. While we acknowledge that emotion can and does influence cognitive processing, our approach does not assume dominance of one system over another or a causal relationship where emotional reactivity overrides sensitivity to probability, nor do we assume true separation between cognitive and emotional processes. Rather, we provide evidence that affective responses incorporate probabilistic information, not just outcomes.

While the PPQ measure does not inherently require an individual respondent to trade emotional reactivity for emotional sensitivity to probability, the PPQ-Slope and Intercept are not entirely independent, as one does constrain the other at the extremes. A very high score on the PPQ-Intercept will necessarily restrict the possible range of the slope. A participant who responds maximally even to events with low probability will have no room to give stronger responses to higher probability events. While this may be a limitation of the measure, it may also reflect the psychological reality of a finite ceiling on emotional reactions.

In Experiment 1, we found remarkably modest relationships between the PPQ-Slope and Intercept and the other individual difference measures (see Table 2). However, in Experiment 2, using the 9-point scale which allowed greater variability in responding, we found stronger relationships with other constructs, providing clearer guideposts for our interpretations of the PPQ-Slope and Intercept. Notably, the PPQ-Slope is most strongly related to objective numeracy, a sensible association as the ability to interpret probabilities is necessarily related to emotional reactions to them. Nevertheless, the correlation is still modest, accounting for only 9% of the variability in PPQ-Slope. The relationship with subjective numeracy is even weaker. The Slope is capturing something that is related to, but quite distinct from numeracy.

Our interpretation of the PPQ-Intercept as emotional reactivity to possibility is also supported by its relationships to other measures. The ERS-A, an existing measure of emotional reactivity (more specifically arousal and intensity of emotional responses) correlates well with the PPQ-Intercept. However, the ERS-A addresses emotional responding when things happen, and we have argued that the PPQ-Slope is capturing emotional responding about possibilities, events that can be imagined but haven't happened and are very unlikely to. This interpretation is supported by the strong relationship between PPQ-Intercept and regret. After all, regret is an emotional reaction to a possibility, an alternative outcome that hasn't occurred. The PPQ-Intercept is also positively related to both optimism and pessimism, two measures that might seem at odds as they assess positive vs. negative expectations, respectively. But each describes an emotional orientation toward possible futures. The PPQ-Intercept cuts across the emotional valence of positive vs. negative events, arguably capturing the intensity of emotional responding to possibilities.

For both the PPQ-Slope and Intercept, these correlations with other individual difference scales help to clarify what the PPQ does and does not measure. The PPQ-Slope is related to numeracy and to a preference for a "rational" thinking style. But it is neither of these things. It is associated with less pessimism, feelings of invalidity, regret, aversion to medical ambiguity, and emotional reactivity, but it has only modest correlations with each of these scales, and it explains unique variance in our health scenario responses that these measures do not. The Intercept is related to the intensity of emotional reactivity and to emotional responses about missed possibilities (regret) and future possibilities (optimism and pessimism), but none of these constructs can account for the majority of variance in the PPQ-Intercept, and the Intercept accounts for far more variance in our health scenario responses than any of these.

The PPQ's validity and utility is further supported by its predictions of worry and other responses to our health scenarios (hypothesis 5). We found the PPQ-Slope and PPQ-Intercept to be useful predictors, accounting for unique variance across a range of responses to these scenarios. In particular, we found that a higher PPQ-Intercept was associated with stronger reactions to our risk situations as expected, while the relationship between slope and risk responses was context dependent. As predicted, the PPQ-Slope was associated with less perceived harm and risk for the prenatal alcohol scenario, arguably because participants with greater emotional sensitivity to probability are responding to the relatively low probability of significant harm from limited prenatal alcohol exposure which might reasonably be interpreted as relatively low risk (O'Keefe, et al., 2015). However, the PPQ-Slope predicted more worry for both the asbestos scenario, which specified the presence of a serious carcinogen within the home without any mitigating information (such as specifying brief or minimal exposure) and the cancer scenario, which described a serious medical condition. An important feature of emotional sensitivity to probability is that it should allow participants to calibrate to risk probabilities, resulting in more concern for high probability risks and less concern when probabilities are low.

A more direct test of this hypothesis, comparing PPQ-Slope effects for explicitly high vs. low probability risks, should be undertaken in future studies.

Measuring PPQ-Intercept and PPQ-Slope may also be useful in exploring when and why risk perceptions differ between the people evaluating risk for themselves and those considering risks to others. An emerging literature shows that self-other differences in risky choice and risk perceptions appear to be context dependent, with some evidence that people may be less risk tolerant when making health decisions for others versus themselves but show different risk patterns when making financial or interpersonal decisions (Batteaux, Ferguson, & Tunney, 2019; Polman & Wu, 2019). There is also evidence that risk messages to others may evoke higher emotional risk perceptions and greater behavioral motivation than do equivalent messages to oneself (Klein, & Ferrer, 2018). Hence, a plausible hypothesis is that inter-individual differences in emotional reactivity and/or sensitivity to risk information might be related to which individuals demonstrate self-other discrepancies (and to what degree). Our prenatal alcohol scenario does describe a risk for someone else (the pregnant woman and her fetus) rather than the participants' self, but the study was not designed to make direct comparisons between self vs. other risk scenarios, an important question for future research.

Notably, our measure was designed to be domain general. There is good evidence for domain specificity in risk perception (Blais & Weber, 2006; Figner, & Weber, 2011; Hanoch, Johnson, & Wilke, 2006; Weber, Blais, & Betz, 2002), but there is also evidence for a general risk factor accounting for variance in risk behavior (Highhouse, Nye, Zhang, & Rada; 2017). Our measure allows us to look at the general emotional response to probability that may be an underlying dimension of risk responses over different domains. Pragmatically, this general approach does provide predictive value for the health scenarios in our study, but the question of domain specificity is an important one to consider in the future. Matching PPQ item domain to the outcome domain may provide even better predictive power.

We acknowledge that using the PPQ is more cumbersome than traditional individual differences measures, requiring regression analyses with random-effects rather than a simple summing of items to generate individual scores. Nevertheless, we argue that measuring these responses to probability and possibility is important because they have unique relevance for predicting how people will react to risky situations, above and beyond existing measures. Decisions in real-world domains, such as health decisions, are often assumed to be driven by people's ability to understand and compare specific probabilities. Medical choices--choosing between medications with different side-effect profiles, or between an aggressive surgery and a prolonged physical therapy regimen, or between a course of chemotherapy and a watchful waiting approach--would ideally rest on the careful weighting of the probabilities of possible outcomes. Many medical decision aids have focused on improving numeric communication, using simplified wording and graphics to improve patients' comprehension of probabilities and encourage more careful consideration of comparative risks (e.g., Trevena, et al., 2013). However, recent research casts doubt on the impact of deliberative processing for improving medical decisions (Scherer, deVries, Zikmund-Fisher, Witteman & Fagerlin, 2015). The current study suggests that this may depend on the individual, with some subset of patients who are little affected by probability information, even when they can intellectually comprehend it. A method for identifying individuals who might be immune to probability-focused interventions may benefit efforts to improve patient decision making as these patients may be better served by other kinds of interventions (deVries, Fagerlin, Witteman, & Scherer, 2013).

A lingering question, however, is the extent to which emotional sensitivity to probability is a consistent trait across time, as opposed to a state experience. While the test-retest correlation for the PPQ-Slope was low, the full pattern of results in Experiment 3 suggests more than a degree of consistency over time. We argue that it is premature to declare the PPQ-Slope either trait or state, a question that can be further addressed in future studies. For present purposes, we present the PPQ as a novel approach to measure responses to probabilities in the moment that predicts responses to health risks in that same moment in ways that are not captured by existing measures and that differs from the wide-spread probability neglect that is anticipated in much of the field.

Conclusions

Our initial work with the PPQ demonstrates that emotional sensitivity to probability information varies across individuals, and that certain people appear more emotionally reactive than others to the possibility of being the one person out of many who would experience rare risk events and we present a method for quantifying these differences. While dual-process models have long proposed a hypersensitivity to possible outcomes and insensitivity to probability in risk perception, the PPQ identifies robust variation in responses to probabilities among individuals with few respondents completely discounting probabilistic information. The results support existing affect-based models of risk perception, but extend them too, illustrating that while emotion may play a disproportionate role in decision making, emotional sensitivity to probability is an important component of that emotional experience and contributes meaningfully to decisions.

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Footnotes

[1]Because the relationship between item probability and affective response was non-linear, we applied a natural logarithm transformation of the data, discussed further in the results section of Experiment 1 and Supplementary Materials. The transformation resulted in an intercept equal to the average natural logarithm of probability, or 0.001 on the probability scale, rather than 0.

[2] Standardizing the variables affects the magnitude of the coefficients in the regression models, placing them on the same scale to make them more comparable, but does not affect significance levels for the effects.

[3] While we acknowledge the danger of arbitrary data transformations (Steegen, Tuerlinckx, Gelman, & Vanpaemel, 2016), the natural logarithm transformation of PPQ item probability was consistent with past literature and warranted given the non-linear relationship between item probability and affective response. We also ran analyses on untransformed data and found substantively consistent results.

Table 1. Summary and mean ratings of the 14 scenario questions testing emotional reactivity to risk

Possible Outcome	Probability	Valence	Domain	*M* (*SD*) Rating
New cure for rare cancer	1 in 10	Positive	Health	3.17 (1.24)
Inherited genetic disease	1 in 16	Negative	Health	3.65 (1.08)
Gene that protects against Alzheimer's disease	1 in 20	Positive	Health	3.37 (1.18)
Unassisted fertility for middle aged couple	1 in 20	Positive	Health	2.91 (1.20)
Cancer from asbestos exposure	1 in 100	Negative	Health	3.68 (1.07)
IRS audit of your business	1 in 100	Negative	Finance	3.39 (1.16)
Upgrade to first class on a flight	1 in 200	Positive	Other	2.78 (1.28)
Airline loses bag on important trip	1 in 350	Negative	Other	2.91 (1.24)
Win raffle for iPad	1 in 500	Positive	Finance	2.55 (1.21)
Depression caused by acne medication for teen	1 in 5,000	Negative	Health	2.69 (1.24)
Stroke caused by drug side effect	1 in 10,000	Negative	Health	2.61 (1.22)
Spontaneous remission of tumor	1 in 10,000	Positive	Health	2.23 (1.30)
Severe complication, child's immunization	1 in 1,000,000	Negative	Health	2.09 (1.21)
Win Powerball lottery jackpot	1 in 10,000,000	Positive	Health	1.91 (1.21)

Notes: Ratings on a 1-5 scale from "Not at all worried" / "Not at all excited" to "Extremely worried" / "Extremely excited". Question order was fully randomized.

Table 2. Correlation coefficients for PPQ-Slope and PPQ-Intercept with other individual difference measures.

	Experiment 1		Experiment 2	
	PPQ-Slope	PPQ-Intercept	PPQ-Slope	PPQ-Intercept
PPQ-Slope	-	-0.22***	-	-0.27***
PPQ-Intercept	-0.22***	-	-0.27***	-
SNS	0.13***	-0.15***	0.19***	0.17***
REI-NFC	0.12***	-0.08***	0.17***	0.10**
REI-FI	-0.01	0.16***	0.01	0.43***
AA-Med	-0.10***	0.16***	-0.10**	0.33***
ELOT-O	0.04†	0.07**	0.05	0.45***
ELOT-P	-0.09***	0.05*	-0.26***	0.40***
PFI	0.03	0.13***	-0.15***	0.32***
MSS-R	-0.01	0.21***	-0.15***	0.61***
BNT-S	-	-	0.31***	- 0.17***
ERS-A	-	-	-0.26***	0.44***

Note †$p < .10$, *$p < .05$,**$p < .01$, ***$p < .001$.

Table 3. Results from regression models of scenario responses and individual difference measures, Experiment 1.

	Scenario Response Items						
	Prenatal Alcohol			Asbestos			Cancer
	Harm	Risk	Discomfort	Worry	Severe	Hopeless	Surgery
PPQ-Slope	-0.04*	-0.03	0.02	0.05*	0.05*	-0.11***	-0.07
PPQ-Intercept	0.08***	0.09***	0.10***	0.25***	0.23***	0.13***	-0.04
SNS	-0.04†	-0.03	-0.06**	-0.03	-0.03	-0.03	-0.17**
REI-NFC	-0.02	0.01	0.04	-0.01	-0.03	-0.05*	0.06
REI-FI	-0.04†	-0.01	-0.01	0.07**	0.07**	-0.06**	0.12*
AA-Med	0.10***	0.09***	0.10***	0.15***	0.16***	0.05*	0.05
ELOT-O	0.02	0.02	0.03	0.02	-0.01	-0.004	0.02
ELOT-P	-0.01	-0.002	-0.02	- 0.002	0.13***	0.14***	0.14†
PFI	-0.04†	-0.02	0.04	0.03	0.004	-0.02	-0.03
MSS-R	0.04†	0.04	0.04	-0.03	-0.01	0.02	-0.11*

Note †$p < .10$, *$p < .05$,**$p < .01$, ***$p < .001$. The results reported here are conditioned on age, gender, education, and race.

Table 4. Results from regression models of scenario responses and individual difference measures, Experiment 2.

	Scenario Response Items					
	Asbestos			Cancer		
	Worry	Severe	Hopeless	Surgery	Worry	Hopeless
PPQ-Slope	0.15***	0.13***	-0.01	0.11	0.17***	0.06†
PPQ-Intercept	0.33***	0.30***	0.22***	0.03	0.20***	0.25***
SNS	0.06	0.03	-0.03	0.05	0.07†	0.06
REI-NFC	0.01	0.02	-0.08*	0.12	0.02	-0.06
REI-FI	0.08*	0.09*	-0.05	0.12*	0.11**	0.06
AA-Med	0.10***	0.11***	0.03	-0.06	0.07*	0.07*
ELOT-O	0.03	0.10***	0.04	-0.22*	0.08*	-0.06
ELOT-P	-0.03	-0.05	0.18***	-0.06	-0.10*	0.07
PFI	0.02	0.06	0.01	0.04	0.17***	0.14***
MSS-R	0.05	-0.002	0.13**	0.02	0.06	0.03
BNT-S	0.04	0.05†	-0.01	0.04	0.12***	0.04
ERS-A	0.04	0.04	0.05	-0.02	0.002	0.02

Note †$p < .10$, *$p < .05$,**$p < .01$, ***$p < .001$. The results reported here are conditioned on age, gender, education, and race.