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The Unlikelihood Effect: When Knowing More Creates the Perception of Less

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ABSTRACT

People face increasingly detailed information related to a range of risky decisions. In order to aid individuals in thinking through such risks, various forms of policy and health messaging often enumerate their causes. While some prior literature suggests that adding information about causes of an outcome increases its perceived likelihood, we identify a novel mechanism through which the opposite regularly occurs. Across seven primary and six supplementary experiments, we find that the estimated likelihood of an outcome decreases when people learn about the (by-definition lower) probabilities of the pathways that lead to that outcome. This "unlikelihood" bias exists despite explicit communication of the outcome's total objective probability and occurs for both positive and negative outcomes. Indeed, awareness of a low-probability pathway decreases subjective perceptions of the outcome's likelihood even when its addition objectively increases the outcome's actual probability. These findings advance the current understanding of how people integrate information under uncertainty and derive subjective perceptions of risk.

Keywords: Probability judgments, risk, uncertainty, information processing, health decisions

Risk-related judgments regularly shape a wide range of consequential situations, including financial, recreational, and ethical decisions. One domain of particularly heightened attention is healthcare, in part due to the growing prevalence and support for prophylactic health planning and patient-directed care (Al-Agba, 2016; Marcus, 2010; Robinson, 2014). As individuals take greater control of their care, their personal interpretation of risk information increasingly influences whether they address immediate health risks and manage potential future harm or illnesses (Covey et al., 2019; Faasse & Newby, 2020). The consequences of these choices can impact not only the decision maker, but also the greater public. Indeed, a range of public health issues, such as managing highly-communicable infectious diseases, depend on community behaviors. And since compliance with many suggested defensive actions is voluntary, the success of these policies depends on individual perceptions and choices (e.g., Dryhurst et al., 2020; Faasse & Newby, 2020).

Messaging and communication can play a primary role in determining the perceived likelihood of health risks and thus people's resulting decisions. For example, a greater subjective likelihood of contracting the flu prompts people to be more likely to vaccinate themselves against it (Brewer et al., 2004), and a greater subjective likelihood of incurring harm from driving without a seatbelt increases people's likelihood of wearing one (Diener & Richardson, 2007). Despite their importance, these likelihood perceptions are often inaccurate (Lek & Bishop, 1995; Mongiello, Freudenberg, Jones, & Spark, 2016; Wogalter, Brems, & Martin, 1993), creating suboptimal decisions with consequences that can veer into life-threatening (e.g. Smith, Weinman, Amlôt, Yiend, & Rubin, 2018).

Substantial prior research has examined whether and how the presentation of risk information can alter these perceptions. Such work has revealed that listing the pathways through which risks can occur often heightens these risks' perceived probability (Biswas, Keller, & Burman, 2012; Brody et al., 2003; Redelmeier, Koehler, Liberman, & Tversky, 1995; Tversky & Koehler, 1994). In the current research, we identify conditions in which the reverse relationship exists between providing more pathway information and risk perceptions. In particular, we find that the estimated likelihood of a risk *decreases* when details about the specific numerical probabilities of all of its pathways are included. Thus we uncover a novel intervention through which enumerating the causes of a potential risk together with their individual probabilities decreases estimates of its likelihood, and can alter people's decisions.

Altering subjective likelihood

When people are informed of a risk's probability, a rational perspective would suggest that there should be little variance in how they interpret that information. However, people's subjective risk assessments often diverge from objective risk information that they receive. For example, in some situations people judge a 70% probability as extremely likely, while in other situations that same 70% probability feels relatively less likely (e.g., Betsch, Haase, Renkewitz, & Schmid, 2015; Bilgin, 2012; Schapira, Nattinger, & McAuliffe, 2006; Windschitl & Wells, 1996). Uncovering the levers that raise and lower subjective perceptions in the face of objective probability information speaks to the diversity of psychological processes that are involved in this form of complex information processing.

We propose that an important domain in which subjective and objective likelihoods may differ is when the probability of a single event is broken down into multiple causes. Individual probabilities for such causes are often provided as part of an overall effort to give people more complete and/or transparent information (e.g., Fox, 2017; Lutz, 2015; Ray, 1999; Weeks, 2019). As noted, prior research finds that providing more information by listing the causes through which a particular outcome can occur generally increases that outcome's total perceived likelihood (Biswas et al., 2012; Redelmeier et al., 1995; Tversky & Koehler, 1994; cf. Sloman et al., 2004). For example, support theory research finds that listing the number of types of fatal natural events increases the subjective likelihood of those events (Tversky and Koehler 1994) and listing the different pathways through which a patient may survive increases the subjective likelihood of survival (Redelmeier et al., 1995). This listing, or "unpacking," of an outcome's causes similarly biases perceived probability in domains beyond health, including the likelihood of financial audit outcomes (Brody et al., 2003), product failures (Biswas et al., 2012), and trial verdicts (Fox & Birke, 2002).

These effects have been attributed, in part, to increases in the outcome's salience with each additional listed cause (e.g., Tversky & Koehler, 1994). As such, each cause may be treated as further corroboration that the event can occur. The resulting accrual of evidence prompts people to conclude that the outcome's total probability is more likely—additional causes translate into additional perceived likelihood (Redelmeier et al., 1995; Rottenstreich & Tversky, 1997).

The unlikelihood effect

Our research uncovers a novel factor related to offering more pathway information which *decreases* an outcome's subjective likelihood. We propose that when people learn the specific probabilities of the ways in which an event can occur (i.e., probabilities that are by definition lower than the event's total probability), their subjective perception of the outcome's total probability declines. As a concrete example, suppose that people are evaluating their likelihood of catching a particular virus from flea bites, and that the objectively stated probability of this event is 60%. Based on support theory, we would predict that people subjectively judge that they have a larger likelihood of catching this virus (above 60%) if they additionally learn that the total probability results from multiple different types of fleas that each independently transmit this disease. However, we predict that taking the additional step of specifying the individual probabilities that each type of flea will transmit the virus *reduces* subjective judgments of the virus's total likelihood of occurrence below 60%.

Prior research suggests that people engage in a process akin to summation when they can access a complete list of all the ways in which an event can occur. In other words, the presence of additional reasons adds to people's subjective likelihood judgments. However, an increased desire for, and availability of, more information means that pathway-specific numerical probability information is also often available. We predict that disclosing the (by-definition lower) probability for each of the causes of an outcome prompts a different pattern of thoughts about the outcome, and that the integration of those thoughts is more akin to averaging than adding.

Averaging-like processes have been documented outside of the likelihood judgment domain. Impression formation research has found that people engage in a form of thought averaging when they integrate attribute information in order to estimate value (e.g., Anderson, 1965; Chernev & Gal, 2010; Lynch, 1979; Weaver & Garcia, 2018). Along similar lines, Shanteau (1974) offers some initial evidence related to estimations of the value of linguistically defined bets for different prizes such as "a toss-up to win a bicycle" or "highly probably to win a watch." While that work was centered on the integration of *value* and likelihood of separate and qualitatively distinct uncertain outcomes, we propose that these principles shape the manner in which people combine multiple vectors leading to the same outcome. Thus we suggest that such a process shapes subjective judgments about *risk*.

More specifically, we propose that disclosing the individual probabilities for each of the causes of a focal outcome increases thoughts about whether that outcome is *unlikely*, rather than likely, to occur. We further predict that the integration of these thoughts decreases estimates of that outcome's total likelihood. This theorizing draws on the persuasion literature, which has shown that interventions or information framing which increase the number of unfavorable thoughts (e.g., counterarguments) about a topic fuel unfavorable judgments about that topic (Eagly & Chaiken, 1993; Petty & Cacioppo, 1986). In a similar vein, we predict that disclosing the probability for each of an outcome's causes sparks elaboration about why the outcome may be unlikely to occur, and the resulting integration of these thoughts lowers subjective judgments of the outcome's total likelihood. As a result, the subjective estimate is "more unlikely" than the objective one. For ease of exposition, we refer to this phenomenon as the "unlikelihood effect." Of note, this proposed elaborative process stands in contrast to the many risk biases that do not operate through high levels of cognitive elaboration (e.g., Baron, 2014; Kahneman, Slovic, Tversky 1982; Morewedge & Kahneman, 2010).

We additionally propose that this process occurs even in the face of objective total probability information. This offers further advances beyond the prior impression formation, averaging, and support theory literatures (as well as research in behavioral economics). Rationally, it should be clear that an outcome's total objective probability is larger than the probability of the multiple vectors that contribute to it. This is necessarily true regardless of whether information specifying those vectors' precise probabilities is present or absent. However, our theoretical framework proposes that people do not spontaneously consider this fact. When numerical probability information is made explicit, the resulting awareness of each vector's relative infrequency initiates an integration process that sharply reduces perceptions of the outcome's total probability. In other words, while people are unlikely to engage in a strict mathematical averaging computation of the probabilities themselves, we propose that people integrate the information such that their awareness that the vectors individually have a relatively lower likelihood of producing an outcome decreases subjective perceptions of that outcome's total likelihood.

Notably, our framework is valence independent. It is true that people are often motivated to pursue beneficial outcomes and avoid aversive ones, which could shift their subjective interpretations of an outcome's likelihood up or down (e.g., Kunda 1990; Krizan & Windschitl 2007; Shiloh, Drori, Orr-Urtreger, & Friedman, 2009). However, we predict that it is the mere presence of information that makes salient that individual causes are relatively improbable that produces the unlikelihood effect; this process is agnostic to whether those causes produce a beneficial or aversive outcome. Thus, although we primarily highlight the unlikelihood effect's impact in health risk communications as an important practical domain of application, we propose that the effect emerges across both positive and negative uncertain outcomes in many fields.

Research overview

The current research is the first to document the manner in which enumerating an outcome's causes can decrease its total perceived likelihood when people receive complete information about each possible cause and its associated probability. Prior literature has shown some situations in which "unpacking" a general category into a limited subset of exemplars can engender attention or recall-based constraints that decrease an outcome's perceived likelihood (e.g., Sloman et al., 2004). However, complete information about the full set of a risk's causes removes those constraints, and in these conditions, we find that "more reasons" create "less likelihood."

Because people are regularly given the objective probability of the multiple pathways that might lead to a risk (e.g., Hull, 2021; Maldonado, 2007; NIH, 2019; Vallejo & Wilkes, 2022), our effect has substantial practical implications. As just one example, Supplementary Materials E documents the unlikelihood effect arising from the exact language featured on a National Institutes of Health (NIH) factsheet designed to provide the public with information about Alzheimer's disease. As is the case with many public health communications, the factsheet lists each probability of a risk's multiple causes (e.g., copies of a gene), but does not include a statement adding up the causes' total probability, or otherwise signaling that addition (NIH, 2019). Our research extends further, demonstrating that the unlikelihood effect is robust even to information contexts in which people do see the total outcome probability and view information that the probabilities of the causes are added up to compute this total.

Policymakers, health care workers, and news reporters employ a diversity of strategies when communicating the likelihood of various risks to the public. As previously noted, these strategies often include listing a risk's causes along with their specific probabilities (e.g., Fox, 2017; Lutz, 2015; Ray, 1999; Weeks, 2019). But some communications may instead list all of an outcome's causes without their specific probabilities (e.g., Tong, 2020; Waterall, 2019), or emphasize a potential risk's total probability without providing any information about its causes (e.g., Little City, 2015; One Health, 2020; Struk, 2017). Our research compares these conditions directly, providing novel insight into how these different approaches shape subjective risk perceptions.

We present seven primary experiments (with six supplementary experiments) examining our predictions regarding the "unlikelihood effect." Experiment 1 demonstrates our hypothesis that the perceived total probability of an outcome decreases when people learn information which makes explicit the fact that an outcome's multiple causes are each less probable than the outcome's total probability. Furthermore, it shows that the unlikelihood effect is not due to mere awareness that an outcome's total probability of occurrence arises from multiple causes—rather, awareness of the causes' numerical probabilities is necessary. Experiment 2 confirms that, consistent with our theoretical framework, the unlikelihood effect can be expressed in both harmful and beneficial domains. Experiments 3A-3B demonstrate the robustness of the effect across different distributions of causes, including by finding that a single low-probability cause is sufficient to create the effect. Experiment 4 directly tests our predicted mechanism regarding the impression formation from high levels of elaboration underlying the unlikelihood effect. Finally, Experiments 5 and 6 find that the perceptions arising from the unlikelihood effect can bias information seeking and decision-making behavior, respectively. Collectively, we demonstrate robust expression of this phenomenon across a variety of operationalizations and outcomes ranging from infectious disease to medications' side effects.

EXPERIMENT 1

As noted, prior literature has suggested that highlighting the existence of numerous vectors which produce a particular outcome heightens the salience of that outcome, and thus its probability (e.g., Ayton, 1997; Tversky & Koehler, 1994). At first glance, the hypothesized unlikelihood effect may appear to conflict with those experiments. However, we propose that the effect does not result from simply learning about the existence of numerous causes, but instead from information which makes explicit the fact that these causes are each less probable than the outcome's total probability.

In Experiment 1, we test the full range of these predictions. We examine people's subjective judgments of an outcome's probability after they view its total probability (in a *Single Probability* condition). We contrast these judgments to those formed when people additionally view the causes that yield that outcome's total probability (in a *Multiple Causes* condition), versus when they additionally view the causes together with their probabilities which together yield that outcome's total probability (in a *Multiple Probabilities* condition). In all three conditions, participants explicitly view the same total objective probability of the same outcome. Consistent with support theory literature (e.g., Ayton, 1997; Tversky & Koehler, 1994), we expect that viewing the outcomes' causes (in the *Multiple Causes* condition) will increase the outcome's total subjective likelihood. By contrast, we predict that numeric information which makes explicit the fact that each cause's probability must necessarily be lower than the outcome's total probability (in the *Multiple Probabilities* condition) will decrease the outcome's total subjective likelihood.

Method

With respect to transparency and openness, we report how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in this experiment and each ensuing experiment. IRB review and approval for the experimental procedures was conducted by either the Boston University Charles River IRB, or by the UC San Diego Human Research Protections Program. All data, analysis code, and research materials are available at https://researchbox.org/451; Experiments 1-4, Experiment 6, and the six supplementary experiments detailed in Supplementary Materials A-E were pre-registered. Data were analyzed using SPSS. In Experiments 2-5, individuals who incorrectly answered a screener question (which displayed a six-word phrase and required individuals to type the third word) were barred from starting the experiment. Sample sizes were determined in advance and estimated based off of ranges used in prior risk research involving Amazon Mechanical Turk, with a recruitment of at least 100 individuals per treatment cell.

We pre-registered Experiment 1 on AsPredicted (https://aspredicted.org/4p6xb.pdf). As specified, three hundred and ninety Mechanical Turk workers (mean age = 38.2 years; 56.3% male, 43.2% female, .5% nonbinary/other) completed an online experiment for monetary compensation via the Cloud Research platform. Participants were randomly assigned to one of three conditions. In all conditions, participants first read that they would view information about fleas. They read that these fleas were present in all parts of the world (i.e., that there is not one part of the world that has a lower or higher quantity of any of these fleas), and participants were asked to answer a question demonstrating that they comprehended this information.

On the next page, all participants read this information: "Every single person has a 58% chance of getting a flea bite that causes a newly discovered bacterial infection," ensuring all participants saw an identical statement explaining the total overall probability. Participants in the *Single Probability* condition then read that "58% of people get this bacterial infection from getting bitten by a siphonaptera flea." Participants in the *Multiple Causes* condition read text describing seven different fleas that could cause this bacterial infection with no additional probability information (e.g., "[p]eople can get this bacterial infection from getting bitten by a siphonaptera flea," "[p]eople can get this bacterial infection from getting bitten by a culex flea," etc.). Participants in the *Multiple Probabilities* condition read the same information as did participants in the *Multiple Causes* condition, accompanied by specific probabilities which summed to 58% (e.g., “8% of people get this bacterial infection from getting bitten by a siphonaptera flea,” “8% of people get this bacterial infection from getting bitten by a culex flea,” etc.). Participants expressed their estimated likelihood that people would get this bacterial infection on a slider scale validated to detect *subjective* perceptions of likelihood, which was anchored by “Not likely at all” to “Extremely likely” (e.g., Bilgin, 2012; Windschitl & Wells, 1996). The scale itself reflected a range from 0-100, but was not marked with any numerical information in this study or in the subsequent studies.

Participants were then asked to indicate their age and gender, and to complete an attention check: “In the information you read, what kind of animal bite would cause a bacterial infection?” As pre-registered, participants who failed to answer the question correctly were excluded from analysis, resulting in a sample of 376 participants (mean age = 38.4; 56.0% male, 43.5% female, .5% nonbinary/other). Finally, participants were given space to leave additional comments; this section was left empty by the majority of respondents.

Results

We followed our pre-registered analysis plan to conduct an ANOVA of the three conditions on perceived likelihood, which revealed the predicted significant overall effect of condition ($F(2, 373) = 23.88$, $p < .001$, partial $\eta^2 = .114$). As predicted, planned contrasts indicated that participants in the *Multiple Probabilities* condition perceived that there was a smaller likelihood of getting the bacterial infection ($M = 47.91$, $SE = 1.84$) than did participants in the *Single Probability* condition ($M = 56.24$, $SE = .96$; $p < .001$; Cohen’s $d = .509$, 95% CI [.262, .755]). Also as expected, participants in the *Multiple Causes* condition ($M = 61.07$, $SE = 1.05$) perceived that there was a larger total likelihood of getting the infection than did participants in both the *Single Probability* condition ($p = .011$; Cohen’s $d = .430$; 95% CI [.178,

.681]) and the *Multiple Probabilities* condition ($p < .001$; Cohen's $d = .786$; 95% CI [.522, 1.048]). These effects occurred despite all three conditions explicitly highlighting that each person's objective probability of getting this infection was 58%.[1]

In sum, consistent with support theory (e.g., Ayton, 1997; Tversky & Koehler, 1994), detailing the existence of numerous specific causes that produce a particular outcome heightens the total perceived likelihood of that outcome. However, this total perceived likelihood sharply declines when the individual probabilities of those causes are made explicit, demonstrating the unlikelihood effect. Because substantial literature has been devoted to documenting the former effect (e.g., Ayton, 1997; Tversky & Koehler, 1994), we devote our next experiment to examining the expression of the unlikelihood effect.

EXPERIMENT 2

While health-related risk information is frequently aimed at educating people about potential harms, our framework for the unlikelihood effect applies to risk perception more broadly across valences. To support this, Experiment 2 explores this phenomenon for both harms and benefits. This is useful because it might seem possible that the unlikelihood effect is driven by a generalized motivation to minimize the likelihood of negative outcomes (e.g. Kunda 1990; Krizan & Windschitl 2007; Shiloh et al., 2009). Learning that one or more of the pathways leading to harm occurs with a relatively low probability could prompt a motivated desire to consider the manner in which the outcome is unlikely to occur. Note that this form of motivated

[1] In these analyses, we implemented our pre-registered exclusion criteria of excluding participants who failed the attention check at the end of the experiment. Exploratory analysis revealed that the pattern and significance of these results remain the same when participants who failed the comprehension check related to fleas being present in all parts of the world are also excluded.

reasoning would be dependent on the focal outcome being aversive. Thus Experiment 2 tests whether the unlikelihood effect is valence independent.

In addition, Experiment 2 includes several controls to address possible alternate influences. First, the unlikelihood effect might occur because people incorrectly conclude that the independent causes must simultaneously occur to cause the outcome. To address this, participants are explicitly asked to confirm that they understand that each pathway through which an outcome can occur is sufficient to produce the focal outcome. Second, to the extent that people believe that conversation partners generally do not share information irrelevant to the aims of the interaction (e.g., Grice, 1975), participants might infer that the experimenter would not have provided the multiple pathway information unless the list was important for answering the ensuing questions. Notably, this inference does not a priori predict how the information would be used, and thus whether it would increase or decrease estimates of the outcome's likelihood. Regardless, to minimize the impact of such inferences, participants learn that the entirety of the information may not be relevant to ensuing survey questions and that it is simply provided in case it is of interest (e.g., Kupor & Laurin, 2020; see also Supplementary Materials A for additional evidence counter to the influence of Gricean norms in the unlikelihood effect).

Method

We pre-registered this experiment on AsPredicted (https://aspredicted.org/ni97v.pdf). We aimed to recruit 500 participants from Mechanical Turk and collected a total of 503 participants. As pre-registered, participants who failed either of two attention checks (described below) were excluded from analysis, leaving a total of 454 participants (mean age = 40.0; 46.2% male, 53.3% female, .4% nonbinary/other).

Participants were randomly assigned to one cell in a 2 (Probability format: Single vs. Multiple) × 2 (Outcome type: Harmful vs. Beneficial) design. First, all participants read that they would view all of the information that is known about the impact of the spice turmeric on the immune system in case it was of interest to them, but that not all of this information would be relevant to the questions they would complete in the survey. Next, participants in the *Harmful* (vs. *Beneficial*) conditions read the following:

> A recent study was conducted on turmeric. This study suggested that turmeric has a 70% chance of harming [boosting] the immune system of people who eat it. This occurs because it interacts with specific proteins in the body. Note also that turmeric will not interact with more than one protein for each person. Put another way, if everyone in the world ate turmeric, 70% of them would experience harm [a boost] to their immune system because of an interaction with one protein in their body.

In order to further ensure that all participants read this information, all participants in the *Harmful* (vs. *Beneficial*) condition then completed the following attention check: "To confirm that you have read this information, please answer the following question: Does turmeric have a 70% chance of harming [boosting] the immune system of people who eat it?" Participants indicated their responses by selecting either "yes" or "no." All participants additionally read "when someone eats turmeric, it will not interact with more than one protein in a single person's body," and completed the following attention check: "For one person, if turmeric interacts with one protein, will it interact with any other protein?" Participants indicated their responses by selecting either "no – it will not" or "yes – it will." As pre-registered, participants who incorrectly completed either of these attention checks were excluded from the analysis.

In the *Single Probability* condition, participants in the *Harmful* (vs. *Beneficial*) condition next read that "[i]n 70% of people, turmeric interacts with the cytochrome protein, and harms [boosts] the immune system of those 70% of people as a result." Participants in the *Multiple*

Probabilities condition read that the total 70% probability resulted from six different types of proteins with which turmeric could interact. These participants were also presented with the (individually smaller) probabilities of interaction with each protein, the sum of which totaled 70%. For example, participants in the *Harmful* (vs. *Beneficial*) condition read the following: “In 67% of people, turmeric interacts with the cytochrome protein, and harms [boosts] the immune system of those 67% of people as a result; In 1% of people, turmeric interacts with the fibrin protein, and harms [boosts] the immune system of those 1% of people as a result” etc.

Participants in the *Harmful* (vs. *Beneficial*) condition then indicated their subjective overall likelihood that consuming turmeric would harm (vs. boost) the immune system by answering the following question: “Overall, how likely is turmeric to harm [boost] the immune system?” As in Experiment 1, participants expressed their subjective likelihood on a slider scale anchored by “Not likely at all” to “Extremely likely.” Also, as in Experiment 1, the scale reflected a range from 0-100, but was not marked with any numerical information.

Results

We followed our pre-registered analysis plan to conduct a 2 (Probability format: Single vs. Multiple) × 2 (Outcome type: Harmful vs. Beneficial) ANOVA on the subjective likelihood data. This analysis revealed the predicted main effect of the probability format condition, such that participants perceived that consuming turmeric was less likely to impact the immune system in the *Multiple Probabilities* condition ($M = 71.60$, $SE = 1.09$) compared to the *Single Probability* condition ($M = 76.33$, $SE = .72$; $F(1, 450) = 11.92$, $p < .001$, Cohen’s $d = .340$, 95% CI [.154, .525]). There was a marginal effect of outcome type condition, such that participants perceived that consuming turmeric was more likely to impact the immune system in the *Beneficial* condition ($M = 75.36$, $SE = .83$) than in the *Harmful* condition ($M = 72.39$, $SE = 1.04$,

$F(1, 450) = 3.75$, $p = .054$[2]). As predicted, no significant interaction emerged ($F(1, 450) = .34$, $p = .559$; Figure 1). The individual post-hoc comparisons were not pre-registered, but are included for completeness. Participants in the *Multiple Probabilities* (vs. *Single Probability*) condition perceived that turmeric was less likely to impact the immune system both when they learned that turmeric harmed the immune system ($M_{Multiple} = 70.03$, $SE = 1.61$; $M_{Single} = 75.33$, $SE = 1.12$; $F(1, 450) = 7.81$, $p = .005$; Cohen's $d = .351$, 95% CI [.081, .620]) and when they learned that turmeric benefited the immune system ($M_{Multiple} = 73.34$, $SE = 1.43$; $M_{Single} = 77.10$, $SE = .93$; $F(1, 450) = 4.30$, $p = .039$; Cohen's $d = .296$, 95% CI [.038, .553]).

These results demonstrate that the unlikelihood effect impacts the perceived likelihood of both harmful and beneficial outcomes. This is inconsistent with the possibility that motivated reasoning specific to negative outcomes underlies the unlikelihood effect. Also of importance, these results emerged when all participants confirmed their understanding of the outcome's objective probability, and confirmed their understanding that turmeric could interact with only one protein in order to produce the focal outcome. Notably, additional empirics replicate the unlikelihood effect in the domain of gains in a financial context (Supplementary Materials A and B). Drawing from behavioral economics, these experiments leveraged lottery game designs in which players can win if a colored ball is drawn from an urn. For example, in Supplementary Materials A, participants learned that they had a 60% chance of winning a lottery by drawing any colored ball, or that they had several (by-definition lower) probability paths to winning which

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[2] Of note, we did not predict this marginal main effect; however, we speculate that motivated reasoning may underlie it—people may want turmeric consumption to benefit rather than harm the immune system, and their responses may reflect this desire (e.g. Kunda 1990). Most relevant to the current theorizing, the outcome's valence did not interact with the unlikelihood effect, providing evidence inconsistent with the possibility that motivated reasoning drives the unlikelihood effect. Because the source of the marginal main effect is not the focus of the current investigation, and because the result does not reach statistical significance, we leave this question to future research.

summed to 60% (i.e., participants viewed the probabilities of drawing specific ball colors from the urn, such as the probability of drawing a purple ball, a gold ball, etc.). Those who viewed these multiple probabilities estimated a lower total likelihood of winning.

Together, Experiment 2 and the experiments detailed in Supplementary Materials A and B suggest that the unlikelihood effect can distort the perceived likelihood of both beneficial and harmful outcomes across events spanning a range of risk communication domains including, but not limited to, health topics.

EXPERIMENT 3A

In this experiment, we investigate a strong version of our hypothesis that discovering the relatively lower probabilities of individual pathways causes people to reduce their subjective estimates of risk. Specifically, we investigate whether people who view a high-probability vector perceive a higher likelihood that its outcome will occur compared to people who see the same high-probability vector plus a low-probability vector (thereby increasing the outcome's total objective probability). Put another way, this experiment tests whether adding more can create a perception of less. In addition, it is possible to raise the question of whether people may perceive information as less credible or believable when it communicates the probability that more than one pathway causes an outcome, perhaps because people are dubious that it is possible to precisely document multiple pathways' probabilities. Experiment 3A tests this alternate explanation.

Method

We pre-registered this experiment on AsPredicted (https://aspredicted.org/h84gy.pdf). Participants who failed an attention check at the beginning of the experiment were barred from proceeding with the task. We aimed to recruit 300 participants from Mechanical Turk and 325 participants completed the experiment (mean age = 41.6; 50.5% male, 49.2% female, .3% nonbinary/other).

All participants viewed the following information about a constipation-relief medication: “A recent study was conducted on this constipation-relief medication. This study suggested that it has a chance of causing headaches because it interacts with specific proteins in the body. Note also that this medication will not interact with more than one protein in a single person's body.” Participants next completed an attention check in which they were asked the following question: “For one person, if the medication interacts with one protein, will it interact with any other protein?” Participants indicated their responses by selecting either a button labeled “no – this medication will not interact with more than one protein” or “yes – this medication will interact with more than one protein.” As pre-registered, the 17 participants who incorrectly completed the attention check were excluded, leaving a final sample of 308 participants (mean age = 41.7; 50.2% male, 49.5% female, .3% nonbinary/other).

In the *Single Probability* condition, participants next read that in total this medication causes a headache in 70% of people who take it and that “[i]n 70% of people, this medication causes a headache because it interacts with a protein in the body.” Participants in the *Multiple Probabilities* condition read that in total this medication causes a headache in 70.001% of people. These participants further read that “[i]n 70% of people, this medication causes a headache because it interacts with the fibrin protein in the body” and that “[i]n 0.001% of people, this medication causes a headache because it interacts with the keratin protein in the body.” As a result, the information in the *Multiple Probabilities* condition communicated a larger total probability of the side effect than did the information in the *Single Probability* condition.

Participants were next asked to indicate a person's likelihood of getting a headache if they took this medication. As in the prior experiments, participants indicated their responses on a numberless slider scale anchored by "Not likely at all" and "Very likely." The scale itself reflected a range from 0-10, but no numerical information was marked on it.

Next, participants indicated their perceptions of the credibility and believability of the information that they read by answering the following two questions: "How credible is the information above?" and "How believable is the information above?" Participants indicated their responses on a numberless slider scale ranging from 0-10 and anchored by "Not credible at all" and "Very credible," and a numberless slider scale ranging from 0-10 and anchored by "Not believable at all" and "Very believable," respectively. As pre-registered, these items were averaged into an index (r = .86, p < .001).

Results

We followed our pre-registered analysis plan to conduct a t-test on the perceived likelihood data. Consistent with our theorizing, participants perceived that there was a lower likelihood of the side effect in the *Multiple Probabilities* condition (M = 6.92, SE = .16) than in the *Single Probability* condition (M = 7.52, SE = .09, $t(306)$ = 3.28, p = .001, Cohen's d = .374, 95% CI [.148, .599]).[3] Also as predicted, there was no difference in the credibility and believability index between conditions (M_{Single} = 5.82, SE = .21; $M_{Multiple}$ = 5.87, SE = .20; $t(306)$ = .17, p = .866).

[3] A post-test (https://aspredicted.org/WJ8_XRJ) found no significant difference between the a priori perceived likelihood of 70.001% versus 70%. In particular, after completing an attention check (which barred participants who answered incorrectly from engaging in the task), 201 participants drawn from the same participant pool learned about the same medication described in Experiment 3A, but this time were randomly assigned to simply learn that the medication causes a headache in either 70% of people (in one condition) or 70.001% of people (in the other condition). Next, participants entered their subjective likelihood judgments on the same scale employed in Experiment 3A. Participants perceived that the medication's total probability of causing a headache was the same in both conditions ($M_{70\%}$ = 7.27, SE = .18; $M_{70.001\%}$ = 7.44, SE = .16; $t(199)$ = .72, p = .473).

We find that the presence of the lower-probability vector reduced the side effect's total *subjective* likelihood despite increasing its total *objective* probability. These results also demonstrate that the unlikelihood effect is triggered by the presence of even a single additional pathway that makes explicit that an outcome has causes less probable than that outcome's total probability. This influence of adding a lower-probability pathway which increases the outcome's total objective probability is replicated in the experiment detailed in Supplementary Materials C. Finally, our results suggest that the effect is not dependent on differences in perceptions of believability and credibility of the information.

EXPERIMENT 3B

Our experiments have thus far examined contexts that include relatively small probabilities (e.g., probabilities less than 15%). However, our theoretical framework predicts that the unlikelihood effect is not limited to such contexts, since it is triggered by encountering the probabilities of an outcome's multiple causes that are constrained only to be smaller than the outcome's total probability. Experiment 3B thus provides a second test of robustness by examining the unlikelihood effect arising from moderate probability pathways (e.g., pathways that have a ~40% probability of unfolding).

Method

We pre-registered this experiment on AsPredicted (https://aspredicted.org/mq9et.pdf). We recruited 400 participants from Mechanical Turk using the Cloud Research Platform (mean age = 36.5; 64.4% male, 35.6% female). All participants viewed the following text, described as a health article excerpt:

> Recently, we've documented a new form of allergic inflammation that has been occurring during rapid changes from cooler to warmer weather. People have a

> 86% chance of experiencing this allergic response due to encountering a particular class of pollens that are widespread in the area. These pollens become active during these weather changes and it's not possible to avoid breathing them in.

In the *Single Probability* condition, participants next read the following information: “More specifically, this total likelihood is because people have a 86% chance of experiencing this inflammation from breathing in the aika pollen.” By contrast, in the *Multiple Probabilities* condition, participants next read the following information: “More specifically, this total likelihood is because people have a 46% chance of experiencing this inflammation from breathing in the aika pollen, and an additional 40% chance of experiencing this inflammation from breathing in the pola pollen.” Participants were next asked to indicate a person’s overall likelihood of experiencing this inflammation. Participants indicated their responses on a numberless slider scale anchored by “Not likely at all” and “Extremely likely.” The scale itself reflected a range from 0-100, but no numerical information was marked on it.

Results

We followed our pre-registered analysis plan to conduct a t-test on the perceived likelihood data. Consistent with our theorizing, participants perceived that there was a lower likelihood of inflammation in the *Multiple Probabilities* condition (M = 70.45, SE = 1.47) than in the *Single Probability* condition (M = 77.35, SE = 1.28; $t(398) = 3.55$, $p < .001$, Cohen’s d = .355, 95% CI [.157, .552]).

Collectively, we find that the unlikelihood effect emerges regardless of whether the outcome’s causes are each relatively probable (Experiment 3B), the outcome’s causes are each relatively improbable (e.g., Experiment 1), or the outcome is produced by both relatively probable and improbable causes (e.g., Experiment 3A). Persistence across these parameters is consistent with our proposed process, which we test directly in Experiment 4.

EXPERIMENT 4

We propose that the unlikelihood effect occurs because disclosing the (by-definition lower) probability for each of an outcome's causes sparks a distinct thought pattern, increasing the share of cognitive resources allocated to considering ways in which the outcome is *unlikely* to occur. These thoughts are, in turn, integrated in a way that reduces the outcome's total perceived likelihood. Experiment 4 tests this mechanism directly by asking participants to record their thoughts as they judged an outcome's total likelihood.

As previously described, Experiment 1's *Multiple Causes* condition replicated a well-documented effect in which listing the causes that produce a particular outcome heightens the total perceived likelihood of that outcome (e.g., Ayton, 1997; Tversky & Koehler, 1994). Notably, there are a number of mechanisms that have been suggested to underlie this effect, including memory, representativeness, and each cause magnifying the outcome's salience (e.g., Brenner & Bilgin, 2011; Hadjichristidis, Geipel, & Gopalakrishna, 2021; Manktelow & Galbraith, 2012; Rottenstreich and Tversky, 1997; Tversky & Koehler, 1994). Because thought records capture elaborative information processing differences, they mediate judgments only when those judgments predominately arise from processes that generate extensive elaboration (Cacioppo, Petty, Feinstein, & Jarvis, 1996; Haugtvedt & Wegener, 1994; Petty, Schumann, Richman, & Strathman, 1993). As a result, we predict that elaboration would mediate the unlikelihood effect but is unlikely to capture the range of mechanisms driving likelihood estimates that result from simply viewing an outcome's causes.

Method

We pre-registered this experiment on AsPredicted (https://aspredicted.org/id8qg.pdf). We aimed to recruit 600 participants from Mechanical Turk and 601 participants completed the experiment (mean age = 45.5 years; 46.3% male, 53.1% female, .7% nonbinary/other). All participants viewed the following information: "Below is side effect information for a constipation-relief medication. When someone takes this medication, the medication will not interact with more than one protein in a single person's body. The medication has a 58% chance of causing a headache in people who take it." Thus, all participants saw the identical statement of the outcome's total probability.

As in Experiment 1, participants were randomly assigned to either a *Single Probability* condition, a *Multiple Causes* condition, or a *Multiple Probabilities* condition. Participants in the *Single Probability* condition then read the following: "This medication interacts with a class of proteins in 58% of people, which causes a headache in those 58% of people." Participants in the *Multiple Causes* condition additionally learned that the reason why the medication has a 58% chance of causing headaches is because there are nine proteins with which it can interact, and viewed information about each one (e.g., "[t]his medication interacts with the cytochrome protein in some people, which causes a headache in those people"). Participants in the *Multiple Probabilities* condition read the same information as did participants in the *Multiple Causes* condition, but this time the information was accompanied by specific probabilities assigned to each protein, totaling 58% (e.g., "[t]his medication interacts with the cytochrome protein in 5% of people, which causes a headache in those 5% of people").

Participants were next asked to consider people's likelihood of getting a headache if they take this medication. Participants were asked to write down their thoughts as they considered this question (methods draw from Cacioppo and Petty, 1981). Then, for each thought listed, they indicated whether it focused on why the headache side effect was likely to occur, why the headache side effect was unlikely to occur, or whether the thought was unrelated to the headache side effect. In accordance with our pre-registered analysis plan, we computed a proportion score of the share of thoughts focused on why the headache side effect was unlikely versus likely to occur. Thus, a higher score reflected a larger proportion of "unlikelihood" thoughts. Finally, participants were asked to indicate a person's total likelihood of experiencing a headache side effect from taking this medication. Participants indicated their responses on a numberless slider scale anchored by "Not likely at all" and "Extremely likely." The scale itself reflected a range from 0-100, but no numerical information was marked on it, as in the prior experiments.

Results

We followed our pre-registered analysis plan to conduct an ANOVA of the three conditions on perceived likelihood. This ANOVA revealed the predicted significant overall effect of condition ($F(2, 598) = 22.02$, $p < .001$, partial $\eta^2 = .069$). As expected, planned contrasts indicated that participants in the *Multiple Probabilities* condition perceived that there was a smaller likelihood of experiencing the headache ($M = 53.90$, $SE = 1.64$) than did participants in the *Single Probability* condition ($M = 59.29$, $SE = .86$; $p = .003$; Cohen's $d = .291$, 95% CI [.092, .490]). Replicating Experiment 1, participants in the *Multiple Causes* condition ($M = 65.78$, $SE = 1.21$) perceived that there was a larger total likelihood of experiencing the headache than did participants in both the *Single Probability* condition ($p < .001$; Cohen's $d = .432$; 95% CI [.234, .629]) and the *Multiple Probabilities* condition ($p < .001$; Cohen's $d = .582$; 95% CI [.384, .780]). These effects occurred despite all three conditions explicitly informing participants that each person's objective probability of experiencing this headache side effect was 58%.

Also as specified in our pre-registered analysis plan, we conducted an ANOVA of the three conditions on the thought record data. This ANOVA revealed a significant overall effect of condition ($F(2, 587) = 3.71$, $p = .025$, partial $\eta^2 = .012$). Participants in the *Multiple Probabilities* condition described a larger proportion of "unlikelihood" thoughts ($M = .16$, $SE = .02$) than did participants in the *Single Probability* condition ($M = .10$, $SE = .02$; $p = .024$; Cohen's $d = .215$, 95% CI [.015, .416]). By contrast, the thought pattern of participants in the *Multiple Causes* condition ($M = .10$, $SE = .02$) and the *Single Probability* condition did not differ ($p = .902$). Mediation with bootstrapping (Hayes, 2013) revealed that this proportion score mediated the effect of the *Single Probability* condition versus the *Multiple Probabilities* condition on the outcome's total perceived likelihood (95% CI [.226, .425]; Figure 2), but did not mediate the effect of the *Single Probability* condition versus the *Multiple Causes* condition on the outcome's total perceived likelihood (95% CI [-.527, .597]).

This experiment provides evidence consistent with our hypothesis that viewing a lower-probability vector causes a larger share of people's thoughts to focus on how the outcome is unlikely to occur. The integration of these thoughts, similar to impression formation, decreases the estimated likelihood for the outcome. However, this process does not underpin the effect demonstrated in the *Multiple Causes* condition (which was consistent with findings documented in the unpacking and support theory literature). The instructions for the thought listing protocol were designed to increase clarity of the task, directly test the theorized mechanism, and avoid any bias in the directionality of the thoughts elicited. However, their candid specificity about likely, unlikely or unrelated thoughts creates a potential limitation, as it could have created other forms of demand effects. Overall then, this experiment suggests that the unlikelihood effect offers a novel contribution to research investigating the consequences of multi-dimensional uncertainty information, but also opens an important domain for future research defining the full scope of mechanisms involved in the information processing taking place.

EXPERIMENT 5

The unlikelihood effect is important in part because people's subjective judgments of an outcome's likelihood are a meaningful driver of their decisions (Brewer et al., 2004; Janz & Becker, 1984; Namerow, Lawton, & Philliber, 1987). In Experiment 5 we examine the impact of the unlikelihood effect on information seeking decisions. Indeed, to combat a lack of information can materially harm people's physical health, many practitioners strive to persuade people to obtain further information (Kwon, 2017; Shi, Nakamura, & Takano, 2004; Warner & Procaccino, 2004). Therefore, we examine the impact of the unlikelihood effect on these types of consequential information seeking choices.

Method

One thousand Mechanical Turk workers (mean age = 38.1; 45.5% male, 54.5% female) completed an online experiment for payment.[4] Participants who answered a screener question incorrectly were barred from continuing on to the experiment. Participants were randomly assigned to either a *Single Probability* condition or a *Multiple Probabilities* condition. In both conditions, participants read the following: "The vast majority of Americans do not consume enough Vitamin B12. Insufficient consumption of Vitamin B12 can harm the immune system.

[4] We made an a priori decision to seek a large sample because this experiment measures a binary (yes/no) information seeking decision. Behavioral measures can result in different effect sizes than perceptual (or attitudinal) measures, and binary choice offers inherently less variance than a scale. Thus, without prior data on this measure, we collected a large sample size in accordance with recommended practices.

Insufficient Vitamin B12 will not impact with more than one protein in a single person's body. Here's how insufficient Vitamin B12 can harm the immune system." Participants in the *Single Probability* condition then read that "[i]nsufficient Vitamin B12 consumption harms the immune system in 96% of people by impacting the cytochrome protein." By contrast, participants in the *Multiple Probabilities* condition viewed 21 proteins that Vitamin B12 could impact, the sum of which totaled 96% (e.g., "Insufficient Vitamin B12 consumption harms the immune system in 5% of people by impacting the cytochrome protein; Insufficient Vitamin B12 consumption harms the immune system in 3% of people by impacting the fibrin protein" etc.).

All participants rated the total likelihood that insufficient Vitamin B12 harms the immune system. As in the prior experiments, participants indicated their responses on a slider scale anchored by "Not likely at all" and "Extremely likely." The scale itself reflected a range from 0-100, but no numerical information was marked on it. We captured participants' behavior with respect to purchase interest by asking them whether they wanted to view information about where to buy the best Vitamin B12. Participants indicated their responses by selecting either "yes" or "no."

Results

Replicating the unlikelihood effect, participants in the *Multiple Probabilities* condition perceived that there was a smaller total likelihood that insufficient Vitamin B12 would harm the immune system (M = 54.25, SE = 1.45) than did participants in the *Single Probability* condition (M = 79.27, SE = 1.00; $t(998)$ = 14.24, p < .001; Cohen's d = .901, 95% CI [.770, 1.031]). In addition, as predicted, participants in the *Multiple Probabilities* condition (43.5%) were less likely to choose to receive information about where to purchase the best Vitamin B12 than were participants in the *Single Probability* condition (50.5%), $\chi^2 = 4.97$, $p = .026$ ($\varphi = .07$).[5] Of note, the effect size of the subjective likelihood result was relatively large in this experiment. This may have occurred because the total outcome probability (96%) in this experiment was larger than in other experiments, which may have moderated the size of the effect.

Beyond the main effects, mediation analysis with bootstrapping (Hayes, 2013) revealed that participants in the *Multiple Probabilities* (vs. *Single Probability*) condition were less likely to click to view where to purchase the best Vitamin B12 because they perceived that insufficient Vitamin B12 was less likely to harm the immune system (95% CI: -.058 to -.015; Figure 3).

EXPERIMENT 6

Subjective judgments of an outcome's likelihood are not only a primary driver of people's information seeking decisions, but also of other consequential decisions as well. For example, people who perceive that an action is more likely to yield benefits are more likely to take that action, as has been shown with vaccinations and consuming specific nutrients (Brewer & Fazekas, 2007; Gerend, Lee, & Shepherd, 2007; Henson, Cranfield, & Herath, 2010). Similarly, people who perceive a higher probability of disease are more likely to proactively defend against it (Brewer et al., 2004; de Vries et al., 2012). As a result, the unlikelihood effect could influence some of people's most consequential decisions. In Experiment 6, we further

[5] Participants additionally completed a final question in which they were asked whether they wanted to take steps to boost their immune system (1 = No, 2 = Yes). We assessed this question in order to examine whether the effect of condition on choice emerged only among participants who wanted to boost their immune system. Exploratory analysis suggested that this was the case. Specifically, the effect of condition on real decisions persisted among participants who desired to take steps to boost their immune system (*Single Probability* condition = 57.4%, *Multiple Probabilities* condition = 48.1%; $\chi^2 = 7.39$, $p = .007$), but not among those that did not (*Single Probability* condition = 4.5%, *Multiple Probabilities* condition = 10.8%; $\chi^2 = 1.87$, $p = .172$). The effect of condition on likelihood judgments persisted both among participants who desired to take steps to boost their immune system ($M_{Multiple} = 56.04$, $SE = 1.54$; $M_{Single} = 80.00$; $SE = 1.03$; $t(862) = 12.94$, $p < .001$; Cohen's $d = .880$, 95% CI [.740, 1.020]) and among those that did not ($M_{Multiple} = 41.57$, $SE = 3.98$; $M_{Single} = 75.75$; $SE = 3.24$; $t(130) = 6.68$, $p < .001$; Cohen's $d = 1.163$, 95% CI [.791, 1.530]).

examine the practical implications of the current phenomenon by investigating its impact on decisions about whether to purchase a prophylactic health product.

Method

We pre-registered this experiment on AsPredicted (https://aspredicted.org/blind.php?x=4v32iu). We followed our pre-registered analysis plan to exclude participants who failed either of two comprehension checks (see below), which resulted in a final sample of 511 participants (mean age = 41.5; 45.9% male, 53.1% female, 1.0% nonbinary/other). Although the pre-registration also describes a "screener" attention check for entering the experiment, this was not implemented in the final survey.

Participants were randomly assigned to one of two conditions. In both conditions, participants read that they would view information about fleas, and that not all of the information would be relevant to the survey questions but was simply provided in case it was of interest. Participants completed a comprehension check in which they were asked whether or not all of the information would be relevant to all of the questions in the survey.

Participants in the *Single Probability* condition read the following: "A recent study was conducted on siphonapera fleas. Each person in the world has a seventy four percent chance of being bitten by this flea and getting a bacterial infection as a result. Siphonaptera fleas are present in all parts of the world – there is NOT one part of the world that has a lower or higher quantity of these fleas." Participants in the *Multiple Probabilities* condition read the same text except that it named nine different types of fleas. Whereas participants in the prior experiments viewed the outcome's total probability in numeric form, participants in Experiment 6 viewed this statement of total probability information in written form[6]. Participants also answered a comprehension check confirming their understanding that there is not a part of the world with higher or lower quantities of these fleas.

In the *Single Probability* condition, participants then read specifically that each person's 74% percent chance of infection comes from the likelihood of being bitten by a siphonaptera flea. Participants in the *Multiple Probabilities* condition viewed the probability of infection from each type of flea summing to a total of 74% (e.g., "8% of people get this bacterial infection from getting bitten by a siphonaptera flea"; "11% of people get this bacterial infection from getting bitten by a culex flea" etc.).

We then assessed participants' behavior with respect to protecting themselves against this infection in the context of the specific information about its causes. All participants read the following: "The CDC (Center for Disease Control) has found that the only way to reduce the odds of getting this infection is by consuming a particular type of lemongrass (i.e., a natural spice). Each gram of this lemongrass costs one dollar, and each additional gram of this lemongrass reduces the likelihood of getting this infection by an additional ten percent. You can purchase up to ten grams of this type of lemongrass that the CDC recommends here." Participants entered their chosen quantity of the prophylactic treatment on an 11-point scale labeled from 0 grams to 10 grams. (Note that the scale answers from 0 to 10 were recoded numerically as 1 to 11 by the survey software; for the purposes of transparency and consistency with the original data, our analyses reflect that recoding.)

[6] Although it is possible that the written (vs. numeric) form of the outcome's total probability (vs. its causes' probabilities) increased the relative salience of its causes' probabilities, seven experiments (i.e., Experiments 1, 2, 3A, 3B, 4 and two experiments in Supplemental Materials B) replicate the unlikelihood effect when both the outcome's total probability, as well as its causes' probabilities, are both presented in numeric form.

Results

We followed our pre-registered analysis plan to conduct a t-test on the purchase order data. As predicted, participants in the *Multiple Probabilities* condition (M = 7.85, SE = .23) entered a smaller purchase order of this prophylactic treatment than did participants in the *Single Probability* condition (M = 8.55, SE = .21; $t(511) = 2.26$, $p = .024$; Cohen's d = .200, 95% CI [.026, .373]). These results are consistent with our theorizing that communicating the individual causes of a risk with their probabilities can alter peoples' health decisions. Experiments 5 and 6 thus offer collective evidence for the type of impact the unlikelihood effect could have such behaviors.

GENERAL DISCUSSION

People receive many forms of risk-related information across a number of domains. When health-related, their interpretation of this information is particularly consequential. This is because people now face a rapid rise in their responsibility for taking care of their own health, and as seen during global viral outbreaks, for choosing behaviors that impact the health of others. In this environment, people often encounter a range of information, and their resulting subjective perceptions of a risk's likelihood frequently guide their decisions about whether to mount a defense (Brewer et al., 2004; Diener & Richardson, 2007; Meadows, Catalan, & Gazzard, 1993). Prior research across several domains of psychology and behavioral economics has shown a number of different types of biases related to estimating risk from multifaceted information. In this research, we uncover the first evidence for the "unlikelihood effect," in which providing additional probability information can decrease the perceived likelihood of risks, and thus alter how people make their corresponding decisions.

Specifically, we examine the impact of listing multiple possible causes of a health risk together with their individual probabilities, compared to exclusively listing the health risk's total probability. Prior literature suggests that enumerating multiple causes of an outcome often increases its perceived likelihood (e.g., Ayton 1997; Biswas et al., 2012; Brody et al., 2003; Redelmeier et al., 1995; Tversky & Koehler, 1994). Notably, that research often gives participants partial information, with just a few examples rather than a complete list of all potential causes. In real-world settings, however, people are regularly given the objective probability of every known pathway that might lead to a risk (e.g., Fox, 2017; Lutz, 2015; Ray, 1999; Weeks, 2019). We find that such full-information contexts lead subjective perceptions of a health risk's total likelihood to sharply decrease. We demonstrate this decrease across a variety of types of causal antecedents (e.g., outcomes caused by medicines, infectious diseases, and nutrition) and types of outcomes (e.g., outcomes impacting immune system functioning, headaches, and bacterial infection).

Our results support a framework in which the overall estimated likelihood of a risk declines when people encounter information which makes explicit the fact that the outcome's probability arises from individually less likely pathways. While Experiments 1-6 involve outcomes with total probabilities above 50%, in Supplementary Materials D we demonstrate that the effect is expressed in a situation where the total objective probability itself is on the "less likely" side of the scale, below 50%.

Our findings contribute to the literature on support theory and unpacking effects. As noted, those theories generally demonstrate that identifying causes of an outcome increases estimates of that outcome's likelihood (e.g., Biswas et al., 2012; Redelmeier et al., 1995; Tversky & Koehler, 1994). However, recent research has demonstrated a few counterexamples, where listing more options can also decrease estimates of risk (e.g., Hadjichristidis, Sloman, & Wisniewski, 2001; Hadjichristidis et al., 1999; Redden & Frederick, 2011; Sloman et al., 2004). Such research related to unpacking focuses on whether the influence of listing multiple pathways to an outcome depends on the estimated typicality or familiarity of those pathways. For example, people judge death from “disease” to be more likely than death from “pneumonia, diabetes, cirrhosis, or any other disease” (Hadjichristidis et al., 2001; Hadjichristidis et al., 1999; Sloman et al., 2004). This is predicated on a working memory mechanism, in which the atypical exemplars (e.g., cirrhosis) consume attention and working memory and potentially block recall of more typical exemplars. In contrast, our experiments employ novel situations in which the causes are all equally (un)familiar and the specific likelihoods are transparent. In addition, we provide complete information about the causes of the health risk, making the ability to recall other causes, or more typical causes, inapplicable as a potential mechanism (see Supplementary Materials F for further distinctions). Collectively, then, this research suggests that these phenomena (e.g., estimated likelihood increases and decreases) may arise from a portfolio of effects rather than a single mechanism (see also Experiment 4).

Our work also can be considered in the context of literature on averaging and impression formation (e.g., Anderson, 1965; Weaver & Garcia, 2018). Such findings largely illustrate subjective estimates of *value* based on integrating information related to multiple attributes of a single entity from an instrumental or utility-based perspective (e.g., Anderson, 1965; Weaver & Garcia, 2018; but see also Shanteau, 1974). We open new possible domains for this research by examining multiple risk pathways that sum up to a total probability. While our findings do not suggest that people directly average the probabilities themselves, they are consistent with people integrating their (un)likelihood thoughts evoked by these probabilities into a subjective estimate of *risk*. In addition, they do so when the objective information about the outcome's total risk is available (see also Supplementary Materials F). Our framework proposes that people do not spontaneously consider the fact that the outcome's total risk may arise from individually smaller probability vectors in the absence of explicit numerical information. When these figures are presented, they initiate a thought process that reduces perceptions of the outcome's total probability.

A potentially interesting resolution of the predictions of support theory, the impression and averaging literature and the present experiments is that when considering the likelihood of a single well-defined outcome, individuals appear to sum reasons when they do not have access to numerical probabilities, but go through a process more like averaging their impressions when they do, as shown in Experiment 1 and Experiment 4. This further suggests an opportunity to define the cognitive processing taking place with increased precision beyond the increased salience of numerical probabilities. For example, this processing may arise from different patterns of engagement or attention, or trigger uncertainty that impacts perceptions of likelihood. Individual differences in the magnitude of the effect could also offer more detailed insights on relevant traits and processes (e.g., Gonzalez & Wu, 1999; Capra, Jiang, Engelmann & Berns, 2013). Thus a comprehensive understanding of the mechanism underlying the unlikelihood effect remains an important domain for future research.

The unlikelihood effect can further be compared to the extant literature examining disjunctive errors, which imply that summary disjunctions are perceived as "less likely" than they should be (e.g., Bar-Hillel & Neter, 1993; Carlson & Yates, 1989; Costello, 2009; Nilsson, Winman, Juslin, & Hansson, 2009). A significant volume of this research considers situations in which the probability of one component of a disjunctive event is misperceived as more likely than the overall disjunctive event. These components are generally framed as separate or unrelated events. In contrast, the unlikelihood effect emerges from multiple causal vectors leading to a single outcome. In this distinct information context, when these vectors are listed, they can either decrease or increase perceptions of an outcome's likelihood depending on whether the explicit probabilities of each vector are disclosed (Experiments 1 and 4). Furthermore, the disjunction error literature (e.g., Bar Hillel & Netter, 1993; Carlson & Yates, 1989; Costello, 2009; Nilsson, Winman, Juslin, & Hansson, 2009), finds that decreases in estimated likelihood occur in the absence of probability information. However, the unlikelihood effect occurs *exclusively* when these probabilities are present, and the absence of these probabilities produces a reverse effect whereby an outcome's total probability is perceived as *more* likely (see Supplementary Materials F for further discussion).

One question that can arise when numerical information is provided is whether it might influence estimates of risk by acting as an anchor. Anchoring and insufficient adjustment is a process by which people focus on a particular value (i.e., an anchor) and then serially adjust away from that value until they reach a plausible answer. This process often leads estimates to be biased in the direction of the initial anchor (Mussweiler, Thomas, & Strack, 2001; Quattrone et al., 1984; Tversky & Kahneman, 1974). However, our experiments provide multiple points of disconfirmation with this heuristic-type mechanism (see Supplementary Materials C for further discussion). For example, anchoring and insufficient adjustment processes do not exert this influence when people are aware of the objectively correct answer (because people aware of a correct answer do not need to engage in the same type of judgment process; Wilson, Houston, Etling, & Brekke, 1996). In contrast, the unlikelihood effect persists even when the overall likelihood of the event is explicitly presented. Additional empirics (detailed in Supplementary

Materials C) manipulated whether or not a small probability in the judgment context was related to the focal outcome, and found that the unlikelihood effect occurred only when that small probability was related. Because anchoring effects occur regardless of an anchor's relevance to a focal judgment (Kahneman & Knetsch, 1993; Wilson et al., 1996), these data provide further evidence inconsistent with an anchoring process.

Our research also advances a prior finding examining how people integrate verbal versus numeric probability information (Mislavsky & Gaertig, 2020). In that work, people who learn that two different advisors judge that an outcome is "likely" infer that the outcome is "very likely" (people appear to sum this verbal information). In contrast, learning that two advisors judge that an outcome has a 60% probability yields an estimate of 60% (people appear to average this numeric information). Notably, their work examined how people integrate others' total probability estimates, while our research examines how people integrate the vectors leading to an outcome. In addition, they compare integration of (only) verbal versus (only) numerical modalities of judgments; by contrast, we investigate how observers integrate implicit versus explicit probabilities associated with an outcome's vectors. Taken together, these findings support the broader notion that people engage in multiple mental processes when considering lexical and numerical information.

Another contribution arises when the unlikelihood effect is juxtaposed with the "dud-alternative" effect, in which the addition of an implausible alternative outcome increases the perceived likelihood of a stronger outcome through a contrast-based mechanism (Windschitl & Chambers, 2004). Our research investigates a distinct context in which all the offered pathways lead to a singular focal outcome, rather than offering competing alternatives that lead to different outcomes. In our setting, the dud-alternative effect might predict that the pathways could compete with each other and create a contrast effect. However, this mechanism is inconsistent with Experiment 3A. If a contrast effect resulted from the addition of a very low-probability pathway, this addition would have magnified the perceived likelihood of the higher-probability pathway, resulting in a higher likelihood estimation—opposite to the unlikelihood effect observed. Our research on the unlikelihood effect thus allows us to expand the overall understanding of how different forms of information are interpreted when applied to various loci of uncertainty.

Expanding the scope of this discussion, the unlikelihood effect also has potentially important practical implications. For example, in Supplemental Materials E, we demonstrate the unlikelihood effect based on the exact wording used to describe risk factors for Alzheimer's disease in public health messaging from the National Institutes of Health (NIH, 2019). Participants estimated a lower total likelihood of risk when they viewed the NIH message, which lists separate probabilities of having genes associated with Alzheimer's, compared to participants who viewed an adapted version of the information which lists only the total probability of having these genes.

Public health officials, marketers, health care workers, and news reporters employ a diversity of strategies when communicating risks to the public. As exemplified by the NIH factsheet, these communications often list a risk's causes along with their specific probabilities (e.g., Fox, 2017; Lutz, 2015; Ray, 1999; Weeks, 2019). Some instead list a risk's causes without their specific probabilities (e.g., Tong, 2020; Waterall, 2019), or emphasize a risk's total probability without providing any information about its causes (e.g., Little City, 2015; One Health, 2020; Struk, 2017). Our research suggests that these strategies can differentially shape viewers' ultimate perceptions of an outcome's total likelihood, and their subsequent decisions. In particular, our findings indicate that public health officials who desire to communicate that a risk is highly probable may better achieve this objective by highlighting its total probability rather than listing each of its possible causes irrespective of their probability. This “focus on the lede” advice clashes with transparency-motivated strategies aimed at ensuring that people are maximally informed, which would favor the inclusion of all available information. Thus, the current research suggests that public communication of health information may require careful and potentially goal-directed management.

Though we have explored the unlikelihood effect in the health and healthcare domains, the underlying mechanism is not specific to this application. Indeed, our framework suggests that communicating the probabilities that multiple pathways will produce any beneficial or harmful risky outcome will decrease that outcome’s subjective likelihood. The experiments detailed in Supplementary Materials A and B are consistent with this possibility, by finding that the unlikelihood effect can alter the subjective likelihood of financial prospects such as a winning lottery outcome. The breadth of potential impact is wide—awareness of the probabilities with which multiple pathways contribute to financial risks (e.g., investing, acquiring debt, and increasing liquidity risks), unethical risks (e.g., cheating, lying, and engaging in illegal activity), and recreational risks (e.g., playing dangerous sports or taking recreational drugs) may decrease the subjective likelihood of these risks’ success, and therefore decrease individuals’ likelihood of taking them. This suggests a rich field of future research to investigate the unlikelihood effect’s potential consequences.

In sum, our findings illuminate the unlikelihood effect, a previously undocumented phenomenon which biases likelihood judgments and causes non-normative decisions. In so doing, our research provides novel insight into the manner in which the nature and even "completeness" of presented probability information can influence the interpretation and use of that information. These findings therefore offer researchers insights into the mechanisms involved in integrating multi-dimensional uncertainty information, and also offer policymakers insights about how to more effectively persuade the public to take beneficial risks as well as appropriately guard against harm.

CONTEXT

People are expected to make increasingly complex decisions for themselves in consequential domains with uncertain outcomes. The coronavirus pandemic has highlighted the personal and social importance of estimating health risks in particular, but also the challenges and aversiveness of doing so. Details regarding the vectors that cause such risks are increasingly available and salient, potentially reflecting an increased desire for information in an effort to manage uncertainty and accurately estimate the total risk. Substantial research including the support theory literature had previously shown that adding pathways caused people to "build up" their risk estimate (and thus perceive a higher total risk). We wondered whether adding the individual numerical probabilities of those vectors would cause people to switch into "breaking down" the objective total probability of a risk, decreasing their subjectively estimated likelihood. The authors of this research have studied decision-making under uncertainty drawing on theory and methods from social psychology, cognitive psychology, behavioral economics and neuroscience. This research builds on their expertise in how people integrate information through multiple mental processes to yield subjective perceptions of risk that govern complex real world choices.

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Figure 1: Likelihood judgments as a function of condition in Experiment 2. Error bars represent standard errors.

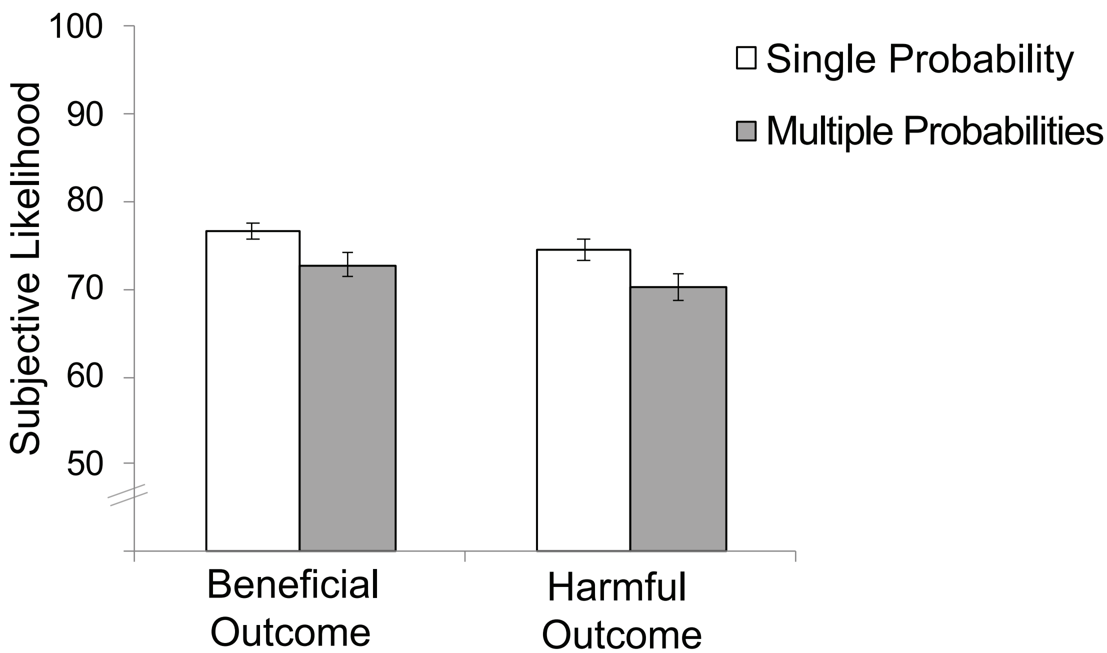

Figure 2. Mediation model in Experiment 4. Path coefficients are unstandardized betas. The value in parenthess indicates the effect of condition on the dependent variable after controlling for the mediator. *p<.05 **p<.01 ***p<.001

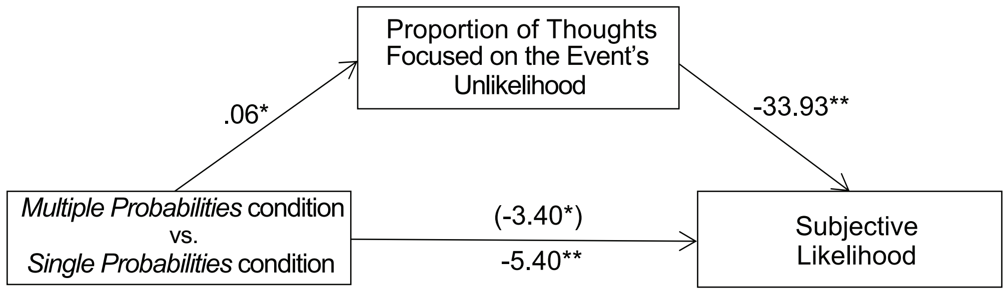

Figure 3. Mediation model in Experiment 5. The path coefficients are unstandardized betas. The value in parenthesis indicates the effect of condition on the dependent variable after controlling for the mediator. **p*<.05 ***p*<.01 ****p*<.001