Ambiguity attitudes in qualitative contexts: The role of prior beliefs

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Abstract

Most studies of ambiguity aversion rely on experimental paradigms involving monetary bets. Thus, the extent to which ambiguity aversion occurs outside of such contexts is much less understood, particularly when the situation cannot easily be reduced to numerical terms. The present work seeks to understand whether people prefer to avoid ambiguous decisions in a variety of different qualitative domains (work, family, love, friendship, exercise, study and health); and, if so, to determine the role played by prior beliefs in those domains. Across three studies, we presented participants with 24 vignettes and measured the degree to which they preferred risk to ambiguity in each. We also asked them for their prior probability estimates about the likely outcomes in the ambiguous events. Ambiguity aversion was observed in the vast majority of vignettes, but at different magnitudes. It was predicted by whether the vignette involved gain or loss as well as by people's prior beliefs; however, the heterogeneity between people meant that the role of prior beliefs was only evident in an individual-level analysis (i.e., not at the group level). Our results suggest that the desire to avoid ambiguity occurs in a wide variety of qualitative contexts but to different degrees for different people, and may be partially driven by unfavourable prior estimates of the likely outcomes of the ambiguous events.

Keywords: Ambiguity aversion, vignettes, qualitative contexts, ambiguity, risk, prior beliefs, pessimism, generalisability.

Ambiguity attitudes in qualitative contexts: The role of prior beliefs

The world is replete with the unknown, yet people generally prefer some types of 'unknown' to others. Here, an important distinction exists between *risk* and *ambiguity*. As defined by Knight (1921), *risk* is a measurable lack of certainty that can be represented by numerical probabilities (e.g., "there is a 50% chance that it will rain tomorrow"), while *ambiguity* is an unmeasurable lack of certainty (e.g., "there is an unknown probability that it will rain tomorrow"). All other things being equal, humans generally prefer risk to ambiguity; they would rather be in a situation with "known unknowns" than one with "unknown unknowns." This phenomenon is known as ambiguity aversion.

A quintessential and well-studied example of ambiguity aversion is known as the two-colour Ellsberg task. In it, people are shown two urns which both contain only red and blue balls and told that if they draw their chosen colour, they will receive $100. People prefer to place a bet on a "risky" urn that they know contains 50 red balls and 50 blue balls while avoiding betting on an "ambiguous" urn that contains red and blue balls in an unknown combination (Ellsberg, 1961; Fellner, 1961). This preference is incredibly robust (for reviews, see Camerer & Weber, 1992 and Trautmann & van de Kuilen, 2015).

However, it is unclear how far it generalises to different situations. Much of the research on ambiguity aversion involves variants of the two-colour Ellsberg task or economic games involving pecuniary contexts outside the lab that are well suited to the quantitative toolkit of the economist. Ambiguity aversion has been found in contexts such as asset markets (Füllbrunn, Rau, & Weitzel, 2014) and insurance (e.g., Kunreuther, Meszaros, Hogarth, & Spranca, 1995). While this work has been useful for understanding and modelling the rules that may underlie people's decisions (for a review of see Machina & Siniscalchi, 2014), these situations are still quantitative, involving bets and utilities quantified numerically and with precision (usually with money), often focusing on the attitudes and choices of experts. Attitudes towards ambiguity may be different in more qualitative situations: since they are more subjective, there may be far more room for individual variation in both prior beliefs and the values attached to possible outcomes to play a role.

There is relatively less work investigating people's attitudes about ambiguity in more real-world contexts and more diverse life domains, especially those that are not as readily understood in precise quantitative terms. Moreover, the sparse literature that does exist is somewhat inconclusive. On one hand, a preference to avoid ambiguity has been observed in medical contexts such as decisions to vaccinate children (when framed as acts of co-mission but not omission; Ritov & Baron, 1990), decisions relating to online phishing (Wang, 2011), where to live based on health risks (Viscusi, Magat, & Huber, 1991), and non-quantifiable choices involving art bequests or weather-forecasting services (Smithson, Priest, Shou, & Newell, 2019). On the other hand, people sometimes appear to be *ambiguity seeking* in medical decisions depending on whether they are framed as gains or losses (Bier & Connell, 1994; Curley, Eraker, & Yates, 1984).

Indeed, even within the economic games paradigm, ambiguity aversion has not always been observed when the context involves losses or lower-likelihood gains (Kocher, Lahno, & Trautmann, 2018; Baillon & Bleichrodt, 2015). Overall, there is mixed evidence as to whether people prefer to avoid ambiguity in both losses and gains (Baillon & Bleichrodt, 2015; Moore & Eckel, 2003; Kocher et al., 2018). Given the widespread evidence that people treat losses and gains differently (see, e.g., Kahneman & Tversky, 1979), perhaps these differences in ambiguity aversion are to be expected.

Overall, it remains largely uncertain to what extent people prefer to avoid ambiguity for both gains and losses, as well as when the situations are more like the qualitative or "everyday" ones we encounter often. A larger question, perhaps, is *why* we might expect it to hold: what makes people prefer risk over ambiguity in the first place?

One possibility is that people tend to make pessimistic assumptions about ambiguous options. Although this explanation may not apply so much to the classic Ellsberg situation — in which people can choose which colour to bet on — it could be applicable more broadly, particularly in real-world situations. After all, ambiguous and risky choices are only equal if people follow the principle of indifference (Marquis de Laplace, 1902) and presume that all possible outcomes are equally likely (or that the probability distribution underlying the ambiguity is otherwise symmetrical around the 'risky' probability; Guney & Newell, 2011; Güney & Newell, 2015). Under this assumption, a risky decision in which the two outcomes are assigned 50/50 probability is equivalent to an ambiguous two-choice scenario in which all options are equally likely. Ambiguity aversion is often seen as a departure from rationality that is worthy of study because it is assumed that, absent any information, people in fact do have a flat prior over all possible events. If, however, people naturally assume that "good" options are rarer than "bad" options, ambiguity aversion would be entirely rational. On this view, people would be acting in accordance with utility theory from a subjective probability or Bayesian sense — that is, ambiguity aversion can be consistent with utility theory as a normative model 'given what one knows' (Frisch & Baron, 1988, p. 149).

There is some evidence to support the idea that people evaluate ambiguous options unfavourably. Smithson et al. (2019) found that people had more pessimistic prior beliefs about ambiguity options than risky options in qualitative scenarios involving weather forecasts and art bequests. Similarly, Pulford (2009) found that highly optimistic people showed a significantly smaller amount of ambiguity aversion than less optimistic people, both when they knew the generating process behind the ambiguity was randomly determined and when it could be influenced by the experimenter. Keren and Gerritsen (1999) found that people thought that a decision maker choosing a precise option was likely to have a more successful bet than a decision maker choosing an ambiguous option. From a Bayesian perspective, this makes sense if people assume that omitted information is biased against them, and thus form pessimistic or unfavourable priors. Indeed, such pessimistic priors for ambiguous events may arise from 'negativity bias' more generally (Rozin & Royzman, 2001). Consistent with this, ambiguity aversion is reduced in situations where participants have evidence against pessimistic priors. For example, some experimental scenarios allow people to verify the nature of the ambiguous option (e.g., by sampling) so that they can ensure that it is not biased against them. This experience results in less ambiguity aversion (Ert & Trautmann, 2014; Güney & Newell, 2015). However, this is not the case when the probabilities are simply described to them; people must *experience* the probability distribution (Curley, Young, & Yates, 1989).

Why might people have pessimistic priors? One possibility derives from the theory of comparative ignorance, which suggests that ambiguity aversion arises when a person feels less competent. Thus, ambiguity aversion emerges when the context invites comparisons to more unambiguous events or more competent individuals (Fox & Tversky, 1995). In the opposite manner, when the context does not invite a comparison to more competent individuals — such as when the probability distribution underlying payoffs becomes clearly 'unknowable' to everyone involved — ambiguity aversion is reduced (Chua Chow & Sarin, 2002; Moore & Eckel, 2003).

Pessimistic priors might also arise less from a feeling of incompetence than from a suspicion about the data generating process. For example, consider the "tennis match" scenarios discussed by Gärdenfors and Sahlin (1982). In Match A, the reasoner must decide how to bet between two players that they know are extremely evenly matched. In Match B, they know nothing at all about the players, and in Match C they have been told that one of the players is strongly favoured, but they do not know which one. In all of these scenarios, the reasoner strictly has a 50% of winning the bet, but one might forgive them for being suspicious about being asked to place a bet in Match C. When competing against others — or, more broadly, when you are suspicious about the reason you are being asked the question in the first place — ambiguity aversion may be reasonable, because the things you do not know can be used against you. It is unclear to what extent people default to approaching all ambiguous situations with a certain level of caution for this reason. Kühberger and Perner (2003) showed that people show more ambiguity aversion in competitive situations than in cooperative situations, supporting such a notion.

Overall, then, we are left with two main questions. First, how robust is ambiguity aversion, especially in more qualitative and realistic everyday situations? Specifically, do people show ambiguity aversion most or all of the time, regardless of the domain or situation, for both losses and gains? Second, does the degree of ambiguity aversion depend on people's prior beliefs about the ambiguous scenarios?

We answer these questions in three pre-registered experiments.[1] In the first study, participants were presented with vignettes asking them to decide between 'risky' and 'ambiguous' scenarios presented as either gains or losses in various qualitative domains (e.g., work, family, love, friendship, exercise, study and health). Our question was whether ambiguity aversion would vary across domain or gain/loss direction. In the second study, we asked a separate set of participants to share their prior beliefs about each of these scenarios. Our question was whether these priors were predictive of variation in ambiguity aversion across the scenarios. In the third study, we conducted a within-participants extension combining the first two experiments, with the goal of ascertaining whether participants' prior estimates regarding the events in the ambiguous scenarios were predictive of their level of ambiguity aversion for the same events one week later.

Experiment 1

Method

Participants. 1206 participants from the United States of America (605 female, 597 male, 3 other, 1 NA; M_{age} = 39.85, *SD* = 11.09, range: 18–75 years) were recruited through Amazon Mechanical Turk. 76 of them failed at least one of two pre-registered

[1] Experiment 1 was preregistered at `https://aspredicted.org/blind.php?x=yq37vw`. Experiment 2 was formulated after the conclusion of Experiment 1, but the method and all analyses were preregistered at `https://aspredicted.org/blind.php?x=3b3rx6`. Experiment 3 was formulated after the conclusion of Experiments 1 and 2, but the method and all analyses were preregistered at `https://aspredicted.org/blind.php?x=ZYY_RLG`. The data and code necessary to recreate all analyses can be found on the Open Science Framework website at `https://osf.io/28azp`.

attention checks, leaving 1130 in the final sample (578 female, 549 male, 2 other, 1 NA; $M_{age} = 40.06$, $SD = 11.09$, range: 18–75 years). All experiments in this paper were approved by the Human Research Ethics Committee of the Melbourne School of Psychological Sciences (Ethics ID 1953838.1).

Materials. Stimuli consisted of 24 vignettes consisting of qualitative descriptions of situations with two possible outcomes. Each vignette asks participants to choose between two situations, each corresponding to different hypothetical possibilities about the probability of these outcomes. For the RISKY situation, each outcome has a probability of exactly 50%, while for the AMBIGUOUS situation, the probability for each outcome is unknown. For illustration, we reproduce one vignette below, but all 24 vignettes appear in the Appendix.

> You have two friends, X and Y. You have a strong crush on X and no romantic interest at all in Y. A mutual friend of yours, Bob, tells you that he heard that either X or Y was interested in you but doesn't remember which one it was. Which of the following situations would you rather be in?
>
> A. There is a 50% chance that person X is interested and a 50% chance that person Y is interested.
>
> B. Either person X or person Y is interested but the exact probability for each is unknown.

In this example, A corresponds to the RISKY situation and B corresponds to the AMBIGUOUS situation, but the order of each was randomised for each participant. The vignettes were constructed so as to span a variety of different life domains such as work, family, love, friendship, exercise, study and health. These life domains were chosen to explore the space of qualitative scenarios as widely as possible, and thus were deliberately not chosen systematically. That said, they correspond reasonably well (though not perfectly) to the domains identified by systematic treatments of risk domains, such as in the Domain-Specific Risk-Taking inventory (DOSPERT; Weber, Blais, & Betz, 2002). We also varied the gain/loss DIRECTION: twelve vignettes were presented as gains, as in this example, and twelve were presented as losses. Where possible, the gain and loss vignettes were designed to match each other as closely as possible except for the gain/loss direction. Where this was not possible, the topics of the vignettes were chosen so that each domain (e.g., work, health, etc.) was represented a similar amount across the gain and loss conditions.

Two of the 24 vignettes (G1 and L1) were urn-based ones as found in Ellsberg (1961); these were included in order to ensure that the classic ambiguity aversion effect could be replicated with our method and sample.

Procedure. Our design was between-participant, so each person rated only one of the 24 vignettes. The experiment began by asking participants to report their age and gender, after which they read the following instructions:

> You will be presented with two short, life-like scenarios which we call 'vignettes'. After reading each vignette, you will be shown two different possibilities for what the true underlying situation in the vignette is. For each vignette we are interested in which of these two situations ***you would rather be in***. You will answer on a scale from "I would definitely rather be in situation A" to "I would definitely rather be in situation B" with "I am indifferent about which situation I would rather be in" in the middle.

Participants were then presented three questions checking their comprehension of the instructions, which they were required to answer each correctly before proceeding. After completing a practice trial, each participant was randomly assigned to one of the 24 vignettes. This resulted in sample sizes for each vignette ranging from 33 to 62. Participants were then asked "Which of the following situations would you prefer to be in?" The two options, labelled A and B, were randomly assigned to either the RISKY or AMBIGUOUS situation. Participants responded on a 7 point Likert scale in which 1 was 'Definitely A', 7 was 'Definitely B', and 4 was 'No preference.'

Exclusion Criteria. Although all participants were paid, we pre-registered two exclusion criteria for removing data from the analysis. First, during the practice trial, participants were given a vignette in which option B is clearly preferable to option A (see Appendix). Participants that did not respond that they definitely, probably or slightly preferred option B were excluded on the grounds that they failed to understand the task or were not paying attention. Second, following completion of the main vignette, participants were asked "what was the last question about?" and asked to choose the correct option out of four possibilities. Participants who answered incorrectly were excluded on the grounds that they failed to read the vignette carefully enough.

Results

Figure 1 shows the degree of preference for ambiguity for each of the 24 vignettes separately. On average, people showed ambiguity aversion for the clear majority of the vignettes, but the degree of the aversion varied. In order to quantify this as well as determine what factors drove ambiguity aversion, we modelled preferences using ordinal logistic regression. The outcome variable was the answer participants gave to the "which situation would you prefer to be in?" question, recoded so that +3 indicated a strong preference for the RISKY option (ambiguity aversion), 0 indicated indifference, and -3 indicated a strong preference for the AMBIGUOUS option. According to the preregistered plan, we compared the following models:

1. Model containing only an intercept[2]
2. Model containing intercept plus a parameter for DIRECTION condition. If preferred to model 1, this suggests participants are systematically acting differently for gain vignettes than for loss vignettes.
3. Model containing intercept plus a parameter for response order. If preferred to model 1, this suggests participants are systematically choosing either the first or the second option presented, regardless of its content. We do not expect this to happen; this is just a precautionary check.
4. Mixed-effect model containing intercept, a parameter for DIRECTION condition, and a random intercept for each vignette. If preferred to model 2, this suggests that ambiguity aversion varies substantially across individual vignettes, over and above variation due to gain/loss direction.

All analyses were carried out under both frequentist and Bayesian paradigms, and results were qualitatively identical in each. The frequentist analysis used the `clm` and

[2] Ordinal regression models do not have one intercept parameter, but instead have $C - 1$ cut-point parameters, where C is the number of categories and the cut-points are thresholds used to differentiate the adjacent levels of the response variable. For simplicity, we refer to this as the intercept throughout. C does not vary between models.

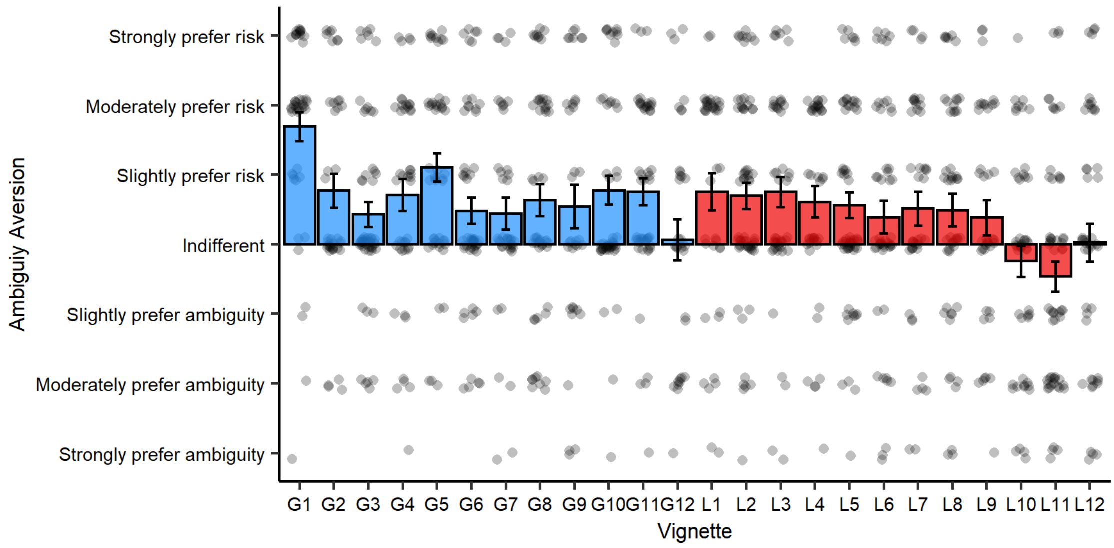

Figure 1. Ambiguity aversion rating for each of the 24 vignettes (x axis). Each dot represents the response given by one participant, and the bars represent the mean ratings for each vignette (gains in blue and losses in red). Error bars represent standard error. A majority of the vignettes showed ambiguity aversion, with participants preferring the riskier option over the ambiguous option. However, there was substantial variation in the strength of this preference across vignettes.

`clmm` functions from the R package `ordinal` (Christensen, 2019), and the model selection metric was the Aikake Information Criterion, or AIC (Akaike, 1974). For Bayesian analyses, the R package `brms` (Bürkner, 2017) was used with default priors.[3] The Leave-one-out Information Criterion calculated via Pareto Smoothed Importance Sampling (Vehtari, Simpson, Gelman, Yao, & Gabry, 2019) was used as the model selection metric for Bayesian models. The purpose of metrics such as LOOIC and AIC is that they penalise more complex models, thus guarding against overfitting.

The results are shown in Table 1. The preferred model is Model 4, which contains an intercept, a parameter for Direction condition, and a random intercept for each vignette. This suggests that gain/loss direction had a significant effect, and that there is also significant variation among the vignettes. Furthermore, since Model 3 was outperformed by all models, the order of response did not appear to affect ambiguity aversion (as expected).

As pre-registered, in order to ascertain whether the classic ambiguity effect was replicated with our version of the Ellsberg urn task, we compared Models 1 and 2 using only the two vignettes involving urns (G1 and L1). Model 2, which contains a parameter for Direction condition, is preferred over Model 1, which does not (Model 2: AIC = 278.55, LOOIC = 278.32; Model 1: AIC = 285.17, LOOIC = 284.86). This suggests that people showed a greater aversion to ambiguity for gains than for losses in the classic urn scenario. Two-tailed one-sample Wilcoxon signed rank tests revealed that both the gain urn vignette ($T = 840, p < .001$), and the loss urn vignette ($T = 416, p = .012$) showed significant ambiguity aversion, thus replicating the classic

[3] This corresponds to an improper flat prior over the reals for all fixed predictors, a half-t distribution with 3 degrees of freedom, and a scale parameter of 2.5 for intercept (i.e., cutpoints) and random-effect standard deviation parameters.

two-colour Ellsberg task ambiguity aversion effect.

Discussion

In Experiment 1, our goal was to investigate how robust the phenomenon of ambiguity aversion is, and specifically whether we would see it when judgments were qualitative rather than monetary and in scenarios similar to those that might be found in real life. We found that participants did show ambiguity aversion in most scenarios, but the degree of ambiguity aversion varied by scenario. We replicated classic ambiguity aversion effects in the 'urn' scenarios using our methodology (Ellsberg, 1961; Fellner, 1961) and determined that scenarios involving gains generally resulted in greater ambiguity aversion than scenarios involving losses.

Interestingly, the scenarios that exhibited the highest ambiguity aversion in their respective gain-or-loss domains were the 'urn' scenarios (G1 and L1). This may suggest that the magnitude of the ambiguity effect estimated from previous studies that used such scenarios may be inflated relative to more 'real-life' situations. However, this difference may also have arisen from two differences between these vignettes and the classic Ellsberg tasks: the setting of this vignette in a casino, and the fact that participants could not choose which colour to bet on. More generally, we found that there was significant variation in the magnitude of ambiguity aversion across these scenarios. This is perhaps not a surprise, as we made no special effort to control for factors that might affect ambiguity aversion, since our goal was to determine the robustness of the effect across those factors. However, it does raise the question of why this variation occurred. Motivated by the literature suggesting that ambiguity aversion may be driven by pessimism about the ambiguous scenario, we designed Experiment 2 to test whether prior beliefs about the probability of success in each scenario predicted the degree of ambiguity aversion in that scenario.

Experiment 2

Method

Participants. 721 people from the United States of America (393 female, 323 male, 4 other, 1 NA; $M_{Age} = 41.05$, $SD = 11.48$, range: 19–78 years) were recruited through Amazon Mechanical Turk. 38 of them failed at least one of two pre-registered attention checks, leaving 683 participants in the final sample (375 female, 304 male, 3 other, 1 NA; $M_{Age} = 41.05$, $SD = 11.40$, range: 19–76 years).

Materials. The vignettes were the same as used in Experiment 1.

Procedure. The procedure was the same as Experiment 1 except that participants were asked "If you had to guess, what is the probability of outcome X and outcome Y?" for the vignette they were shown.

This was designed to elicit point estimates of people's priors about the outcomes in the vignettes. Because the two events were mutually exclusive and collectively exhaustive, participants responded on a slider between 0% and 100% ; if one bar was moved, the other would automatically change to accommodate the above constraints. The starting point was randomised for each person to start at 0 for one outcome and 100 for the other outcome. Participants were forced to click the slider before continuing to ensure that they did not simply leave the value at the default outcome without adequate consideration of the question. After continuing, they were then asked, "How confident are you in your answer to the previous question?" They responded on a scale ranging from 0 ("Not at all confident") to 4 ("Extremely confident").

Exclusion Criteria. As in Experiment 1, there were two exclusion criteria. First, during the practice trial, participants were given a vignette in which outcome A was clearly described to be more likely than outcome B. Participants responded on the slider as above. People who assigned a prior probability for A of 50% or less were excluded on the grounds that they failed to understand the task or were not paying attention. The second exclusion criterion was the same as in Experiment 1, based on responses to a question about what the previous scenario was about.

Results

Descriptives. Figure 2A shows the prior probabilities assigned by participants for each of the vignettes. The y axis shows the difference in probability between the favourable and unfavourable events in the vignette. For instance, for the vignette described above, the favourable event would be person X being interested and the unfavourable one would be person Y being interested; the difference in probabilities reflects how much more likely the person thinks it is that X is interested. Thus, a difference of greater than zero means the participant is relatively optimistic about the situation, while a negative difference means they are pessimistic and believe that the unfavourable outcome is more likely. Visual inspection of Figure 2A reveals that there was some variation across vignettes, with none showing striking levels of either pessimism or optimism. The exception was the urn-based gain vignette (G1), which participants were highly pessimistic for, rating the unfavourable event as 50% more likely than the favourable one.

Figure 2B shows the corresponding confidence ratings for each vignette, illustrating that participants rated themselves as around moderately confident overall, with G1 not being unusual. There was no significant correlation between confidence ratings and prior probability percent difference, Spearman's $\rho = .05$, $p = .222$. Nor was there a significant correlation between confidence ratings and absolute prior probability percent difference, Spearman's $\rho = .01$, $p = .856$.

In order to quantify the extent to which prior probabilities and/or confidence on each vignette predicted ambiguity aversion, we compared several linear regression models. The outcome variable in all models was the degree of ambiguity aversion for each vignette obtained in Experiment 1. A key predictor variable was "percentage difference" (PRIORS) shown on the y axis of Figure 2A and calculated as $P(F) - P(U)$ where F is the favourable outcome and U is the unfavourable outcome.[4] This measure was then averaged across participants to obtain one value for each vignette. The other predictor variables were DIRECTION, as in Experiment 1 (whether the vignette depicted a gain or loss) and CONF, which reflects the mean confidence rating for each vignette (averaged across participants).

[4] This analysis deviates from our pre-registration in one way. The pre-registered analysis uses odds ratios between the favourable and unfavourable outcomes as the dependent variable, but upon doing the analyses we realised that this approach has two problems we did not originally consider. The first is that odds ratios are undefined when the denominator is 0. This occurred numerous times in our data. Secondly, and relatedly, the measurement properties of the odds ratio are heavily skewed, making it not ideal for use in a regression. We therefore used the percentage difference rather than the odds ratio, but in all other ways followed the pre-registration precisely.

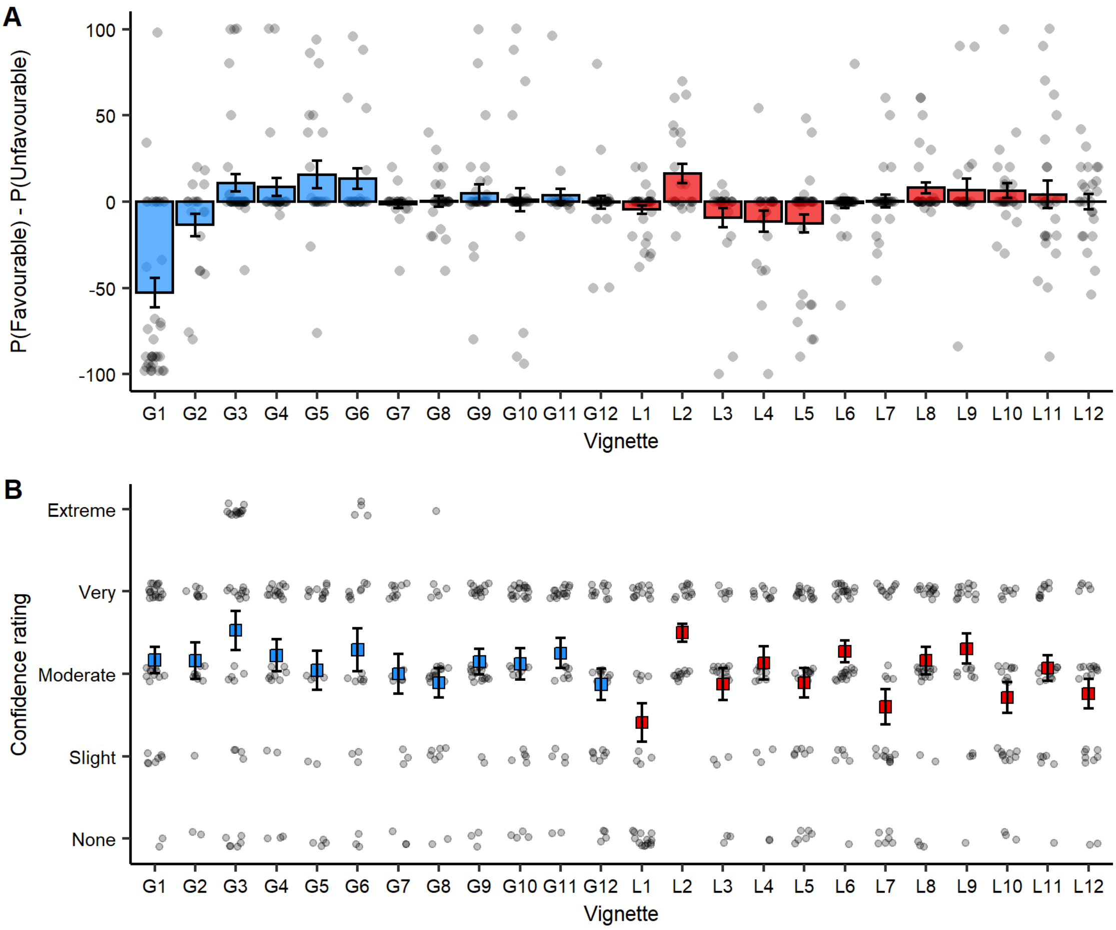

Figure 2. (A) Prior probability ratings for each of the 24 vignettes (x axis). Each dot represents one participant, and the bars represent means for each vignette (gains in blue and losses in red). Error bars represent standard error. The y axis reflects the difference between people's prior probabilities of the favourable event and the unfavourable event. Thus, a positive value indicates optimism about the unobserved events. There was some variation across vignettes but no strong tendency toward optimism or pessimism, with the exception of the urn vignette (G1) for which people were very pessimistic. (B) Confidence ratings for each vignette. Confidence varied but was usually moderate.

Before conducting the main analysis, in order to ensure that there were no confounding effects due to the randomised start point of the slider bar, we compared an intercept-only model to a model containing a 'starting point' parameter. The intercept-only model had a better fit (AIC = 6,661.31, LOOIC = 6,662.69) than the model that included a parameter for slider bar starting point (AIC = 6,663.29, LOOIC = 6,664.59). This indicates that the randomised starting point of the slider bar had no systematic effect on participant responses; as a result, all subsequent models exclude it.

We created the subsequent models by systematically increasing model complexity to take into account three possible predictors of interest: DIRECTION (as gain or loss), PRIORS (the percentage difference, calculated as described above), and CONF (the confidence people had in their priors). As before, we used AIC as the model selection metric for the frequentist analysis and LOOIC for the Bayesian equivalent. Analyses were carried out as in Experiment 1 with the exception that the frequentist analysis used the `lm` function from Base R (R Core Team, 2020). The models we considered were:

1. Model containing only an intercept
2. Model containing intercept plus a parameter for DIRECTION condition.
3. Model containing intercept and a parameter for PRIORS.
4. Model containing intercept, a parameter for DIRECTION condition, and a parameter for PRIORS.
5. Model containing intercept, a parameter for DIRECTION condition, and a parameter for PRIORS, allowing an interaction between the DIRECTION and the PRIORS.
6. Model containing intercept and a parameter for CONF.
7. Model containing intercept, a parameter for DIRECTION condition, and a parameter for CONF.
8. Model containing intercept, a parameter for DIRECTION condition, and a parameter for CONF, allowing an interaction between the DIRECTION and the CONF.
9. Model containing intercept, a parameter for DIRECTION condition, a parameter for PRIORS, and a parameter for CONF.
10. Model containing intercept, a parameter for DIRECTION condition, a parameter for PRIORS, a parameter for CONF, and a parameter for the interaction between DIRECTION and PRIORS.

Table 2 shows the model selection metrics of the fitted regression models predicting vignette ambiguity aversion. The best-fitting model was Model 4, which contained parameters for DIRECTION condition as well as the PRIORS, but no parameter for CONF and no interaction. This model showed moderate fit, adjusted $R^2 = .319$, $F(2, 21) = 6.39$, $p = .007$, and both DIRECTION condition, $\beta = -.31$, $t(22) = -2.18$, $p = .041$, and PRIORS, standardised $\beta = -0.47$, $t(22) = -2.74$, $p = .012$, were significant predictors. Figure 3A shows the relationship between ambiguity aversion and the PRIORS for each of the 24 vignettes, along with the linear regression lines from the best-fitting model.

Although this analysis appears to indicate that ambiguity aversion is related to PRIORS, an investigation of the model residuals suggests that this effect was heavily dependent on vignette G1, the gain-direction two-colour Ellsberg task vignette, which had high influence (Cook's $D = 1.15$, standardised $\text{DFBeta}_{intercept} = 0.58$, standardised $\text{DFBeta}_{priors} = -1.76$), high leverage ($h = 0.690$) and was a multivariate outlier (Mahalanobis distance = 15.25). To ascertain whether our findings were dependent on this observation, we redid all analyses with it removed. Table 3 shows the metrics for all models on the dataset without vignette G1, and Figure 3B shows the relationship between ambiguity aversion and PRIORS when G1 is removed as well. Both demonstrate that when G1 is not included, the effect of the priors disappears. The best fitting model is now the model with only DIRECTION as a predictor (Model 2), although the overall fit is poor: adjusted $R^2 = .076$, $F(1, 21) = 2.81$, $p = .109$.

Discussion

The goal of Experiment 2 was to determine whether the ambiguity aversion ratings from Experiment 1 were related to the prior probability that people assigned to outcomes. We found that when we excluded an outlier vignette (G1), there was no

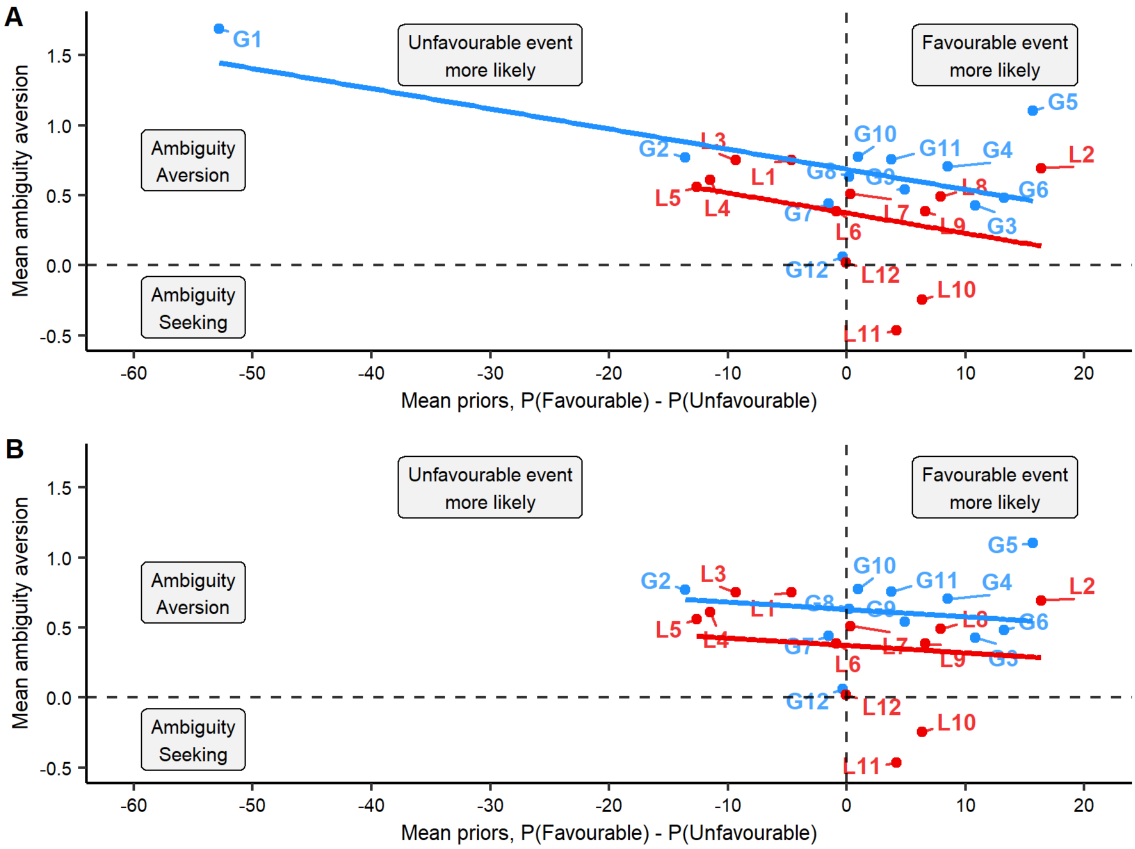

Figure 3. The relationship between the mean ambiguity aversion rating for each vignette (x axis) and the PRIORS, i.e., the mean prior probability percent difference of that vignette (y axis). Each dot point is one vignette. (A) Full data set. Regression lines of best fitting model for gains (blue) and losses (red) appear to show a relationship between PRIORS and ambiguity aversion. (B) Data set excluding vignette G1. Regression lines of the best-fitting model illustrates that without it, there appears to be no relationship between PRIORS and ambiguity aversion.

observed relationship between people's priors and the degree of ambiguity aversion. That said, it is possible that we would have observed an effect had we been able to do an individual-level rather than aggregate-level analysis: perhaps an individual's ambiguity aversion might be predicted by *their specific* priors even if the overall ambiguity aversion at a vignette level is not predicted by the mean priors for that vignette. We explore this in Experiment 3 by measuring the priors and ambiguity aversion within the same participants, measured at two different timepoints a week apart.

Experiment 3

Method

Participants. 301 participants from the United States of America (174 male, 125 female, 2 other; $M_{age} = 41.17$, $SD = 12.08$, range: 21–78 years) were recruited through Amazon Mechanical Turk. 16 of them failed at least the pre-registered attention/comprehension check, leaving a sample of 285 at Time 1, in which participant prior probabilities in relation to the vignettes were measured. Seven days later, these participants were invited to complete Time 2 in which we elicited their Ambiguity Aversion in relation to the scenarios. 247 of these participants completed Time 2 (144 male, 102 female, 1 other; $M_{age} = 41.7$, $SD = 11.92$, range: 21–78 years). After excluding another 10 participants who failed the pre-registered attention/comprehension check, the final sample contained 237 participants who successfully completed both times 1 and 2 (134 male, 94 female, 1 other, 1 NA; $M_{age} = 41.71$, $SD = 11.67$, range: 21–78 years). Unless stated otherwise, all analyses were performed on this sample.

Materials. In this within-subjects design, each participant saw multiple vignettes; to limit fatigue, we did not include all the original 24 vignettes in Experiments 1 and 2, instead focusing on a subset of ten. These ten were chosen based on the following criteria. First, in order to be as representative as possible, we chose a gain and a loss vignette for four of the five DOSPERT domains: Health/Safety, Financial/Investing, Recreation, and Social (Weber et al., 2002); we excluded Ethical because none of the original 24 vignettes involved ethical issues. Second, we included the gain and loss 'urn' vignettes that closely follow the Ellsberg Ambiguity Aversion paradigm; this allows us to compare our results to the rest of the literature that uses it. This yielded the following vignettes: G1 & L1 (traditional urn paradigm), G2 & L2 (Social), G5 & L5 (Financial/Investing), G9 & L10 (Health/Safety) and G11 & L11 (Recreation). We chose vignettes that, besides the urn ones, showed the greatest and smallest ambiguity aversion (G5 and L11 respectively) and those that had the most skewed priors (most favourable priors: L2; most unfavourable priors: G2).

The following minor alterations were made to these vignettes to resolve possible confounding issues in the vignettes in previous experiments:

- In vignettes G1 and L1, we removed the introductory clause "At a casino," that gave a setting for the vignette. This was done to reduce the strong priors that people have about bets at casinos generally being negative expected value.
- Vignette L10 was changed to ensure that the scenario presented a loss option and neutral possibility, because previously the scenario may have been understood as comparing a large loss and a small loss. In order to accomplish this, we rephrased as follows: "Variant X is potentially deadly while variant Y is ~~somewhat benign~~ *known to be completely harmless with no negative effects*".
- For Vignette L11, we changed the context from travelling for work to travelling for a holiday, so that it better fit within the DOSPERT Recreation category ("You have left your car in an uncovered airport carpark while you are travelling ~~to a far away city for work~~ *on an overseas vacation*")

Procedure. Because this experiment is a within-participants expansion of Experiments 1 and 2, with Time 1 (elicitation of prior beliefs) corresponding to Experiment 2 and Time 2 (ambiguity aversion) corresponding to Experiment 1, the procedure for each was thus identical to the corresponding experiments, except that participants saw all ten vignettes each time (rather than only one). The order of the vignettes was randomised for each participant at each timepoint, with one constraint: vignette pairs that were extremely similar except for their gain/loss DIRECTION (i.e., G1 & L1, G2 & L2, G5 & L5) were never placed within two vignettes of each other. The exclusion criteria were identical to those used in the corresponding experiments.

Results

Our main question in this experiment is whether people's priors at Time 1 are related to the degree of ambiguity aversion at Time 2. However, before performing this analysis, we evaluate each timepoint individually. This permits us to determine whether the overall pattern of results in Experiments 1 and 2 remains the same despite the fact that each participant saw multiple vignettes and also provided both their priors and degree of ambiguity aversion (although at different timepoints, seven days apart), rather than only one or the other.

Time 1. Figure 4 shows the prior probabilities and confidences assigned by participants for each of the vignettes. Visual inspection reveals that there was some variation across vignettes – not surprising, given that we chose them in part because they showed variation in Experiment 2. As before, none showed striking levels of either pessimism or optimism, and for the most part had similar priors as previously. The main differences were sensible given the wording changes we made to some vignettes. Although the urn-based gain vignette (G1) was again the most pessimistic, it was about half as pessimistic as in Experiment 2, probably due to the removal of the phrase "at a casino." Vignette L10 was substantially more optimistic, probably because it was now clear that the alternative was neutral rather than negative. There was also substantial variation between people and vignettes: even where prior means were similar, vignettes varied considerably in their distribution and range; for instance, nearly everyone rated L1 the same, whereas they differed markedly on L11.

In order to explore whether people gave different prior ratings at the beginning and end of the experiment, we compared a model containing trial number as a predictor to a model without it. The models were otherwise identical, with the outcome variable corresponding to the "percentage difference" (PRIORS), calculated as $P(F) - P(U)$ where F is the favourable and U is the unfavourable event. Both models also had random intercept effects corresponding to participant and vignette. The model with trial number had a marginally better fit (AIC = 28,422.07, LOOIC = 28,396.10) than the model that did not (AIC = 28,422.52, LOOIC = 28,397.80). This suggests that there was a small order effect, corresponding to an increase of 3.87 in the prior "percentage difference" for the last trial compared to the first trial (out of 200, since prior values could range from -100 to 100), showing that as the trials progressed participants had, on average, more favourable priors.

Time 2. Figure 5 shows the degree of preference for ambiguity for each of the ten vignettes separately. The degree of ambiguity aversion for each vignette is strikingly similar to Experiment 1. The largest difference is found for the urn-based gain vignette (G1), where ambiguity aversion was reduced (although still noticeable); this, again, probably reflects the change in wording as it was not set in a casino like in experiment 1. As before, there was substantial variability between vignettes and people.

As in Time 1, in order to explore whether people had different levels of ambiguity aversion at the beginning and end of the experiment, we compared an ordinal logistic regression model containing trial number as a predictor to a model without it. The models were otherwise identical. The outcome variable (AA) captured the degree of ambiguity aversion, coded so that +3 indicated a strong preference for the RISKY option (ambiguity aversion), 0 indicated indifference, and -3 indicated a strong preference for the AMBIGUOUS option. Both models also had random intercept effects corresponding to participant and vignette. The model with trial number had a much better fit (AIC = 8,180.75, LOOIC = 7908.9) than the model that did not (AIC = 8,190.34, LOOIC = 7,919.0). This suggests that participants showed less ambiguity aversion as the experiment went on, with the odds of choosing a higher ambiguity aversion option on the last trial decreasing by 30% compared to the first trial. We will discuss the two order

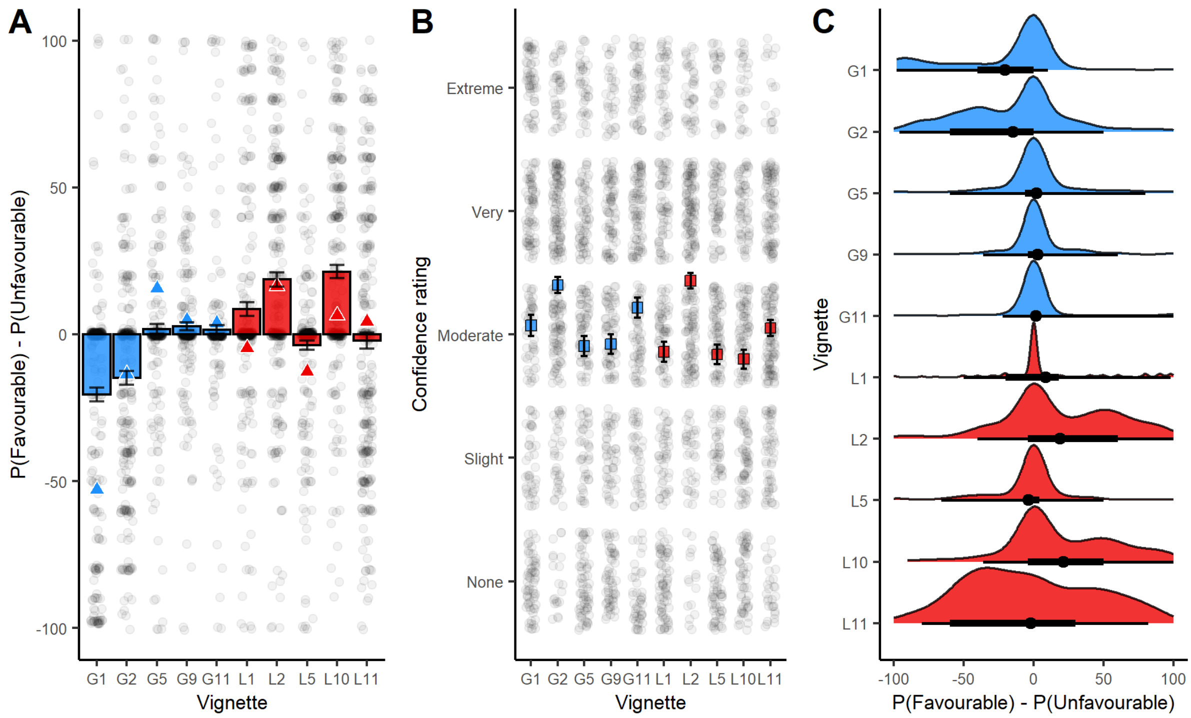

Figure 4. (A) Prior probability ratings for each of the ten vignettes (x axis). Each dot represents one participant, and the bars represent means for each vignette (gains in blue and losses in red). Error bars represent standard error. The y axis reflects the difference between people's prior probabilities of the favourable event and the unfavourable event. Thus, a positive value indicates optimism about the unobserved events. For reference, the mean prior from Experiment 2 for each vignette is shown as a large blue or red triangle. Priors were for the most part similar to Experiment 2, with divergences in G1, L1, and L10 likely due to the changes in wording of those vignettes. (B) Confidence ratings for each vignette, which varied but were usually moderate, and not substantially different for more extreme priors. (C) The same information as in Panel A but shown as density distributions. Black dots indicate mean prior, and black intervals indicate the 66% (thicker) and 95% (thinner) continuous highest density intervals. It is clear that for some vignettes (e.g., L1) most participants have the same prior while for others (e.g., L11) there is substantial variation.

issues at each timepoint more thoroughly in the main analysis, to which we now turn.

Relationship between ambiguity aversion and prior beliefs. The main question driving this experiment was whether prior beliefs predicted ambiguity aversion in the same people. As Figure 6 illustrates, there is a small negative relationship, both when aggregated across participants and vignettes (Spearman: $\rho = 0.14, p < .001$), and also for most of the vignettes taken individually. This means that favourable or optimistic priors correspond to less ambiguity aversion, as one might expect. That said, there is substantial variation still unexplained. This may in part reflect that it is not quite appropriate to aggregate the data in the way we have, since each participant contributed multiple datapoints, and there may be additional influences from confidence and the direction of the vignette. In order to better account for these factors, we now turn to a more principled quantitative analysis based on ordinal logistic regression.

The outcome variable in all of our models was the degree of ambiguity aversion (AA), just as at Time 2. One of the key predictor variables was PRIORS, just as at Time 1. The other predictor variables were DIRECTION (whether the vignette depicted

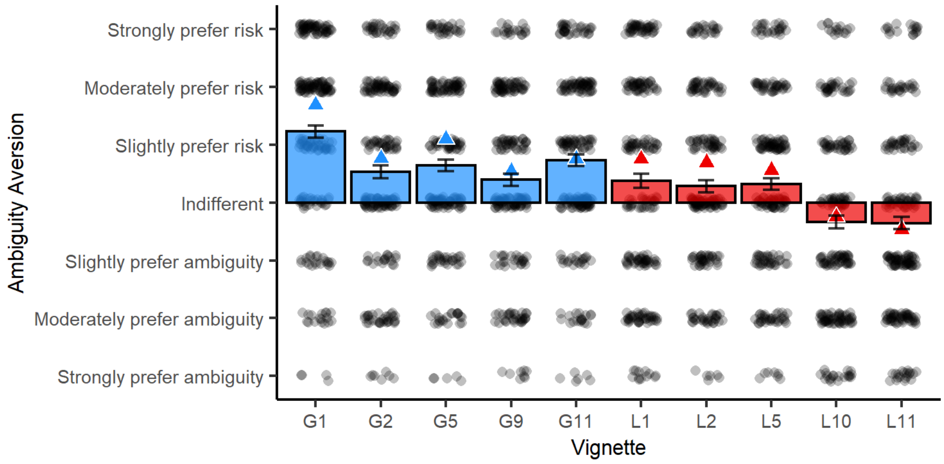

Figure 5. Ambiguity aversion rating for each of the ten vignettes (x axis). Each dot represents the response given by one participant, and the bars represent the mean ratings for each vignette (gains in blue and losses in red). Error bars represent standard error. For reference, the mean ambiguity aversion from Experiment 1 is shown as a large blue or red triangle. The degree of ambiguity aversion for each vignette was strikingly similar to before, with the vignettes varying but most showing some ambiguity aversion.

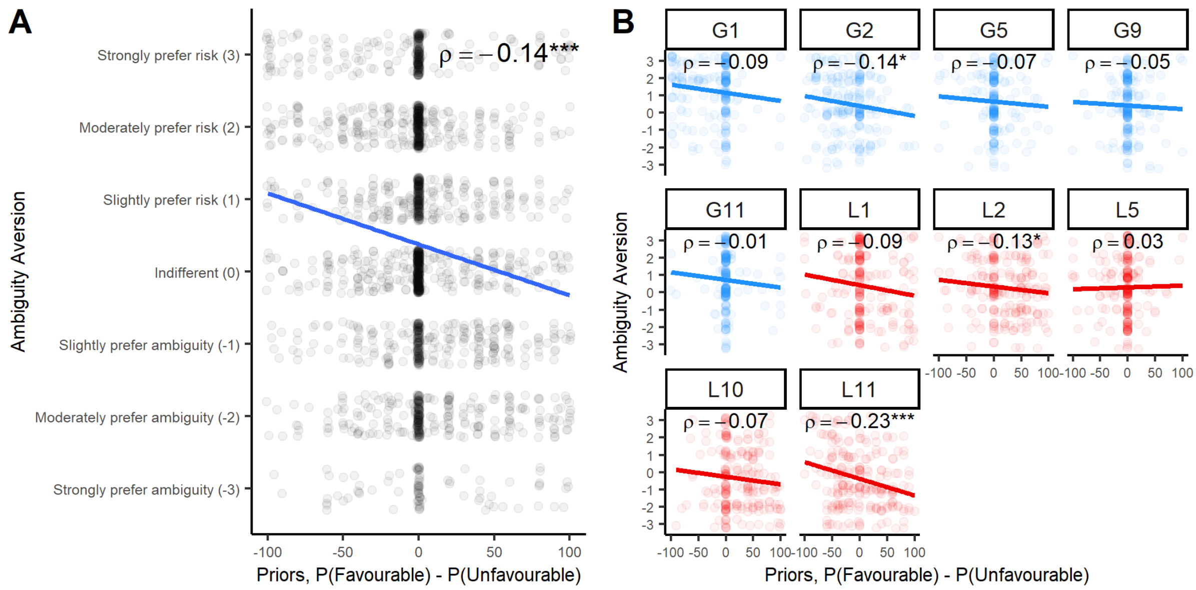

Figure 6. (A) Relationship between ambiguity aversion rating and prior beliefs, collapsed across vignettes and participants. Each dot represents the response given by one participant for one vignette. The relationship is negative, indicating that more optimistic priors are associated with less ambiguity aversion. (B) The same relationship broken down by vignette, demonstrating that it holds for most but not all of them. In both panels, Spearman's correlation coefficients are reported given the non-linear relationship between the variables, and the non-normal nature of their distributions. However, to aid in visualising the nature of the relationship, linear ordinary least squares lines of best fit are shown. $* < .05$, $** < .01$, $*** < .001$.

a gain or loss) and CONF, which reflects the confidence rating for each vignette from that participant. Each participant contributed one data point for each vignette, and all the models considered included separate random effects for participant and vignette.

We created the models by systematically increasing model complexity to take into account variations of the three predictors of interest. As before, we used AIC as the model selection metric for the frequentist analysis and LOOIC for the Bayesian equivalent. We considered the same models as in Experiment 2.

Table 4 shows the model selection metrics of the fitted regression models predicting ambiguity aversion for each vignette and person. The best-fitting model was model 9 in the Bayesian analyses and Model 10 in the frequentist analyses. Both these models contained parameters for CONF, DIRECTION, and PRIORS, with model 10 also including an interaction between DIRECTION and PRIORS. Although the interaction term was included in the preferred model in the frequentist analyses, this effect was tiny and not significant ($b = 0.004$, $z = 1.45$, $p = .147$). Thus, we will interpret the best-fitting Bayesian model (i.e., without the interaction parameter) going forward. The parameter for CONF was small and positive (greater confidence predicting greater ambiguity aversion; 0.08, 95% CI [0.004, 0.16]), while the parameters for DIRECTION (-0.75, 95% CI [-1.427, -0.081]) and PRIOR (-0.0083 95% CI [-0.012, -0.0046]) were more clear. For a 1 point more favourable prior, the odds of showing greater ambiguity aversion is multiplied by $e^{-0.0083} = 0.9917$ and thus it decreases by almost 1%. For a gain vignette compared to a loss vignette, it is multiplied by $e^{0.75} = 2.117$; in other words, it increases the odds of showing ambiguity aversion by 112%. In other words, in apparent contradiction to Experiment 2, this experiment suggests that one's priors *do* influence ambiguity aversion – with people showing less aversion when they are more optimistic about the underlying probability structure.

Is this truly a contradiction with Experiment 2, or does it simply reflect the fact that in this experiment we had fine-grained data about individual people's actual priors, rather than having to use vignette-level priors estimated from others? To address this issue, we can perform the same analysis as in Experiment 2 on our data here, collapsing across participant, and then estimate vignette-level ambiguity aversion based on vignette-level priors. As Table 5 shows, regardless of whether vignette G1 was included, the preferred model now contains only DIRECTION as a fixed effect (not PRIORS). Taken together, these results suggest that priors *do* matter, but there is enough heterogeneity between people that one cannot discern this based on group-level data.

This seems sensible, but the presence of order effects at both Time 1 and Time 2 may be tempted to give one pause. If people had more favourable priors at later trials in Time 1, and lower ambiguity aversion on later trials in Time 2, might this be an alternate explanation of our results? This is doubtful for at least two reasons. First, trial order was randomised not just by participant but also at each time, so the vignettes did not occur in the same order at both Time 1 and Time 2. Second, as Figure 7 shows, the negative relationship between prior beliefs and ambiguity aversion remains even when conditioning on trial number, for both time 1 and time 2.

Discussion

Overall, our results suggest that ambiguity aversion is a robust but by no means universal phenomenon, and also that it is partially explained by the prior beliefs one has about the probability structure of the situation. When a person is optimistic about it – meaning that in an ambiguous situation, they presume the favourable outcome is more likely – they show less ambiguity aversion. This is consistent with normative reasoning, assuming one does not follow the principle of indifference (Marquis de

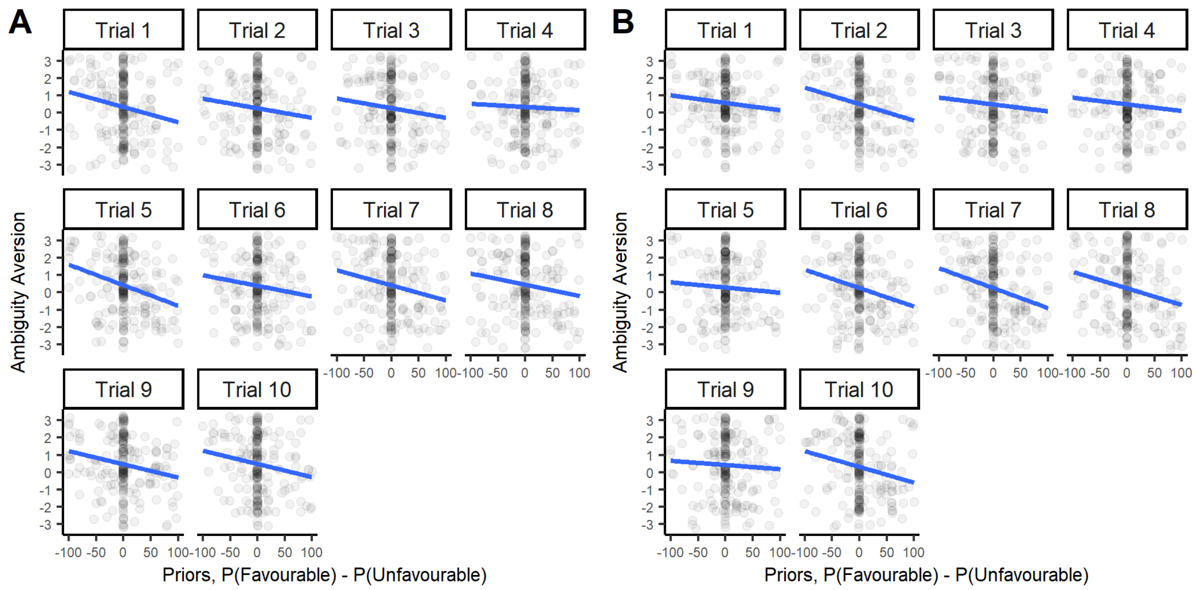

Figure 7. (A) Relationship between ambiguity aversion rating and prior beliefs for every trial position based on Time 1 (prior rating). Each panel indicates a trial position, with prior shown on the x axis and ambiguity aversion shown on the y axis. The relationship is similar at all trial positions, suggesting that order effects do not drive the negative correlation between prior beliefs and ambiguity aversion. (B) Relationship between ambiguity aversion rating and prior beliefs for every trial position based on Time 2 (ambiguity aversion), with the same outcome. In both panels, linear ordinary least squares lines of best fit are shown in blue.

Laplace, 1902) but instead adopts a more general negativity bias (Rozin & Royzman, 2001). That said, we also found significant individual differences across people as well as across vignettes; for this reason, the relationship between priors and ambiguity aversion was not evident when the data were aggregated on a group level. This is an important methodological and theoretical consideration to keep in mind.

What do our results suggest about vignette G1? It is a variant of the classic two-colour Ellsberg task, presented with a gain framing. In Experiment 2, for it alone we observed both a large amount of ambiguity aversion and very pessimistic priors. In Experiment 3 when we removed the wording that stated that it was taking place in a casino, people were less pessimistic and – consistent with our results about the role of priors – also less ambiguity averse. That said, G1 was still the outlier, suggesting that the urn situation may be especially likely to cause people to assume that any unknowns are likely to be "stacked against" them, and thus to prefer the known risks, particularly when set in a casino, and when the colour of the ball to bet on is fixed. This is consistent with the 'comparative ignorance' hypothesis which proposes that ambiguity aversion is produced by a comparison with less ambiguous events or with more knowledgeable individuals (Fox & Tversky, 1995), as well as with sensitivity to data generation, as in the scenarios proposed by Gärdenfors and Sahlin (1982). Conversely, the absence of any possible information asymmetry or comparative ignorance in vignettes G12 and L12 may also have contributed to the lack of ambiguity aversion shown in those vignettes.

However, comparative ignorance cannot be the only force at play for ambiguity aversion. For example, vignette L10 was likely to give rise to comparative ignorance (the patient relative to the doctor), but on average showed no ambiguity aversion.

Thus, while comparative ignorance and/or pessimistic priors may in some cases give rise to greater ambiguity aversion, they are not sufficient or necessary in themselves to do so. Indeed, there were participants that had pessimistic or neutral priors that did not show ambiguity aversion, and vice versa. That comparative ignorance is just one possible (and underdetermined) cause of ambiguity aversion in our vignettes is also clear by the fact we only saw a relationship between pessimistic priors and ambiguity aversion at the participant level and not at the vignette level. Thus, person-specific factors gave rise to pessimistic priors that predicted ambiguity aversion more so than situation-specific factors like comparative ignorance. Determining which factors give rise to such pessimistic priors, and how they differ between situations and persons, would indeed be a fruitful avenue for future research.

More generally, we did find that ambiguity aversion was a robust phenomenon. This is consistent with a large existing body of work (Keren & Gerritsen, 1999) but extends it to show that it occurs even in qualitative situations across a wide variety of topics. The fact that it did not *always* occur is consistent with research showing that ambiguity seeking or neutrality sometimes arises (Kocher et al., 2018; Baillon & Bleichrodt, 2015), although we did find that the degree of ambiguity aversion was stronger for gains than losses (Curley et al., 1984). It remains unclear what factors besides prior beliefs predict when exactly ambiguity aversion will emerge. In part, this is because our vignettes were not designed to include or control for all the factors that either have already been shown to affect ambiguity aversion, or might be shown in future to do so. These factors include the utility of outcomes, familiarity with the situation, fear of negative evaluation, whether the stakes are high, whether the non-ambiguous outcome is 50/50 or not, individual differences in optimism or need for closure or interpretation of probabilistic information, education level, and socioeconomic status, among many others. The lack of systematicity was a necessary first step, as our primary goal was to evaluate the robustness of the effect. For that, it was necessary to capture the range of situations where it might occur in the real world, where situational and interpersonal factors will vary considerably, rather than to limit that range by trying to control for a small set of specific factors. Further exploring these factors is a direction for future work (see, e.g., Shou & Olney, 2020 for one such example).

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Table 1
Model evaluation for Experiment 1

Model	Description	Pseudocode	AIC	LOOIC
1	Intercept only	`AA ∼ 1`	3,973.75	3,973.57
2	Intercept & DIRECTION parameter	`AA ∼ direction + 1`	3,963.89	3,964.28
3	Intercept & order parameter	`AA ∼ order + 1`	3,975.24	3,975.20
4	Intercept, DIRECTION, and random intercept by vignette	`AA ∼ direction + 1 + (1|vignette)`	**3,943.56**	**3,929.56**

Note. AIC (Akaike Information Criterion) is reported for frequentist instantiations of models, and LOOIC (Leave-one-out Information Criterion) is reported for Bayesian instantiations of models. Pseudocode is reported according to `lme4` syntax. `AA` = Ambiguity aversion rating. `direction` = DIRECTION condition, i.e., gain or loss. `order` = the response order, i.e., whether AMBIGUOUS and RISKY options were assigned to options A or B. The preferred model (Model 4) is the one with the lowest AIC and LOOIC, indicated in bold.

Table 2
Model evaluation for Experiment 2

Model	Description	Pseudocode	AIC	LOOIC
Preliminary models				
1	Intercept only	`AA ~ 1`	29.96	31.32
2	Intercept & DIRECTION parameter	`AA ~ direction + 1`	27.90	28.91
Point prior models				
3	Intercept & PRIORS parameter	`AA ~ priors + 1`	25.46	27.59
4	Intercept, DIRECTION, & PRIORS parameters	`AA ~ direction + priors + 1`	**22.55**	**23.91**
5	Intercept, DIRECTION, & PRIORS parameters, and interaction	`AA ~ direction*priors + 1`	24.55	27.19
Confidence rating models				
6	Intercept & CONF parameter	`AA ~ conf + 1`	31.13	32.50
7	Intercept, DIRECTION, & CONF parameters	`AA ~ direction + conf + 1`	29.79	31.16
8	Intercept, DIRECTION, & CONF parameters, and interaction	`AA ~ direction*conf + 1`	31.74	34.07
Combined point priors and confidence rating model				
9	Intercept, DIRECTION, CONF, & PRIORS parameters	`AA ~ direction + priors + conf + 1`	23.42	25.70
10	Intercept, DIRECTION, CONF, PRIORS, with interaction	`AA ~ direction*priors + conf + 1`	25.32	28.77

Note. AIC (Akaike Information Criterion) is reported for frequentist instantiations of models, and LOOIC (Leave-one-out Information Criterion) is reported for Bayesian instantiations of models. Pseudocode is reported according to `lme4` syntax. `AA` = Mean vignette ambiguity aversion rating taken from experiment 1. `direction` = DIRECTION condition, i.e., gain or loss. `priors` = mean percentage differential (prior probability of favourable event minus prior probability of unfavourable event) for each vignette. `conf` = Mean vignette confidence rating. The preferred model (Model 4) is the one with the lowest AIC and LOOIC, indicated in bold.

Table 3

Model evaluation for Experiment 2 without vignette G1

Model	Description	Pseudocode	AIC	LOOIC
Preliminary models				
1	Intercept only	`AA ~ 1`	20.45	21.49
2	Intercept & DIRECTION parameter	`AA ~ direction + 1`	**19.57**	**20.34**
Point prior models				
3	Intercept & PRIORS parameter	`AA ~ priors + 1`	22.41	23.63
4	Intercept, DIRECTION, & PRIORS parameters	`AA ~ direction + priors + 1`	21.17	22.30
5	Intercept, DIRECTION, & PRIORS parameters, and interaction	`AA ~ direction*priors + 1`	21.83	24.10
Confidence rating models				
6	Intercept & CONF parameter	`AA ~ conf + 1`	21.87	22.88
7	Intercept, DIRECTION, & CONF parameters	`AA ~ direction + conf + 1`	21.47	22.75
8	Intercept, DIRECTION, & CONF parameters, and interaction	`AA ~ direction*conf + 1`	23.46	24.89
Combined point priors and confidence rating model				
9	Intercept, DIRECTION, CONF, & PRIORS parameters	`AA ~ direction + priors + conf + 1`	22.76	25.70
10	Intercept, DIRECTION, CONF, PRIORS, with interaction	`AA ~ direction*priors + conf + 1`	23.17	28.78

Note. AIC (Akaike Information Criterion) is reported for frequentist instantiations of models, and LOOIC (Leave-one-out Information Criterion) is reported for Bayesian instantiations of models. Pseudocode is reported according to `lme4` syntax. `AA` = Mean vignette ambiguity aversion rating taken from experiment 1. `direction` = DIRECTION condition, i.e., gain or loss. `priors` = mean percentage differential (prior probability of favourable event minus prior probability of unfavourable event) for each vignette. `conf` = Mean vignette confidence rating. The preferred model (Model 2) is the one with the lowest AIC and LOOIC, indicated in bold.

Table 4

Model evaluation for Experiment 3

Model	Description	Pseudocode	AIC	LOOIC
Preliminary models				
1	Intercept only	`AA ~ 1`	7,922.99	7,655.52
2	Intercept & DIRECTION parameter	`AA ~ direction + 1`	7,918.02	7,654.07
Point prior models				
3	Intercept & PRIORS parameter	`AA ~ priors + 1`	7,894.30	7,631.29
4	Intercept, DIRECTION, & PRIORS parameters	`AA ~ direction + priors + 1`	7,890.03	7,628.79
5	Intercept, DIRECTION, & PRIORS parameters, and interaction	`AA ~ direction*priors + 1`	7,890.14	7,628.46
Confidence rating models				
6	Intercept & CONF parameters	`AA ~ conf + 1`	7,919.81	7,654.07
7	Intercept, DIRECTION, & CONF parameters	`AA ~ direction + conf + 1`	7,914.96	7,652.99
8	Intercept, DIRECTION, & CONF parameters, and interaction	`AA ~ direction*conf + 1`	7,915.62	7,653.34
Combined point priors and confidence rating model				
9	Intercept, DIRECTION, CONF, & PRIORS parameters	`AA ~ direction + priors + conf + 1`	7,888.28	**7,626.60**
10	Intercept, DIRECTION, CONF, PRIORS, with interaction	`AA ~ direction*priors + conf + 1`	**7,888.17**	7,627.33

Note. All models also include random effects for participant and vignette (i.e., in `lme4` syntax, `(1|participant)` and `1|vignette`). AIC (Akaike Information Criterion) is reported for frequentist instantiations of models, and LOOIC (Leave-one-out Information Criterion) is reported for Bayesian instantiations of models. Pseudocode is reported according to `lme4` syntax. `AA` = vignette ambiguity aversion rating for each person; `direction` = DIRECTION condition, i.e., gain or loss; `priors` = percentage differential (prior probability of favourable event minus prior probability of unfavourable event) for each vignette for that person; `conf` = vignette confidence rating for that person. The preferred model for the frequentist analysis (with lowest AIC), is model 10, whereas for the Bayesian analysis, the preferred model (with lowest LOOIC) is model 9. These are indicated in bold.

Table 5

Between-participants model evaluation for Experiment 3 using AIC

Model	Description	Pseudocode	with G1	without G1
Preliminary models				
1	Intercept only	`AA ~ 1`	16.76	11.57
2	Intercept & DIRECTION parameter	`AA ~ direction + 1`	**11.22**	**7.19**
Point prior models				
3	Intercept & PRIORS parameter	`AA ~ priors + 1`	14.25	12.24
4	Intercept, DIRECTION, & PRIORS parameters	`AA ~ direction + priors + 1`	12.14	9.19
5	Intercept, DIRECTION, & PRIORS parameters, and interaction	`AA ~ direction*priors + 1`	13.57	11.02
Confidence rating models				
6	Intercept & CONF parameters	`AA ~ conf + 1`	18.16	12.78
7	Intercept, DIRECTION, & CONF parameters	`AA ~ direction + conf + 1`	13.17	9.02
8	Intercept, DIRECTION, & CONF parameters, and interaction	`AA ~ direction*conf + 1`	15.06	10.98
Combined point priors and confidence rating model				
9	Intercept, DIRECTION, CONF, & PRIORS parameters	`AA ~ direction + priors + conf + 1`	14.11	11.02
10	Intercept, DIRECTION, CONF, PRIORS, with interaction	`AA ~ direction * priors + conf + 1`	15.56	12.50

Note. AIC (Akaike Information Criterion) is reported for all models; "with G1" reports the AIC value when vignette G1 is included, and "without G1" reports the AI when G1 is excluded. Pseudocode is reported according to `lme4` syntax. `AA` = Mean vignette ambiguity aversion rating taken from experiment 3. `direction` = DIRECTION condition, i.e., gain or loss. `priors` = mean percentage differential (prior probability of favourable event minus prior probability of unfavourable event) for each vignette. `conf` = Mean vignette confidence rating. The preferred model (Model 2) is the one with the lowest AIC in both cases, indicated in bold.

Appendix A
Vignettes

Gain Vignettes

Vignette G1

At a casino, there is an urn on the table which contains 1000 balls. Each of these 1000 balls is either red or yellow. You are to randomly select one of these balls from the urn and, if you select a red ball, you will win $1000. Which of the following situations would you prefer to be in?

A. There is a 50% chance that the selected ball will be red, and a 50% chance the selected ball will be yellow.
B. The selected ball will be red or yellow, but the exact probability for each is unknown.

Vignette G2

Your friend has set you up on a blind date. When you arrive at the arranged meeting place you notice that there are two people who fit the general description that your friend has given to you. You find one of these people, person X, extremely attractive; while the other person, person Y, is of only average attractiveness. Which of the following situations would you prefer to be in?

A. There is a 50% chance that person X is your date, and a 50% chance that person Y is your date.
B. Either person X or person Y is your date but the exact probability for each is unknown.

Vignette G3

You have just been offered a promotion at work along with the choice of becoming head of department X or head of department Y. Your boss tells you that his boss is planning on heavily supporting only one of these departments, but he does not know which one his boss has in mind. Which of the following situations would you rather be in?

A. There is a 50% chance that department X will be highly supported and a 50% chance that department Y will be highly supported.
B. Either department X or department Y will be highly supported but the exact probability for each is unknown.

Vignette G4

Your child has extreme talent and interest in two things: X and Y. You have heard that in a few years a local rich person is planning on funding a very generous scholarship for talented young people in either X or Y. However, at this point they have not decided whether to support X or Y. In order for your child to be eligible they will need to receive specialised training starting now, and the skills are sufficiently time-consuming that they need to pick just one. Which of the following situations would you rather be in?

A. There is a 50% chance that X will get the generous scholarship, and a 50% chance that Y will get the generous scholarship.
B. Either X or Y will get the generous scholarship, but the exact probability for each is unknown.

Vignette G5

You have a stock portfolio of two stocks: X and Y. You get a call from your stockbroker who advises you that he has received a reliable tip that only one of your stocks is about to skyrocket in value, although he doesn't know which one. Unfortunately, you must sell one of the stocks immediately because of a recent medical emergency. Which of the following situations would you prefer to be in?

A. There is a 50% chance that stock X will skyrocket and a 50% chance that stock Y will skyrocket.
B. Either stock X or Y will skyrocket in value but the exact probability for each is unknown.

Vignette G6

You are currently unemployed, but have just been offered two jobs from two different companies: company X and company Y. You have heard that one of them is in line to receive a great deal of investor funding within the next year, but you don't know which one. Which of the following situations would you rather be in?

A. There is a 50% chance that company X will receive significant investor funding and a 50% chance that company Y will receive significant investor funding.
B. Either company X or company Y will receive significant investor funding but the exact probability for each is unknown.

Vignette G7

You are in the market to buy a house and have identified two that you really like, X and Y. Your real estate agent tells you that the local government is planning on building an amazing school in the neighbourhood of either X or Y, which would greatly increase its property values (and is also very appealing to you since you are planning a family). Unfortunately no decision has been made at this point about where it will be built, and you need to put an offer in now in order to get either house. Which of the following situations would you rather be in?

A. There is a 50% chance that the school will be built in neighbourhood X, and a 50% chance that it will be built in neighbourhood Y.
B. The school will be built in either neighbourhood X or neighbourhood Y but the exact probability for each is unknown.

Vignette G8

You have two friends, X and Y. You have a strong crush on X and no romantic interest at all in Y. A mutual friend of yours, Bob, tells you that he heard that either X or Y was interested in you but doesn't remember which one it was. Which of the following situations would you rather be in?

A. There is a 50% chance that person X is interested and a 50% chance that person Y is interested.
B. Either person X or person Y is interested but the exact probability for each is unknown.

Vignette G9

You are a competitive runner. Your coach has recently returned from a sports science conference and advises you that she has been informed of two new training protocols: protocol X and protocol Y. Each of these training protocols has been shown to result in significant and long-lasting improvements, but they each work for different people. Unfortunately, it is so far impossible to determine ahead of time which people will benefit from which. The protocols are are mutually exclusive (i.e. they can't both be completed at the same time): you must choose one. Which of the following situations would you prefer to be in?

A. There is a 50% chance that training protocol X will help you and a 50% chance that training protocol Y will help you.
B. Either training protocol X or Y will help you but the exact probability for each is unknown.

Vignette G10

You are invited to two parties on the same night. You have heard that the person you are romantically interested in is definitely attending one of them, but you don't know which one. Unfortunately, the parties are three hours away from each other, so you cannot attend both. Which of the following situations would you prefer to be in?

A. There is a 50% chance that this person will be at a party X and a 50% chance that they will be at party Y.
B. The person will be at either party X or party Y but the exact probability for each is unknown.

Vignette G11

You have one day left of your vacation, and within a few hours' driving distance from your hotel are two different wildlife preserves: preserve X and preserve Y. There is a rare bird, one of the only ones of its kind, that has been spotted in both X and Y. The bird cannot be in two places at once and you do not have time to go to both. Which of the following situations would you prefer to be in?

A. There is a 50% chance that the rare bird is at preserve X, and a 50% chance that the rare bird is at preserve Y.
B. The rare bird is at either preserve X or preserve Y, but the exact probability for each is unknown.

Vignette G12

You are a medical student and final exams are two weeks away. You have recently been told about two study drugs, drug X and drug Y, which if taken during study can significantly improve memory retention. Both drugs have been shown to work very well, but each works for different people. Unfortunately, it is so far impossible to determine ahead of time which people will benefit from which. Further, both drugs are slow acting, so you only have time to try one before your exams commence. Which of the following situations would you prefer to be in?

A. There is a 50% chance that drug X will improve your memory retention, and a 50% chance that drug Y will improve your memory retention.
B. Either drug X or drug Y will improve your memory retention, but the exact probability for each is unknown.

Loss Vignettes

Vignette L1

At a casino, there is an urn on the table which contains 1000 balls. Each of these 1000 balls is either red or yellow. You are to randomly select one of these balls from the urn and, if you selct a red ball, you will lose $1000. Which of the following situations would you rather be in?

A. There is a 50% chance that the selected ball will be red, and a 50% chance the selected ball will be yellow.
B. The selected ball will be red or yellow, but the exact probability for each is unknown.

Vignette L2

Your friend has set you up on a blind date. When you arrive at the arranged meeting place you notice that there are two people who fit the general description that your friend has given to you. You find one of these people, person X, extremely unattractive; while the other one, person Y, is of average attractiveness. Which of the following situations would you rather be in?

A. There is a 50% chance that person X is your date, and a 50% chance that person Y is your date.
B. Either person X or person Y is your date, but the exact probability for each is unknown.

Vignette L3

You have just been offered a promotion at work along with the choice of becoming head of department X or head of department Y. Your boss tells you that the CEO of the company is planning on slashing the budget of only one of these departments, but your boss does not know which one the CEO has in mind. Which of the following situations would you rather be in?

A. There is a 50% chance that department X's budget will be slashed and a 50% chance that department Y's budget will be slashed.

B. Either department X's budget or department Y's budget will be slashed but the exact probability for each is unknown.

Vignette L4

Your child has extreme talent and interest in two things: X and Y. You have heard that the local schools are planning on discontinuing programs in either X or Y in a few years due to lack of funds; however, at this point they have not decided which one to eliminate. You don't have the funds to get your child private lessons, so their only option is through the schools. Neither your nor your child wants to start something that they will have to stop. Which of the following situations would you rather be in?

A. There is a 50% chance that programs in X will be discontinued, and a 50% chance that programs in Y will be discontinued.
B. Programs in either X or Y will be discontinued, but the exact probability for each is unknown.

Vignette L5

You have a stock portfolio of two stocks: stock X and stock Y. You get a call from your stockbroker who advises you that he has received an anonymous tip that one of your stocks is about to plummet in value, while the other will continue to grow steadily. Due to taxation and investment regulations, you can only sell one of these stocks. Which of the following situations would you rather be in?

A. There is a 50% chance that Stock X will plummet and a 50% chance that Stock Y will plummet.
B. Either stock X or Y will plummet in value, but the exact probability for each is unknown.

Vignette L6

You work at a bank and are moving to a new city that has two branches of this bank, branch X and branch Y. Your boss is willing to transfer you to either X or Y in your new city. However, The bank's CEO has announced that within two years one of these branches will be closed because the city is only big enough to sustain one branch. The employees of the closed branch will be made redundant. Which of the following situations would you rather be in?

A. There is a 50% chance that branch X will be closed, and a 50% chance that branch Y will be closed.
B. Either branch X or Y will be closed, but the exact probability for each is unknown.

Vignette L7

You have developed an insect infestation in your house. The inspector tells you it is either species X or species Y. He cannot tell which one without further tests, but he is certain that it is not both because they are very territorial and will fight each other off. An infestation of species X will ruin the structural integrity of the house and cause it to plummet in value. Species Y, however, is completely benign and will impose no costs (financial, aesthetic, or otherwise) to your property. Which of the following situations would you rather be in?

A. There is a 50% chance that the infestation is of species X and a 50% chance that the infestation is of species Y.
B. The infestation is of either species X or Y, but the exact probability for each is unknown.

Vignette L8

You are on a hike in the remote wilderness when you are bitten by a snake; the bite happened so quickly that you could not determine the species. Only two species of snake exist in the area in which you are hiking: species X and species Y. A bite from species X is possibly lethal, while a bite from species Y is harmless. Which of the following situations would you rather be in?

A. There is a 50% chance that the bite is from species X and a 50% chance that the bite is from species Y.
B. The bite is from either species X or Y, but the exact probability for each is unknown.

Vignette L9

Your computer has a virus. A consultant tells you that it is either of type X or type Y; he cannot tell without further tests, but he is certain that it is not both because they cannot operate on the same machine. Virus type X will require your computer to sit at the shop for weeks in order to fix, while Y can be removed in less than an hour. Which of the following situations would you rather be in?

A. There is a 50% chance that your computer has virus X, and a 50% chance that your computer has virus Y.
B. Your computer has either virus X or Y, but the exact probability for each is unknown.

Vignette L10

On a routine doctor visit, you learn that your body has acquired a pathogen with two possible variants: variant X and variant Y. Your doctor cannot determine which it is without further tests, but he is certain that it is not both because each one kills the other. Variant X is potentially deadly while variant Y is somewhat benign. Which of the following situations would you rather be in?

A. There is a 50% chance that the pathogen is variant X and a 50% chance that the pathogen is variant Y.
B. The pathogen is either variant X or Y, but the exact probability for each is unknown.

Vignette L11

You have left your car in an uncovered airport carpark while you are travelling to a far away city for work. Since you left, you have heard news that a large hailstorm has struck near the airport but you have not been able to determine exactly where. If this hailstorm hit the airport carpark, your car has probably sustained serious and costly damage (you are uninsured). Which of the following situations would you rather be in?

A. There is a 50% chance that the hailstorm has struck your car, and a 50% chance that it hasn't.
B. The hailstorm either struck your car or it didn't, but the exact probability for each is unknown.

Vignette L12

You are the five-term mayor of your city and you are again running for re-election, coming to the end of a long campaign against a surprisingly powerful challenger. You have scheduled a meeting with your campaign manager to talk about your prospects of losing the election. Which of the following situations would you rather be in?

A. There is a 50% chance that you will lose the election, and a 50% chance that you will not.
B. You will either lose the election or you will not, but the exact probability for each is unknown.

Appendix B
Exclusion Criteria

Experiment 1

You are on holidays when you hear news that the river near your home town has experienced serious flooding. Which of the following situations would you rather be in?

A. Your house is close to the river.
B. Your house is far from the river on a hill.

Experiment 2

You are planning on attending an outdoor, uncovered event this afternoon and you are interested in knowing whether it will rain. The weather forecast from multiple sources says that it is very likely to rain. Further, you look out the window and see heavy, dark, threatening rain clouds overhead. Both of these pieces of information lead you to believe that it is much more likely to rain than it is not to rain.

If you had to guess, what is the probability that it will rain and the probability that it will not rain?