

Contingent Belief Updating

Chiara Aina* Andrea Amelio† Katharina Brütt‡

December 2, 2024

Abstract

We study the impact of contingent thinking on belief updating. Engaging in contingent thinking calls for both processing hypothetical information and contrasting multiple contingencies during the belief-updating process. Our experimental findings show that contingent thinking leads to significant deviations from Bayesian updating. These deviations arise from the diminished perceived informativeness of hypothetical signals and the challenges posed by asymmetric signals, where comparing contingencies becomes more difficult. These results have implications for contingent planning, information acquisition, and information design.

Keywords: Belief Updating; Contingent Thinking; Experiment.

JEL Classification: C91; D83; D91.

*Universitat Pompeu Fabra and BSE. E-mail: chiara.aina@upf.edu.

†Bocconi University. E-mail: andrea.amelio@unibocconi.it.

‡School of Business & Economics, Vrije Universiteit Amsterdam. E-mail: k.bruett@vu.nl.

We are grateful to Katie Coffman, John Conlon, Benjamin Enke, Christine Exley, Agata Farina, Shengwu Li, Nick Netzer, Florian Schneider, Arthur Schram, Josh Schwartzstein, Andrei Shleifer, Joep Sonnemans, Jakub Steiner, Matthew Rabin, Chris Roth, Emanuel Vespa, Roberto Weber, Florian Zimmermann, as well as the seminar and conference participants at Cornell University, NYUAD, UCSD, BSE Summer Forum, ECBE, EAYE Annual Meeting, and the ESA conference. We also thank all those who took the time to participate in our expert survey. The preregistration plan is available at https://aspredicted.org/D2G_X81. The experiment was approved by the Ethics Committee Economics and Business (EBEC) at the University of Amsterdam with reference number 20220303100340. Funding from the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy EXC 2126/1-390838866 and the Amsterdam Center for Behavioural Change is acknowledged.

1 Introduction

Adjusting beliefs in response to new information is often essential to determine the best course of action. Numerous situations demand that we incorporate a not-yet-observed piece of information into our belief system, anticipating how expectations evolve in response to diverse contingencies. Think about writing a contract, pricing a structured financial asset, or deciding to run a survey to collect new data. However, research in economics and psychology has focused on settings where individuals incorporate an already-observed piece of information into their belief system. Do we process the same information in the same manner in these circumstances? While, according to the Bayesian benchmark, the revision of beliefs should not depend on whether individuals engage with data contingently, this study shows that it does.

This paper experimentally studies whether and to what extent contingent thinking affects belief updating. To sharpen our question, we focus on the following working definition of contingent thinking: ahead of the resolution of some uncertainty, one reasons through the mutually exclusive potential realizations of such uncertainty (contingencies), assessing one's reaction to each potential realization. Economics examines several situations that require the use of contingent thinking in belief updating. To formulate a strategy in sequential games, players often have to form beliefs contingently about the opponent's type or the state of nature. Also, decisions to acquire information, to experiment, or design information structures call for an ex-ante assessment of the value of information for different contingencies.

As an illustration, consider a doctor deciding whether to administer a test to a patient. The test produces an informative but noisy signal from which the doctor can learn about the patient's health. To make the decision, the doctor needs to anticipate how they would learn given each result, thereby engaging in contingent thinking. To do so, the doctor has to reason through both scenarios of a positive and a negative test result and update their beliefs for each contingency without having observed either. This is what we refer to as *contingent belief updating*, that is, assessing updated beliefs for all the possible signal realizations that could materialize. We distinguish this from what we call *conditional belief updating*: One observes a new piece of information and then assesses the updated beliefs only for that realized and relevant signal. Are beliefs assessed contingently the same as beliefs assessed conditionally? If not, would contingent belief updating help you form more accurate beliefs, or would this only lead to more biased beliefs?

Understanding the impact of contingent thinking on belief accuracy is important for three reasons. First, it provides an opportunity to deepen our understanding of the underlying factors contributing to why we observe biased beliefs. While much is known about biases in belief updating when individuals observe relevant and realized information, we cannot take for granted that the biases observed in this setting equally apply when reasoning through contingencies. Second, this research question is economically relevant. On the one hand, if contingent thinking leads to less accurate beliefs, this is crucial in settings in which agents engage in contingent planning or information acquisition, such as in negotiating contracts or evaluating insurance plans. In the doctor’s example, if beliefs updated conditionally differ from the ones assessed contingently, the ex-ante evaluation of the test might be misleading, resulting in either under- or over-testing. On the other hand, if contingent thinking proves effective in debiasing inaccurate beliefs, we would have an easily implementable and portable debiasing mechanism to correct beliefs. If this were the case in our previous example, the doctor would be better off sticking to how they evaluate the test results contingently rather than revising their beliefs upon observing the actual test result. Last, addressing this question is methodologically important. Framing the question differently, we investigate whether there is a systematic difference across beliefs elicited with the direct or strategy method. If this were the case, studies employing these methods should account for it in both the design and inference stages.

We conduct an online experiment to investigate the effect of contingent belief updating. The experiment implements three between-subject treatments in the commonly used “balls-and-urns” updating paradigm with binary state and signal. To investigate the underlying mechanisms, we employ two approaches. First, we identify two features of contingent belief updating that set it apart from conditional belief updating: (i) the hypothetical nature of the considered contingency (*hypothetical thinking*), and (ii) the consideration of all possible contingencies (*contrast reasoning*). Our treatments break down the effect of contingent thinking into these two components. The participants face contingent belief updating by employing the strategy method to elicit beliefs, while conditional belief updating can be induced by eliciting beliefs with the direct method. Both components of contingent thinking are present in the first, but absent in the second. Therefore, we introduce a third treatment that requires hypothetical thinking but not contrast reasoning by eliciting posteriors conditional on one (random) hypothetical contingency. Second, we examine how the characteristics of the information structure

and individual traits interact with the effect of contingent thinking. Specifically, participants face ten different signal-generating processes with different characteristics that could affect their updating, such as how diagnostic signals are (signal strength) and whether the different signals are equally diagnostic for different states (symmetric vs. asymmetric signal-generating processes).

We find that, overall, contingent thinking leads to more distortion in belief updating: compared to the Bayesian benchmark, we report both more biased beliefs in terms of the absolute distance and more underinference if beliefs are elicited contingently compared to conditionally. Contingent belief updating increases the absolute bias by one-third. In the doctor’s example, this finding would suggest under-testing by an uninformed doctor. This effect seems to be entirely driven by hypothetical thinking rather than contrast reasoning. Indeed, the most striking insight emerging from our data is the harmful effect of hypothetical thinking. It leads to an increase of more than 50% in absolute bias and pushes participants to systematically underinfer more. We report how hypothetical thinking worsens a wide range of accuracy and consistency measures: not only are beliefs further from being Bayesian, but also, there is more noise in the reported beliefs and less consistency in how beliefs are updated across contingencies. The biasing effect of hypothetical thinking is more pronounced with stronger signals, and it also makes the task appear more challenging for participants.

Contrast reasoning compensates for the biasing effect of hypothetical thinking depending on the characteristics of the signal-generating processes. In particular, we report how treatment effects vary with the symmetry of the signal-generating process. Our data show that contrast reasoning fully offsets the negative impact of hypothetical thinking when the signal-generating process is symmetric but has no effect when asymmetric. We further explain this sharp result by showing that the effectiveness of contrast reasoning decreases in a continuous measure of the asymmetry of the signal-generating process. We can trace back the resulting increase in the bias to beliefs that respond to asymmetric signals as if they were symmetric. As a consequence, contingent and conditional belief updating do not differ for symmetric signal-generating processes. In the example, the doctor’s assessment of their beliefs evolve to the test’s potential outcomes is accurate when the false positive and false negative rates coincide. Finally, we find that individual measures of cognitive reflection and cognitive uncertainty do not mediate the ability to engage in either hypothetical thinking or contrast reasoning in this belief-updating task.

The importance of studying the impact of contingent thinking on belief updating is emphasized by the fact that it is non-trivial, even for experts, to predict its directional effect. We asked a sample of academic experts in economics to predict how contingent belief updating affects belief distortions. We document significant heterogeneity in experts' predictions, with the majority expecting biases would be unaffected or reduced if individuals update their beliefs contingently compared to conditionally. Our findings directly oppose these predictions.

Our project speaks to several strands of literature. First, we contribute to the literature on biases in beliefs. Ample evidence shows that individuals tend to underinfer from signals (Benjamin, 2019). Recent studies by Augenblick et al. (2024) and Ba et al. (2024) replicate this result, studying belief updating for several levels of signal diagnosticity, but also find overinference for weak signals. We purposefully exclude weak signals from our design to restrict our attention to underinference, allowing for a stronger identification of the effect. However, inspired by these studies, we employ several signal-generating processes that vary in signal strength to study how contingent belief updating is affected. Closely related to our work, Gonçalves et al. (2024) find that people underinfer from retractions due to their increased complexity, which also requires contingent thinking. In contrast, we offer a direct test of the role of contingent thinking in belief updating.

Second, there is a growing and recent body of literature in economics related to contingent thinking. These studies highlight the widespread challenges associated with contingent thinking (e.g., Li, 2017; Martínez-Marquina et al., 2019; Espónida and Vespa, 2014, 2023; Ngangoué and Weizsäcker, 2021).^{1,2} Our approach complements the existing literature on contingent thinking, recently surveyed by Niederle and Vespa (2023), as it differs in three key aspects from these papers. First, our focus lies on belief updating — processing of new information to report revised

¹As in these papers, we assume contingencies to be known and foreseeable, ruling out concerns related to unawareness. While we believe this to be an interesting strand of literature (e.g., Schipper, 2024; Becker et al., 2024; Karni and Vierø, 2013, 2017), it is beyond the scope of this paper. Moreover, we focus on contingent thinking instead of *counterfactual thinking*. In the psychological literature, (e.g., Kahneman and Tversky, 1982; Epstude and Roese, 2008; Byrne, 2016), counterfactual thinking refers to mental simulations of past events. Hence, the distinction between the two concepts lies in the object of the simulation, which concerns alternative versions of a realized event (counterfactual) as opposed to a potential future event (contingency). Recent studies embrace a clear-cut distinction between the two (Pearl, 2009; Ferrante et al., 2012; Gerstenberg, 2022).

²Recent studies highlight mental imagery—"representation resulting from perceptual processing not triggered by sensory input" (Stanford Encyclopedia of Philosophy)—as a tool for improving economic outcomes (Dube et al., 2023; Ashraf et al., 2024; John and Orkin, 2022; Alan and Ertac, 2018).

beliefs — rather than choosing an action — evaluating and comparing the implications of each alternative to implement the preferred one. Second, in these papers, individuals are normatively expected to engage in contingent reasoning to solve the task at hand optimally. Instead, one can treat each contingency in isolation to report accurate beliefs. Third, our approach involves participants reporting multiple contingency-specific guesses, either in the case where one contingency is observed (ex-post) or in the case there is uncertainty on the relevant realized contingency (ex-ante). In contrast, previous works focus on ex-ante decision-making, where contingent thinking is instrumental in properly comparing the different contingency-specific consequences to choose the optimal action. Regardless of these differences, our paper and this literature document ways in which contingent thinking could impede payoff maximization, primarily rooted in the difficulty of considering hypothetical realizations, as discussed further in Section 5.

Last, this paper also contributes to the literature on elicitation methods. While most studies investigating biased beliefs employ the direct method to elicit beliefs, some few others adopt the strategy method (e.g., Esponda et al., 2024; Cipriani and Guarino, 2009; Toussaert, 2017; Agranov et al., 2024; Charness et al., 2021b; Ambuehl and Li, 2018).³ Therefore, it becomes crucial to understand how to compare the results across methods of belief elicitation. The predominant focus of the literature on belief elicitation has been on the impact of payment schemes, rule complexity, and correspondence with actions (e.g., Charness et al., 2021a; Schlag et al., 2015; Schotter and Trevino, 2014). Despite a substantial body of research on the difference between direct and strategy methods for eliciting desired actions (for example, see Brandts and Charness, 2003; Brosig et al., 2003; Casari and Cason, 2009; Aina et al., 2020; and Brandts and Charness, 2011 for a review), to the best of our knowledge, our study is the first to demonstrate the that the method of belief elicitation impacts the reported posterior beliefs.

The rest of the paper is organized as follows: Section 2 describes our experimental design and data collection, Section 3 briefly describes the experts' predictions, Section 4 presents the results, and Section 5 discusses our findings.

³Kozakiewicz (2022) and Lilley and Wheaton (2024) use hypothetical signals to identify the effect of motivated reasoning on belief updating, while our research shows that there is a large difference in beliefs elicited for hypothetical signals and realized ones, even in a neutral setting.

2 Experimental Design

Studying how contingent thinking affects belief updating and the underlying mechanisms requires (i) a setting that prompts contingent thinking in belief updating, (ii) a treatment variation that disentangles the effects of hypothetical thinking and contrast reasoning, and (iii) a clean manipulation of the characteristics of the signal-generating process.

To study belief updating, we employ the classic balls-and-urns paradigm. The participants face two bags, A and B, which are equally likely to be selected, $\Pr(A) = \Pr(B) = 50\%$. Each bag has a total of either 80 or 60 balls, which are either blue or orange.⁴ While the participants do not know which bag is selected, they know the distribution of the colored balls in the bags and the computer draws from the selected bag a ball whose color can be informative. The participant's task is to guess the probability of each bag being selected given the available information.⁵

Table 1: Treatments

		Contrast Reasoning	
		No	Yes
Hypothetical Thinking	No	Conditional	—
	Yes	One-Contingency	All-Contingency

2.1 Treatments

To manipulate whether participants engage in hypothetical thinking and contrast reasoning, the treatments change the method of belief elicitation. The treatments vary whether the signal for which beliefs are reported has been observed (signal realization observed *vs.* hypothetical) and how many contingencies are considered (one *vs.* both signal realizations), as shown in Table 1. The three between-subject treatments, as detailed below, are summarized in Figure 1 and the corresponding choice interface is shown in Figure 2 (see Online Appendix 3.2 for all interfaces).

⁴We do not use bags with a total of 100 balls to avoid the heuristic answer (i.e., the probability of bag A after observing a blue ball is the number of blue balls in bag A) corresponds to the correct answer for the symmetric SGPs.

⁵We employ a version of this task in which participants are in control of each step: first, by clicking on ‘Select the bag,’ a bag is selected through a virtual coin flip; then, by clicking on ‘Draw the ball,’ a ball is drawn from the selected bag. We use graphical animations for the coin flip and the ball draw to create a realistic setting online and remind the participants of the basic structure of the task in each round.

- 1. Conditional:** The beliefs are elicited conditional on the realized signal. The participant observes the color of the drawn ball and is then asked to assess beliefs only conditional on that relevant contingency. This corresponds to the classic balls-and-urns task and what we refer to as *conditional belief updating*. It also corresponds to eliciting beliefs with the direct method.
- 2. All-Contingency:** The beliefs are elicited conditional on both possible signal realizations. Before observing the color of the drawn ball, the participant is asked to report beliefs conditional on both cases on the same screen, in a randomized order: (i) the computer draws an orange ball, and (ii) the computer draws a blue ball. Thus, participants consider the two hypothetical contingencies with the possibility of comparing their beliefs conditional on one signal realization to their beliefs conditional on the other signal realization. After the beliefs are reported, the participants learn the color of the drawn ball. We refer to this as *contingent belief updating*. This features both *hypothetical thinking* and *contrast reasoning*. This treatment corresponds to a belief elicitation that employs the strategy method (as introduced in Mitzkewitz and Nagel, 1993).
- 3. One-Contingency:** The beliefs are elicited conditional on only one possible signal realization. When participants have not yet observed the signal realization, they are asked to consider one of the following hypothetical cases: (i) the computer draws an orange ball, or (ii) the computer draws a blue ball. Each case is chosen with equal probability in each round. As in *All-Contingency*, participants learn the color of the drawn ball after the belief elicitation. This treatment, therefore, requires to engage in *hypothetical thinking*, but not *contrast reasoning*.⁶

2.2 Signal-Generating Processes

The task is repeated for ten rounds. In each round, participants face a different signal-generating process (hereafter, SGP). Figure 3 summarizes and illustrates the 10 SGPs used in this experiment in terms of their characteristics and induced Bayesian posteriors for both signals. In what follows, we refer to each SGP with the respective “ $\Pr(\text{blue}|A) - \Pr(\text{blue}|B)$ ” as in Figure 3a.

⁶Although other treatments could have been designed to disentangle the effect of hypothetical thinking and contrast reasoning, we found this version to be the cleanest for our purpose. For example, beliefs could have been elicited sequentially for each hypothetical signal realization. We discard this option as it might have triggered contrast reasoning over rounds. Alternatively, beliefs could have been elicited conditional on the observed signal realization for two identical but independent tasks on the same screen. This approach would trigger contrast reasoning whenever different signals were observed for the two independent tasks. We chose to avoid this treatment because participants may not easily understand the independence assumption.

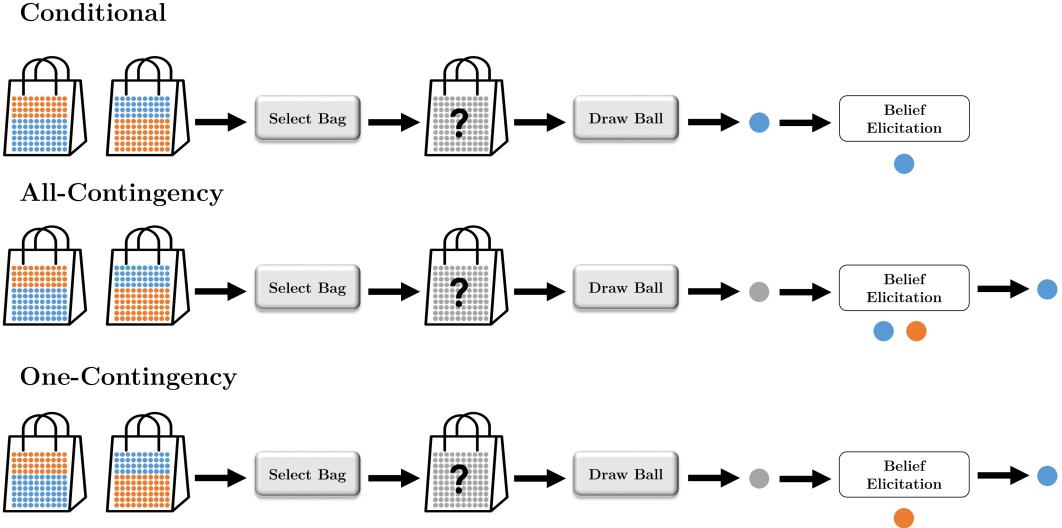


Figure 1: Task Timeline by Treatment

Notes. Treatments branch out after a ball is drawn from the selected bag. The treatments differ depending on whether the color of the drawn ball is revealed before or after the belief elicitation and whether the beliefs are elicited for one or two contingencies. In *Conditional*, participants observe an animated colored ball being drawn, while in the other two treatments, the drawn ball is uncolored with a question mark.

Each SGP specifies how diagnostic a ball of a specific color ball is for each bag. We measure the *signal strength of signal s for bag A* as

$$\lambda_s = \frac{\Pr(s|A)}{\Pr(s|B)}.$$

If $\lambda_s = 1$, the signal is not diagnostic for either bag; however, if $\lambda_s > 1$ ($\lambda_s < 1$), the signal is more diagnostic for bag A (B) and λ_s measures by how much.⁷ To compare signals more easily across SGPs, we consider the signal strength of each signal in terms of the bag for which the signal is more diagnostic: $\bar{\lambda}_s = \lambda_s$ if $\lambda_s \geq 1$ and $\bar{\lambda}_s = \lambda_s^{-1}$ otherwise. Varying signal strength within-subject over rounds allows us to investigate the mechanism along this dimension and the robustness of the effect of contingent thinking on belief updating.

We include both symmetric and asymmetric SGPs. An SGP is *symmetric* if the probability of drawing a blue ball from bag A is the same as the probability of drawing an orange ball from bag B. Hence, for symmetric SGPs, the signal strengths of a blue ball and of an orange ball coincide, i.e., $\bar{\lambda}_{blue} = \bar{\lambda}_{orange}$. In such cases, examining only one bag provides all the necessary information to determine the signal strength and, thus, to guess the posterior correctly. This simple rela-

⁷Note that the Bayesian posterior for equal priors can be calculated as $\Pr(A|s) = (1 + \lambda_s^{-1})^{-1}$.



Figure 2: Choice Interface by Treatment

Notes. The figure displays screenshots of choice interfaces for each treatment. Panel (a) presents the interface for *Conditional*, in the case where participants are asked to make a guess upon observing the drawing of a blue ball. Panel (b) presents the interface for *One-Contingency*, in the case where participants are asked to make a guess for the contingency in which the drawn ball was blue. Panel(c) presents the interface for *All-Contingency*.

tionship between signal strengths might facilitate contrast reasoning, leading to a heterogeneous effect of contingent thinking for symmetric and asymmetric SGPs.

To explore this further, alongside the binary classification, we introduce a continuous measure that quantifies the degree of asymmetry in an SGP by comparing how diagnostic signals are against each other. This measure captures the extent to which signals vary in their signal strength relative to their average signal strength:

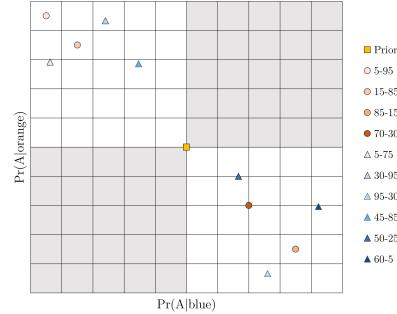
$$\sigma(\bar{\lambda}_s, \bar{\lambda}_{s'}) = \frac{|\bar{\lambda}_s - \bar{\lambda}_{s'}|}{\bar{\lambda}_s + \bar{\lambda}_{s'}}.$$

The ratio is zero for symmetric SGPs, but positive otherwise: the higher the ratio,

the more asymmetric the signals are in their diagnosticity.^{8,9}

Name	Pr(blue A)	Pr(blue B)	Symmetric	Mirrored	Total Balls
5-95	5%	95%	Yes	No	60
15-85	15%	85%	Yes	Yes	80
85-15	85%	15%	Yes	Yes	60
70-30	70%	30%	Yes	No	80
5-75	5%	75%	No	No	60
30-95	30%	95%	No	Yes	60
95-30	95%	30%	No	Yes	80
45-85	45%	85%	No	No	60
50-25	50%	25%	No	No	80
60-5	60%	5%	No	No	80

(a) Characteristics



(b) Bayesian Posteriors

Figure 3: Signal Generating Processes

Notes. Panel (a) summarizes the different characteristics of the SGP. Panel (b) illustrates the induced posteriors across signal realizations for the different SGPs. The name of the SGP refers to the corresponding “ $\text{Pr}(\text{blue}|A) - \text{Pr}(\text{blue}|B)$ ”.

Lastly, some SGPs are *mirrored*, meaning that participants are exposed to the same SGP twice, inverting the distributions of balls in the bags and changing the number of balls in the bag. Throughout the experiment, we vary whether the total number of balls in the bags is 80 or 60. The mirrored SGPs are presented once with bags with 80 balls and once with 60 balls. We mirrored one symmetric SGP (15-85 and 85-15) and one asymmetric SGP (30-95 and 95-30). The reason why we include mirrored SGPs is twofold. First, we use them to check the consistency of reported beliefs given the same signal across rounds. This is a measure of how stable the deviations from Bayesian updating are within-task (*within-consistency*). Second, this allows us to better compare *Conditional* and *One-Contingency* to *All-Contingency*. When beliefs are elicited contingently, participants report their conditional beliefs on both signal realizations, while they report their beliefs only conditional on one signal in *Conditional* and *One-Contingency*. This allows us to study whether posteriors across signal realizations are consistent with the Bayes rule between signal realizations (*between-consistency*).

For the last task, we also elicited cognitive uncertainty (Enke and Graeber, 2023). For comparability, the last choice displays the same SGP, 70-30, for all partici-

⁸In perception studies (for a review in economics, see Woodford, 2020), the contrast between stimuli is quantified analogously to highlight the importance of relative rather than absolute differences in perceptual experience. In economics, salience theory (e.g., Bordalo et al., 2022) uses this functional form to measure the salience of certain attributes in decision-making.

⁹There is no canonical way to quantify the degree of asymmetry. We adopt this measure for its simplicity and intuitive relevance in our setting. As we preregistered a binary version of this measure, but not the continuous counterpart, Online Appendix 1.2 replicates related findings using a conceptually similar measure: the distance between the posteriors across signals.

pants, while we randomize the order of the SGP for the remaining 9 choices. We pick 70-30 for this because this SGP is closest to the most widely used SGP (67-33) in this type of experiment (see meta-analysis by Benjamin, 2019).

2.3 Incentives

The belief elicitation was incentivized using the binarized scoring rule (Hossain and Okui, 2013): the closer the reported beliefs are to the realized state, the higher the probability of receiving the bonus of GBP 2.¹⁰ One of the ten tasks is randomly selected for payment.

We design our incentives to (i) ensure incentive-compatibility for truthful reporting and (ii) keep the strength of the incentives comparable in all three between-subject treatments. To achieve the first, we ensure that each contingency occurs with non-trivial probabilities for all SGPs (50-50 for symmetric SGPs, and at most 70-30 for asymmetric SGPs). To keep the strength of incentives comparable to *Conditional*, the incentivization requires minimal adjustments in *One-Contingency* and *All-Contingency*. In *All-Contingency*, participants' beliefs are elicited for both contingencies, and the realized contingency determines which guess is relevant for the payment. Paying both belief elicitation tasks could have affected the participants' attention because of the difference in the magnitude of incentives across treatments, confounding our results. In *One-Contingency*, incentives are the same as in *Conditional* if the randomly-proposed contingency corresponds to the realized one; otherwise, the elicited guess is irrelevant for determining the bonus, and the participant receives a fixed payment of GBP 1.¹¹

2.4 Logistics

The experiment was pre-registered on AsPredicted.¹² It was conducted on Prolific in March 2023, restricting the pool to participants located in the UK. The participants received a link to a Qualtrics survey that includes the instructions, choice

¹⁰Danz et al. (2022) show that providing complex details on the elicitation procedure might confuse participants and distort their incentives. Therefore, instructions clarify that “to maximize the chance of winning the bonus, it is in your best interest always to give a guess that you think is the true chance.” This is also checked in one of the control questions. If interested, participants could read further about the details of this elicitation rule.

¹¹While some guesses being payoff-irrelevant could lead to lower attention, we chose this incentivization as consistency of incentives across treatments is our priority. We do not find any evidence that attention is affected, see Section 4.3.3. Furthermore, evidence in similar tasks has shown that the strength of incentives does not impact the belief accuracy (Enke et al., 2023a).

¹²The preregistration plan is available at https://aspredicted.org/D2G_X81.

tasks, cognitive uncertainty elicitation for the last choice, and a final survey — eliciting Cognitive Reflection Test (Frederick, 2005), Berlin numeracy task, demographics, and a short questionnaire. The average payment was 3.37 GBP, with an average duration of approximately 24 minutes. The participants earned GBP 2 for completing the study and could earn an additional bonus of GBP 2 depending on their performance in the tasks.

Instructions were split into two blocks, each followed by a set of control questions. The first block was the same for all treatments: it welcomed the participants, provided general information on the experiment, and explained the balls-and-urns task in detail. The second block focuses on the treatment-specific choice procedure and payment, and thus it varies by treatment. See Online Appendix 3 for the instructions and control questions. Only participants who pass these questions are included in the analysis, as preregistered. A total of 525 participants completed the study, of which 86% passed the control questions about the experiment instructions (not statistically different between treatments: 88% in *Conditional*, 86% in *All-Contingency*, and 83% in *One-Contingency*). This leaves valid observations from 150 participants per treatment. In our final sample of 450 participants, 50% are female, 36% have low schooling ('High school' or lower educational level), and the median age is 37.

3 Expert Survey

To contextualize our findings, we elicit predictions from a sample of academic experts in economics that we considered knowledgeable about topics related to expectations or contingent thinking, before collecting the data. Answers to this expert survey were collected through the Social Science Prediction Platform. We report details of the data collection, survey, and results in Online Appendix 2.

Our survey focuses on the comparison of the treatments *All-Contingency* and *Conditional* and documents significant heterogeneity in experts' opinions on the effect of contingent belief updating. Of 38 responses, 37% expected more accurate beliefs when they are elicited contingently compared to when they are elicited conditionally, 61% did not expect any significant difference between the two elicitation methods, and only one expert expected the opposite. The majority of the experts also do not expect any heterogeneous effects based on the characteristics of the SGPs or individual traits. We take this expert survey as evidence that experts believe that beliefs are not less accurate when assessed contingently.

4 Results

In this section, we first introduce our two main outcomes of interest, *bias* and *underinference*, and we provide an overview of the main treatment effects. We continue with a discussion of potential mechanisms, considering the characteristics of both the SGPs and the participants as drivers of the treatment effects.

4.1 Main Outcomes

We investigate our treatment effects on two preregistered measures, both capturing distinct aspects related to deviations from Bayesian updating.

First, bias is defined as the absolute distance between the reported posterior and the Bayesian posterior for each task. We focus on absolute differences to determine whether individual guesses are systematically more accurate across treatments. In contrast, a directional measure assesses whether the average guess is more or less accurate, allowing individual biases to cancel out. Second, we consider how participants respond to the signal strength to capture directional deviations from Bayesian updating. We use the following model introduced by Grether (1980) that defines the posterior-odds ratio given equal priors as:

$$\frac{\Pr(A|s)}{\Pr(B|s)} = \left[\frac{\Pr(s|A)}{\Pr(s|B)} \right]^\alpha = \lambda_s^\alpha.$$

Deviations from $\alpha = 1$ capture participants' distortion in how their beliefs respond to the signal strength. While Bayes' rule prescribes $\alpha = 1$, *underinference* corresponds to $\alpha < 1$: the reported posteriors are as if the signal strength is perceived as less diagnostic for bag A and more diagnostic for bag B than it actually is. Conversely, *overinference* implies the opposite distortion, with $\alpha > 1$. Unlike bias, α is a directional measure of deviations from Bayesian updating defined across SGPs.¹³ As our SGPs are chosen such that the signals would be classified as strong according to Augenblick et al. (2024), we expect underinference.

Our experiment replicates the deviations from Bayesian updating reported in the literature for both measures. Comparing the available data in the online appendix of Benjamin (2019) to our results in *Conditional* for comparable SGPs (equal prior, symmetric SGPs, including SGPs 60-40, 67-33, and 83-17), we find that the average bias of 5.9 percentage points for the most similar SGP in *Conditional*

¹³In Online Appendix 1.1, we consider the alternative measure of underinference introduced in Ba et al. (2024) and show that our results are robust.

(70-30) aligns closely with the average bias of 6.7 percentage points in comparable studies. Moreover, in his meta-analysis, Benjamin (2019) estimates

$$\log \frac{\Pr(A|s)}{\Pr(B|s)} = \alpha \log \lambda_s + \beta$$

and finds strong evidence for underinference with $\hat{\alpha} = 0.86$ for incentivized similar tasks (equal prior, one observed signal, symmetric SGP). In line with this, the estimated coefficient in *Conditional* for symmetric SGPs is also exactly $\hat{\alpha} = 0.86$.

4.2 Treatment Effect

First, we consider our main treatment effects on the two outcomes of interest. Figure 4a reports the average bias by treatment. Column I of Table 2 displays the corresponding results for OLS regressions of the bias on indicators for the different treatments.¹⁴ Figure 4b shows the plot of the estimated relationship of the log posterior-odds ratio against the log signal strength. The slope captures the underinference estimated across SGPs.¹⁵ In Column I of Table 3, we show the results of regressing the log posterior-odds over the log signal strength interacted with treatment indicators.

Finding 1. *Deviations from Bayesian updating are significantly larger if beliefs are updated contingently compared to conditionally.*

The treatment *All-Contingency* increases the bias compared to *Conditional*. The estimated bias amounts to 7.2 percentage points in *Conditional*. We estimate that the average bias increases in *All-Contingency* by 2.4 percentage points, so by one-third, compared to *Conditional* ($p = 0.006$; Column I in Table 2).

We find directionally similar results in terms of underinference. Overall, there is strong evidence of underinference: the estimated coefficients $\hat{\alpha}$ are 0.76 in *Conditional* and 0.70 in *All-Contingency*, displaying significant deviations from the Bayesian benchmark of $\alpha = 1$ in both treatments ($p < 0.001$). This is reflected by the estimated log posterior-odds ratio being below the 45° line in Figure 4b.

¹⁴Analyses in Table 2 include SGP fixed effects. Table A1 reproduces the analyses with SGP \times contingency fixed effects. Contingency here refers to the observed signal realization in *Conditional* and to the contingency relevant for the belief elicitation in *One-Contingency* and *All-Contingency*. This does not change the interpretation of our results.

¹⁵Figure A2 shows the average bias by treatment for each SGP separately. See Figure A5 for an overview of the estimated degree of underinference by treatment and SGP. In all treatments, we observe underinference for most SGPs. For a more nuanced picture, Figure A6 provides an overview of the heterogeneity in the estimated degree of underinference by subject and treatment.

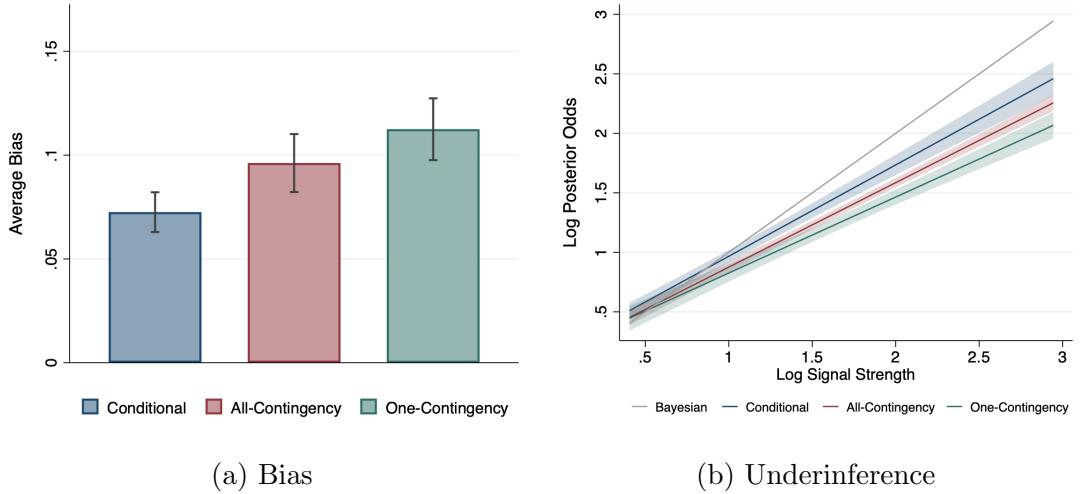


Figure 4: Treatment Effect

Notes. Panel (a) shows the average bias defined as the absolute value of the difference between the reported posterior and the Bayesian benchmark by treatment. Panel (b) shows the plot of the estimated relationship between the log posterior-odds ratio and the log signal strength by treatment as an illustration of underinference. Error bars in Panel (a) and shaded areas in Panel (b) indicate 95% confidence intervals, clustered at the individual level.

While the slope is visibly less steep for *All-Contingency* than for *Conditional*, the estimated underinference in *All-Contingency* is not statistically different from the one in *Conditional* ($p = 0.243$; see the coefficient on ‘Log Signal Strength \times All-Contingency’ in Column I of Table 3).

Next, we look at how the effect of contingent thinking can be explained by its decomposition into hypothetical thinking and contrast reasoning. Recall that comparing *One-Contingency* to *Conditional* isolates the effect of hypothetical thinking without any opportunity for contrast reasoning, while comparing *All-Contingency* to *Conditional* captures both hypothetical thinking and contrast reasoning.

Finding 2. *Hypothetical thinking is driving the biasing effect of contingent belief updating.*

Comparing the bias in *One-Contingency* to *Conditional*, we see a significant change of 4 percentage points ($p < 0.001$; Column I in Table 2), increasing the observed bias by more than 50%. The average bias in *All-Contingency* lies in between the bias in *Conditional* and in *One-Contingency*, even if the latter is not statistically different ($p = 0.118$; see the difference of the coefficients on ‘All-Contingency’ and ‘One-Contingency’ in Column I in Table 2). Therefore, we can attribute the entire increase in the bias induced by contingent thinking to hypothetical thinking.

Interestingly, the treatment effects seem to be robust to learning throughout the

Table 2: Bias

	I	II	III	IV
All-Contingency	0.024** (0.009)	0.010 (0.011)	0.017* (0.008)	0.011 (0.009)
One-Contingency	0.040*** (0.009)	0.045*** (0.011)	0.014 (0.010)	0.039*** (0.010)
Asymmetric		0.026* (0.010)		
All-Contingency × Asymmetric		0.023* (0.009)		
One-Contingency × Asymmetric		-0.008 (0.010)		
Log Signal Strength			0.013* (0.005)	
All-Contingency × Log Signal Strength			0.003 (0.006)	
One-Contingency × Log Signal Strength			0.015* (0.007)	
Degree of Asymmetry				0.027* (0.012)
All-Contingency × Degree of Asymmetry				0.041** (0.015)
One-Contingency × Degree of Asymmetry				0.003 (0.018)
Constant	0.062*** (0.008)	0.068*** (0.009)	0.019 (0.013)	0.064*** (0.006)
<i>N</i>	6000	6000	6000	6000
adj. <i>R</i> ²	0.024	0.026	0.028	0.019
Clusters	450	450	450	450

Notes. OLS estimates. Individual-level clustered standard errors. SGP fixed effects in Columns I - III. The dependent variable is defined as the absolute value of the difference between the reported posterior and the Bayesian benchmark; * p<.05, ** p<.01, *** p<.001.

experiment, as shown in Figure A3. We do not find evidence of learning over rounds in *Conditional* ($p = 0.650$). Instead, the average bias increases in each trial by 0.4 percentage points in *One-Contingency* ($p = 0.017$) and decreases by 0.3 percentage points in *All-Contingency* ($p = 0.021$). If anything, the treatment effect seems to strengthen throughout the experiment.

Moreover, the treatment effects cannot be attributed to a small subset of participants. Figure A1 presents the estimated coefficients from quantile regressions across different quantiles of the absolute bias, separately for *All-Contingency* and *One-Contingency*. The figure shows how the treatment effect is significantly different from zero, at the 5% level, for all values of bias above the 70th and the 30th percentile, for *All-Contingency* and *One-Contingency*, respectively.

Turning to our second outcome measure, participants underinfer significantly more in *One-Contingency* ($\hat{\alpha} = 0.63$) than in *Conditional*, with $\hat{\alpha}$ decreasing by 12.9 percentage points ($p = 0.021$; see the coefficient on ‘Log Signal Strength × One-Contingency’ in Column I of Table 3). Hypothetical thinking thus pushes participants to systematically underinfer more. The level of underinference is not

Table 3: Underinference

	I	II	III
Log Signal Strength	0.768*** (0.035)	0.862*** (0.043)	0.874*** (0.037)
All-Contingency	-0.034 (0.056)	0.034 (0.082)	-0.033 (0.064)
One-Contingency	-0.012 (0.071)	0.118 (0.116)	0.005 (0.082)
Log Signal Strength \times All-Contingency	-0.058 (0.046)	-0.035 (0.057)	-0.007 (0.050)
Log Signal Strength \times One-Contingency	-0.129* (0.055)	-0.184* (0.081)	-0.137* (0.065)
Asymmetric		0.293*** (0.082)	
Log Signal Strength \times Asymmetric		-0.127* (0.056)	
All-Contingency \times Asymmetric		-0.061 (0.101)	
One-Contingency \times Asymmetric		-0.169 (0.143)	
Log Signal Strength \times All-Contingency \times Asymmetric		-0.071 (0.067)	
Log Signal Strength \times One-Contingency \times Asymmetric		0.071 (0.098)	
Degree of Asymmetry			0.849*** (0.166)
Log Signal Strength \times Degree of Asymmetry			-0.382*** (0.103)
All-Contingency \times Degree of Asymmetry			0.018 (0.215)
One-Contingency \times Degree of Asymmetry			-0.002 (0.278)
Log Signal Strength \times All-Contingency \times Degree of Asymmetry			-0.151 (0.128)
Log Signal Strength \times One-Contingency \times Degree of Asymmetry			0.016 (0.171)
Constant	0.199*** (0.044)	-0.019 (0.066)	-0.044 (0.051)
<i>N</i>	6000	6000	6000
adj. <i>R</i> ²	0.249	0.252	0.258
Clusters	450	450	450

Notes. OLS estimates. Individual-level clustered standard errors. The dependent variable is defined as the logarithm of the ratio of the reported posterior belief for each bag for a given signal. The interactions of each treatment indicator and Log Signal Strength give the estimated underinference parameter $\hat{\alpha}$ per treatment; * p<.05, ** p<.01, *** p<.001.

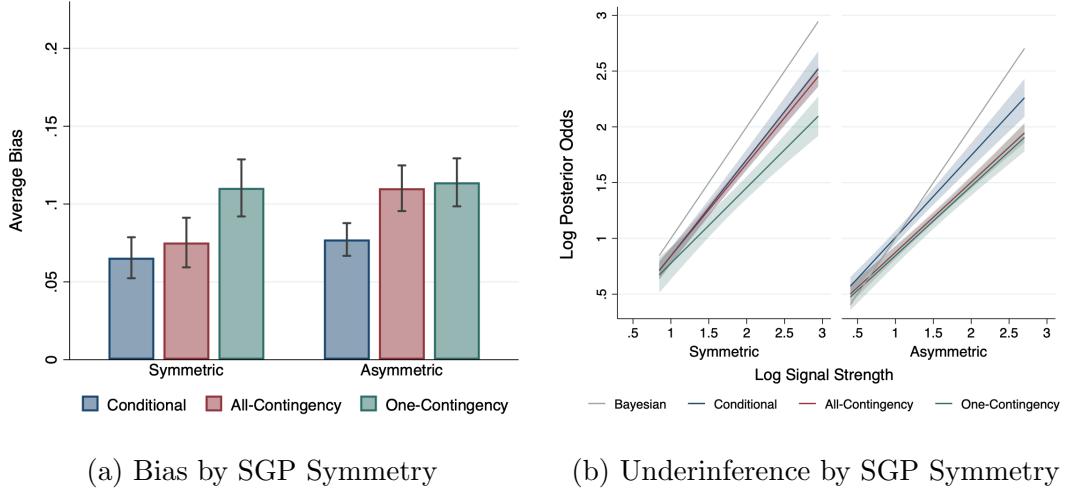
statistically different between *One-Contingency* and *All-Contingency*, providing support for the argument that contrast reasoning does neither further increase nor decrease deviations from Bayesian updating.

4.3 Mechanisms

We now further explore the mechanisms that drive the effect of contingent thinking on belief updating by first highlighting the role of the characteristics of the SGPs and then by looking at measures of consistency and additional individual measures.

4.3.1 Characteristics of SGPs

Looking at the features of the SGPs, we find that symmetry and signal strength differently impact hypothetical thinking and contrast reasoning.



(a) Bias by SGP Symmetry

(b) Underinference by SGP Symmetry

Figure 5: Treatment Effect by SGP Symmetry

Notes. Panel (a) shows the average bias defined as the absolute value of the difference between the reported posterior and the Bayesian benchmark by treatment split and the symmetry of the SGP. Panel (b) shows the estimated relationship between the log posterior-odds ratio and the log signal strength by treatment as an illustration of underinference split by the symmetry of the SGP. Error bars in Panel (a) and shaded areas in Panel (b) indicate 95% confidence intervals, clustered at the individual level.

Symmetric vs. Asymmetric We begin our analysis of the mechanisms by looking at the heterogeneity of our treatment effects using the binary measure of symmetry, as defined in Section 2.2. Figure 5a provides an overview of the average bias of the posterior beliefs depending on whether the SGP is symmetric or asymmetric. Column II of Table 2 reports the difference-in-difference analysis of regressing the average bias on treatment indicators, a dummy indicator of whether the SGP is symmetric, and their interactions. Over all treatments, the average bias increases by 3.5 percentage points if signals are asymmetric ($p < 0.001$; Column II in Table 2). Hence, asymmetric SGPs clearly increase the difficulty of Bayesian inference. We document substantial heterogeneity in the treatment effect depending on the symmetry of the SGP.

Finding 3. *The impact of hypothetical thinking does not vary with the symmetry of the SGP. Contrast reasoning entirely offsets the effect of hypothetical thinking for symmetric SGPs, but not for asymmetric SGPs.*

For symmetric SGPs, the average bias increases by 4.5 percentage points when

participants consider one hypothetical contingency instead of observing the realized signal ($p < 0.001$; Column II in Table 2). However, we do not observe a significant increase in the average bias when beliefs are updated contingently compared to conditionally ($p = 0.354$; Column II in Table 2). We estimate that the posterior beliefs in symmetric SGPs are 3.5 percentage points more accurate in *All-Contingency* than in *One-Contingency* ($p = 0.005$; see the difference of the coefficients ‘All-Contingency’ and ‘One-Contingency’ in Column II in Table 2). By breaking down the effect of contingent thinking into hypothetical thinking and contrast reasoning, we observe that only hypothetical thinking further biases beliefs, but the presence of contrast reasoning fully compensates for this biasing effect for symmetric SGPs.

In contrast, our results for asymmetric SGPs show that the average bias is significantly higher in both *One-Contingency* and *All-Contingency* than in *Conditional*. Hypothetical thinking with or without contrast reasoning increases the bias respectively by 3.3 and 3.6 percentage points, respectively (both $p < 0.001$; see the sum of the coefficients of the treatment indicators and their interactions with ‘Asymmetric’ in Column II in Table 2), so by more than 40%. The biases in these two treatments are indistinguishable for asymmetric SGPs ($p = 0.727$).

Therefore, these findings suggest that contrast reasoning only produces a debiasing effect for symmetric SGPs while exhibiting no impact for asymmetric SGPs. Furthermore, this insight indicates that Finding 1 summarizes a more nuanced picture. Recall that participants complete the task for 10 SGPs, of which 4 are symmetric and 6 are asymmetric. Given the heterogeneous effect by the SGP symmetry, we can infer that our main result about the harmful effect of contingent thinking on Bayesian updating is primarily driven by asymmetric SGPs, wherein contrast reasoning proves ineffective in mitigating the higher bias.

We report similar results also in terms of underinference, as illustrated in Figure 5b. Interacting the variables to estimate the degree of underinference in Column I of Table 3 with indicators of the SGP symmetry in Column II of Table 3, we observe that, while hypothetical thinking increases the degree of underinference also if the SGP is symmetric ($p = 0.024$; see the coefficient on ‘Log Signal Strength \times One-Contingency’ in Column II of Table 3), hypothetical thinking in combination with contrast reasoning only does so marginally for asymmetric SGPs ($p = 0.084$; see the sum of the coefficients on ‘Log Signal Strength \times All-Contingency’ and ‘Log Signal Strength \times All-Contingency \times Asymmetric’ in Column IV of Table 3). Therefore, contrast reasoning reduces the degree of underinference if the SGP is

symmetric but fails to do so if it is asymmetric.

Signal Strength Signal strength has a documented moderating effect on deviations from Bayesian updating (Augenblick et al., 2024). In Column IV of Table 2, we present the results of regressing the bias on indicators of the treatment, the signal strength, and their interactions. In line with the literature, we document a larger bias for stronger signals ($p = 0.011$). However, there is treatment-dependent heterogeneity. In *One-Contingency*, this effect is significantly stronger than in *Conditional* ($p = 0.039$; see Column IV of Table 2), suggesting that signal strength is an important driver of bias due to hypothetical thinking. Contrast reasoning has no such effect ($p = 0.741$; see the sum of the coefficients on ‘One-Contingency’ and ‘All-Contingency’ in Column IV of Table 2).

Finding 4. *Hypothetical thinking has a stronger effect on deviations from Bayesian updating for stronger signals.*

In the previous paragraphs, we show how the SGP’s characteristics, such as symmetry and signal strength, influence our treatment effects. Next, we further explore their connection in two complementary ways.

Relative Signal Strength For symmetric SGPs, signals share the same signal strength, but for asymmetric ones, it is possible to distinguish between a weaker and a stronger signal. This might affect belief updating, which we explore by examining the role of *relative signal strength*. Formally, signal s is stronger than signal s' if $\bar{\lambda}_s > \bar{\lambda}_{s'}$. That is, the stronger signal moves beliefs further away from the prior compared to the weaker signal.¹⁶

Figure 6 reports the average underinference level by weaker *vs.* stronger signal, treatment, and SGP symmetry. Since signals are equally diagnostic in symmetric SGPs, the underinference level should not vary by signal within the same treatment. Indeed, we do not observe that the participants react differently to the two signals. Turning to asymmetric SGPs, reported guesses exhibit a significantly higher degree of underinference for stronger signals. Across all treatments, we observe an underinference gap when comparing stronger and weaker signals: Rel-

¹⁶One can show that, for an asymmetric SGP, the stronger signal is the a priori less likely one, that is, $\bar{\lambda}_s > \bar{\lambda}_{s'}$ is equivalent to $\Pr(s) < \Pr(s')$. This allows us to offer another interpretation of these results based on the comparison between more likely or less likely signals. Note that the bias decreases in the probability of the signal ($p < 0.001$), but the probability of the signal does not interact with our treatment effect ($p = 0.293$ and $p = 0.338$).

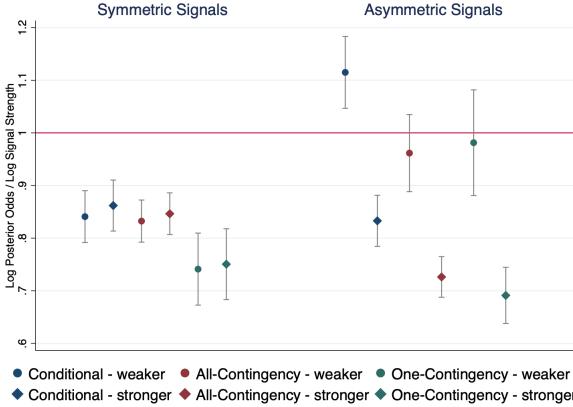


Figure 6: Underinference for Stronger and Weaker Signals

Notes. The ratio of log posterior-odds and the log signal strength by treatment, symmetry of the SGP, and stronger *vs.* weaker signal; for symmetric SGPs, signals are equally diagnostic and we classify the blue ball as stronger arbitrarily. Error bars indicate 95% confidence intervals.

ative signal strength matters for inference.¹⁷ We find this underinference gap even at the individual level for *All-Contingency*. Specifically, the average individual underinfers more in response to the stronger signal compared to the weaker one, even when they report guesses for the same SGP on the same screen (Figure A7).

We observe significant differences in the level of underinference across treatments. These differences follow the same pattern as in Finding 3, both for symmetric and asymmetric signals. Consider now only asymmetric SGPs, where relative signal strength is a meaningful measure. While underinference prevails for most treatments, for *Conditional*, weaker signals generate significant overinference. However, the underinference gap does not differ significantly across treatments. Table A3 reports the results of the regressions supporting these findings.

Degree of Asymmetry Finding 3 shows a sharp result: contrast reasoning fully offsets the biasing effect of hypothetical thinking for symmetric SGPs, but has no impact for asymmetric SGPs. To explore further the relation between contrast reasoning and symmetry, we turn to a more nuanced measure: the degree of asymmetry. As formalized in Section 2, this quantifies the difference in signal strength between the two signals as a continuous measure of an SGP’s asymmetry.

¹⁷This result builds and extends on the key result in Augenblick et al. (2024). Their analysis focuses on symmetric SGPs, where differences in signal strength can only be differences in absolute signal strength across different SGPs. Instead, we show that relative signal strength also drives the level of underinference by focusing on asymmetric SGPs where signals may have different strengths within the same SGPs.

The degree of asymmetry captures when contrast reasoning is effective in reducing bias.¹⁸ The coefficient of the interaction between the degree of asymmetry and *All-Contingency* is significantly positive ($p = 0.009$; Column IV of Table 2) and significantly larger than the coefficient of the interaction between the degree of asymmetry and *One-Contingency* ($p = 0.033$; Column IV of Table 2). Therefore, an increase in the degree of asymmetry decreases the effectiveness of contrast reasoning in counteracting the biasing effect of hypothetical thinking.

Next, we consider three channels to explain why a higher degree of asymmetry limits how contrast reasoning offsets the impact of hypothetical thinking. First, individuals may wrongly interpret an asymmetric SGP as if it were symmetric. For symmetric SGPs, the reported posteriors for the same bag across signals should sum up to one because $\Pr(A|b) = \Pr(B|o)$. This is not the case for asymmetric SGPs. The higher the degree of SGP's asymmetry, the more consequential this mistake is, leading to a higher bias. This may explain why contrast reasoning proves ineffective in reducing bias for more asymmetric signals.

To detect the use of such a heuristic, we classify pairs of guesses in *All-Contingency* as ‘Treated as Symmetric’ if there is an absolute distance between the reported posteriors $\Pr(A|b)$ and $\Pr(B|o)$ of at most one percentage point.¹⁹ Assuming that participants use this heuristic, we should observe (i) a substantial share of pairs of guesses classified as ‘Treated as Symmetric,’ and (ii) that the bias increases more with the degree of asymmetry for those pairs of guesses than for those that do not fall under this classification. Both are indeed the case. Within all pairs of guesses for asymmetric SGPs, 14.1% are classified as ‘Treated as Symmetric.’²⁰ As Figure 7 illustrates, the increase in bias in *All-Contingency* with the degree of asymmetry can be attributed to choices classified as ‘Treated as Symmetric.’

The bias increases significantly more with the degree of asymmetry for guesses being classified as ‘Treated as Symmetric’ than for those that are not ($p < 0.001$; Column I in Table A2). Note that the share of guesses treating signals as symmetric decreases in the degree of asymmetry ($p < 0.001$). Nevertheless, we find that the entire increase in the bias with the degree of asymmetry is driven by the pairs

¹⁸We only examine the effect of the degree of asymmetry on bias, but not on underinference, as its effect on underinference would be hard to interpret because both measures are defined in terms of signal strength.

¹⁹The results are similar if we use more or less strict classifications. We cannot perform this analysis in the other treatments, as it requires a pair of guesses within the same SGP and variation in the degree of asymmetry across multiple SGPs.

²⁰The pairs of guesses for symmetric SGPs in *All-Contingency* classified ‘Treated as Symmetric’ is 75.3%. Figure A9 illustrates the scatter plot of these pairs of guesses by SGP symmetry.

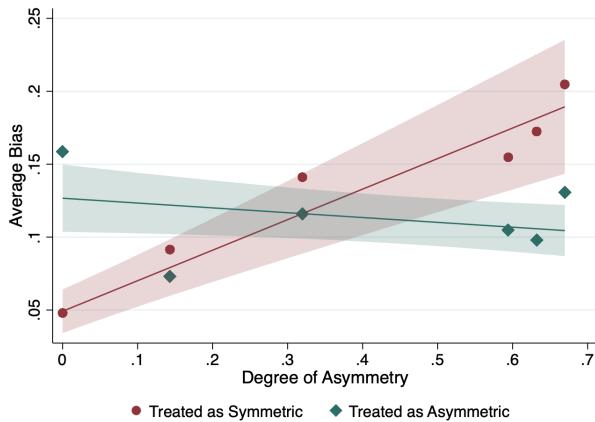


Figure 7: Treating an SGP as Symmetric and the Degree of Asymmetry

Notes. Average bias in *All-Contingency* by the degree of asymmetry for the pairs of guesses for asymmetric SGPs that are classified as ‘Treated as Symmetric’ and those that are not. Shaded regions indicate 95% confidence intervals.

of guesses classified as ‘Treated as Symmetric’ ($p = 0.057$ for negative coefficient ‘Degree of Asymmetry’ in Column I in Table A2).

A second possibility that may explain why contrast reasoning fails to counteract hypothetical thinking is that the participants report their beliefs “as if” both signals are realized when asked to report their beliefs for both contingencies on the same screen. By construction, for each SGP, one signal is more diagnostic for bag A ($\lambda_s > 1$), and one signal is more diagnostic for bag B ($\lambda_{s'} < 1$). Thus, if participants misinterpret the treatment *All-Contingency* in this manner, beliefs would be reported as if they respond to a convex combination of the two signal strengths for bag A, λ_{blue} and λ_{orange} . This mistake would result in higher underinference in *All-Contingency* compared to *One-Contingency*, where hypothetical signals are considered separately. However, as reported in Section 4.2, this is not what we observe, ruling out this mechanism.

A third possibility is that participants mix the overall diagnosticity of the signals, perceiving a signal’s strength as a convex combination of the two signal strengths, $\bar{\lambda}_{blue}$ and $\bar{\lambda}_{orange}$. This would imply an attenuated effect in *All-Contingency* compared to *One-Contingency*: There would be less underinference for the stronger signal and more underinference for the weaker signal in *All-Contingency* compared to *One-Contingency*. As shown in Figure 6 and Table A3, this is not the case.

Finding 5. *Contrast reasoning is less effective in reducing the bias for SGPs with a higher degree of asymmetry. This can be attributed to individuals who treat asymmetric SGPs as symmetric.*

4.3.2 Consistency Measures

Our analysis of the mechanisms continues by looking at the treatment effects on additional outcomes related to consistency.

Table 4: Consistency

	Δ Posteriors	Bayes-Inconsistent
All-Contingency	0.011 (0.016)	0.026 (0.024)
One-Contingency	0.066** (0.022)	0.081* (0.035)
Constant	0.112*** (0.015)	0.068** (0.021)
<i>N</i>	904	896
adj. R^2	0.016	0.006
Clusters	379	375

Notes. OLS estimates. Individual-level clustered standard errors. Symmetry SGP fixed effects. The dependent variable in Column I is the absolute difference in the reported posteriors for the same signal for mirrored SGPs, and in Column II a dummy taking value one if the vector of posteriors for mirrored SGPs is Bayes-inconsistent; * $p < .05$, ** $p < .01$, *** $p < .001$.

Within-Consistency Exploiting the mirrored SGPs, we investigate the stability of the reported posteriors within a task, *within-consistency*. This measure allows us to evaluate whether the treatments have the important side effect of increasing the noise in how beliefs are updated.²¹

With this goal, our dependent variable Δ Posteriors is defined as the absolute difference between the posteriors for the probability of bag A given the same signal reported for two mirrored SGPs (see Appendix A.4.1 for details). While participants should report the same beliefs in both instances and this difference should be zero, our pooled data provides evidence of inconsistent beliefs for the same task: the average Δ Posteriors is 12 percentage points (statistically different from zero, with $p < 0.001$), with a median of 5 percentage points.²²

Compared to *Conditional*, participants in *One-Contingency* are significantly more likely to be inconsistent ($p = 0.004$; Column I in Table 4). This is not the case in *All-Contingency* ($p = 0.477$; Column I in Table 4), where we observe a higher level of within-consistency than in *One-Contingency* ($p = 0.009$; see the difference

²¹This measure is conceptually related to cognitive uncertainty under the assumption that participants are well-calibrated in assessing their own performance, which is not the case for belief-updating tasks (Enke et al., 2023b). Also, since our measure of within-consistency and cognitive uncertainty are measured for different SGPs, they are not properly comparable.

²²While on average beliefs are inconsistent within a task, a good portion of participants are perfectly consistent. Figure A8 shows the cumulative distribution of this measure by treatments. 30% are perfectly consistent in *All-Contingency*, 20% in *Conditional*, and 16% in *One-Contingency*.

of the coefficients of the treatment indicators in Column Δ Posteriors in Table 4). Therefore, hypothetical thinking leads to less within-consistent beliefs, while the presence of contrast reasoning counteracts this increase completely.

Between-Consistency So far, we have looked at measures of deviations from Bayesian updating given a signal realization. Next, we consider a way to categorize deviations from Bayesian updating by looking at the performance across contingencies: the consistency of the reported beliefs across signal realizations given the same SGP (*between-consistency*).

Bayes' rule prescribes that beliefs cannot be updated in the same direction for all signal realizations. Therefore, holding posteriors given both signal realizations either above or below the prior would be an extreme violation of Bayesian updating. For this analysis, we need for each participant the reported *vector of posterior beliefs*, that is, the elicited posteriors conditional on each contingency given an SGP. We construct those thanks to our mirrored SGPs; see Appendix A.4.2 for details. Following Aina (2024), we say that a vector of posteriors is *Bayes-inconsistent* if both posteriors are higher or lower than 50%. Bayes-inconsistency is an extreme deviation from Bayesian updating because not only are the posteriors different from the ones implied by the known SGP, but it is also impossible to find an SGP that would rationalize the reported vector of posteriors given the prior (Aina, 2024; Bohren and Hauser, 2024). Bayes-inconsistency is quite rare: 6% in *Conditional*, 8% in *All-Contingency*, and 14% in *One-Contingency* in our mirrored SGPs.

This analysis underlines the biasing effect of hypothetical thinking in the absence of contrast reasoning. In *One-Contingency*, there is an 8.1 percentage points increase in Bayes-inconsistent vectors of posteriors ($p = 0.021$; Column II in Table 4). This is, even if only marginally significantly so, a larger increase than the statistically insignificant increase in *All-Contingency* ($p = 0.096$; see the difference of the coefficients of the treatment indicators in Column II in Table 4). Thus, there is suggestive evidence that contrast reasoning decreases Bayes-inconsistencies, while hypothetical thinking does the opposite.²³

Finding 6. *Hypothetical thinking leads to more inconsistent belief updating both within a task and across contingencies. Due to contrast reasoning, the consistency of belief updating does not differ between contingent and conditional belief updating.*

²³In Table A5, we report analogous findings for a more nuanced measure of between-consistency: the squared distance between the reported and Bayesian vectors of posteriors.

4.3.3 Individual Measures

Finally, we examine the role of individual measures both for heterogeneous treatment effects and additional measures.

Cognitive Reflection Test We study the moderating effect of a participant’s cognitive reflection capacity, as measured by the Cognitive Reflection Task (CRT), on our treatments. The CRT measures an individual’s tendency to override intuitive responses and engage in reflective and analytical thinking (Frederick, 2005); it appears to correlate with mental heuristics also related to belief updating (e.g., Oechssler et al., 2009; Hoppe and Kusterer, 2011; Augenblick et al., 2024).

We categorized participants who made one or no mistakes on the CRT as *high CRT* (56%), those who made two or more mistakes were categorized as *low CRT* (44%).²⁴ In line with the existing literature, individuals classified as low CRT exhibit significantly higher biases, underlining that cognitive reflection captures a component relevant to belief updating. If beliefs are elicited conditional on the observed signal, individuals with a high CRT are on average 4.3 percentage points closer to the Bayesian posterior ($p < 0.001$; Column V in Table A4) and display a lower levels of underinference ($p = 0.004$; Column VI in Table A4).

While a high CRT is associated with a lower bias and underinference in all three treatments, CRT seems to have no effect on hypothetical thinking ($p = 0.165$; Column V of Table A4) nor on contrast reasoning ($p = 0.282$; see the difference between ‘All-Contingency \times High CRT’ and ‘One-Contingency \times High CRT’ in Column V in Table A4). Column VI in Table A4 reports analogous results for underinference.

Cognitive Uncertainty Next, we examine whether our treatments impact cognitive uncertainty, which is measured for the last task in the experiment. Enke and Graeber (2023) define cognitive uncertainty as “[...] people’s subjective uncertainty over which decision maximizes their expected utility.” Their findings indicate that, in a belief-updating setting, an increase in cognitive uncertainty is associated with a stronger bias. Consistently, pooling all treatments, we find that an increase in

²⁴We modified the original version of the CRT, as reported in Online Appendix 3.3, to avoid confounds for participants who may have previously encountered the classic version. Out of the three questions, 26% of our participants made no mistakes, 30% made one mistake, 25% made two mistakes, and 19% made three mistakes. See Figure A4 for an illustration of this heterogeneity using the full scale (0-3) instead of the binary classification. The results are qualitatively comparable.

cognitive uncertainty increases the bias ($p = 0.001$): the more uncertain individuals tend to report more biased posteriors.

It is, therefore, relevant to assess to what extent cognitive uncertainty responds to hypothetical thinking and contrast reasoning in this setting, but we find no difference across treatments. The average cognitive uncertainty in *Conditional* is not significantly different from the one in *One-Contingency* ($p = 0.306$) or *All-Contingency* ($p = 0.657$). This suggests that cognitive uncertainty is unaffected by hypothetical thinking or reasoning. However, cognitive uncertainty was measured only for the 70-30 SGP, for which we observe no significant treatment effects.²⁵

Measures of Engagement We consider two measures of engagement: response time and self-reported degree of challenge in completing the tasks.

Response Time. Response time is an important measure because it can provide insights into the cognitive processes that underlie decision-making (e.g., Woodford, 2014; Krajbich et al., 2015; Alós-Ferrer et al., 2021; Schotter and Trevino, 2021). We regard the response time as a proxy of the indirect costs associated with the belief elicitation method, given the comparable strength of incentives across treatments. Longer response times may indicate that individuals are exerting more effort in the belief elicitation task, thus willing to incur higher indirect costs. Pooled across treatments exhibit a lower bias when taking more time ($p = 0.033$), suggesting that taking more time to perform a task could be due to the fact that the participants are engaging in more deliberate and reflective thinking.

On average, the response time for each task is 27 seconds in *Conditional*, 46 in *All-Contingency*, and 31 in *One-Contingency*. We estimate that per elicitation task, the participants take more than 50% longer in *All-Contingency* than in *Conditional* ($p < 0.001$; Column I in Table A4). At the same time, the hypothetical nature of signals in *One-Contingency* appears not to decrease engagement with the task ($p = 0.110$; Column I in Table A4). This suggests that the longer response time is due to contrast reasoning, not hypothetical thinking.

Our treatment effects cannot be explained by the differences in time participants spent per elicitation task and treatment. Controlling for the response time, both

²⁵As discussed in Section 2.2, we elicit cognitive uncertainty for the SGP most similar to those used in the literature. Running the OLS regressions of the bias on indicators of the different treatment effects (as in Column I in Table 2) for each SGP, we find that 70-30 is the only SGP for which there is no treatment effect for either *All-Contingency* ($p = 0.728$) or *One-Contingency* ($p = 0.10$). For all other SGPs, at least one of the treatment effects is significant at the 5% level.

All-Contingency and *One-Contingency* still significantly increase the bias compared to *Conditional*, by 2.7% and 4.1% respectively ($p = 0.002$ and $p < 0.001$; Column II in Table A4). Importantly, there is no interaction effect of the time spent per task and either treatment indicator ($p = 0.884$ and $p = 0.567$; Column III in Table A4). Therefore, we rule out the possibility that our findings are due to a particular treatment inducing some participants to spend less time on the task.²⁶

Perception of Difficulty. The perceived level of challenge serves as a complementary measure to response time in assessing the difficulty in each treatment.²⁷ Unlike for response time, the self-reported challenge level is significantly higher ($p = 0.002$; Column ‘IV’ in Table A4) in *One-Contingency* compared to *Conditional*. Participants perceive a greater challenge when engaging in hypothetical thinking despite not disengaging with the task. Interestingly, contrast reasoning does not increase the perceived level of challenge despite the longer response time and the higher computational complexity. If anything, the reported level is lower in *All-Contingency* than in *One-Contingency*, but not significantly so ($p = 0.351$).

5 Discussion

Our findings reveal a surprising effect of contingent thinking on how we process new information. While experts predict, if anything, a larger bias for conditional belief updating, our results indicate a different and more nuanced picture. Contingent belief updating can lead to less accurate beliefs than conditional belief updating. However, the effect is not uniform. We show how the effect varies depending on the characteristics of the signal-generating process. Our findings suggest that the effect is mediated by the complexity of the information structure (symmetry of the SGP) but not by one’s ability to engage with it (performance in CRT).

To learn more about the mechanisms behind this finding, we break down the effect of contingent thinking into hypothetical thinking and contrast reasoning using a treatment that requires engaging only in the former. On the one hand, our findings show a harmful effect of hypothetical thinking that is systematic across a

²⁶A within-subject design would allow us to examine more general forms of individual-level heterogeneity in our treatment effects. However, we do not employ this approach due to the detected learning effects and the associated threat of spillover effects between treatments, where a demand for consistency may overshadow the perceived differences in the elicitation.

²⁷In the final questionnaire, participants also answered an unincentivized question about how challenged they felt during the elicitation tasks on a 7-point scale.

wide range of measures of deviations from Bayesian updating. Thus, the results cast doubt on our ability to properly process information that may only realize in a future scenario. This suggests that simulating a prospective scenario requires exerting mental effort. On the other hand, this data suggests that contrast reasoning can compensate to some extent for the negative consequences of hypothetical thinking. The range of this effect is broad: from fully compensating with symmetric SGPs, it continuously decreases in the degree of asymmetry of SGPs due to some individuals treating asymmetric SGPs as if they were symmetric.

These results have broad implications for situations that involve contingent thinking in belief updating, such as information acquisition, information design, and experimentation. First, our findings offer an explanation for the “compression effect” in information acquisition documented in Ambuehl and Li (2018), where individuals undervalue informative sources due to underinference in belief updating. We provide a new perspective on this result: when individuals consider acquiring information, they also engage in contingent belief updating. This leads to underinference and can generate this compression effect. Second, our results also provide insights into the behavior observed by Zultan et al. (2024), where participants favor acquiring information from symmetric sources rather than asymmetric ones, even when suboptimal. We not only observe a higher degree of underinference when beliefs are elicited contingently, but this effect is particularly pronounced for asymmetric SGPs, which can explain why participants underestimate the informational value from these sources. Moreover, our results also open a promising avenue for future research regarding strategic interactions both theoretically and empirically. This is because contingent belief updating is often required to formulate a strategy in sequential games with uncertainty about players’ types or unknown payoff-relevant variables.

Finally, we want to address similarities and differences in our results with the emerging literature on failures of contingent thinking. In the recent survey, Niederle and Vespa (2023) argue that there are failures of contingent thinking *“when an agent does optimize in a presentation of the problem that helps her focus on all relevant contingencies (i.e., contingencies in which choices can result in different consequences), but does not optimize if the problem is presented without such aids (i.e., standard representation).”* At first glance, it would seem that we report the opposite effect, but this is not the case. There are important differences in our research questions but similarities in the reported findings. As highlighted in the introduction, the main difference is not only the type of tasks — choosing an ac-

tion *vs.* updating beliefs — but rather the overall problem structure and the type of suboptimal behavior under examination. In Martínez-Marquina et al. (2019) and Esponda and Vespa (2023), suboptimal behavior arises because participants should think contingently and fail to do so when making a choice ahead of the resolution of uncertainty, commonly implemented for all contingencies. Thus, individuals behave optimally when placed in the relevant contingency but struggle to determine the correct (common) action without knowing the realized contingency. Similarly, our paper also shows that participants’ beliefs are less biased upon observing the relevant contingency. However, we do not compare this to a setting where individuals choose an ex-ante action implemented across contingencies. Instead, we study how people determine their contingency-specific behavior. We find that participants struggle when they have to update beliefs that may become relevant in a not-yet-observed contingency. So here, individuals are placed in a setting in which they have to think contingently, but doing so might bias how they would react if they were to observe the relevant contingency. Interestingly, a common aspect drives both suboptimal behaviors: biases related to thinking about hypothetical events.

Pitfalls of hypothetical thinking seem not to be limited to a specific type of task but rather to numerous instances of failures of contingent thinking (Esponda and Vespa, 2014; Ali et al., 2021; Farina and Leccese, 2024) and other relevant contexts (Paolacci and André, 2023; Gandhi et al., 2023). We show its relevance in a new setting, belief updating. Theoretical approaches have recently emerged to incorporate this bias in simulations of expected future utilities (Piermont and Zuazo-Garin, 2024; Piermont, 2024), to link associative memory to belief formation about novel risks (Bordalo et al., 2024), to explore cognitive frictions that could explain differences in ex-ante and ex-post posteriors (Samuelson and Steiner, 2024; Bohren and Hauser, 2024). Also, Cohen and Li (2023) consider an extensive-form solution concept where players neglect the information from hypothetical events, which Cohen (2024) builds on to model dynamic markets. These approaches can account for the biases introduced by hypothetical thinking. However, the effect of contrast reasoning is underexplored, both experimentally and theoretically. It would be valuable to develop formal models to incorporate both hypothetical thinking and contrast reasoning. As suggested by Bordalo et al. (2023), the framing of the inference problem can lead to observing different types of biased beliefs. A first key challenge in formalizing our findings is developing a compelling model that accounts for differences in belief updating based on the asymmetry of the signal-

generating process. Only then, would it be possible to provide a comprehensive theoretical account of our treatment differences.

An open question is whether the presence of contrast reasoning could extend beyond merely neutralizing hypothetical thinking and thus lead to more accurate beliefs in other contexts. Two potential avenues could address this. One approach is to explore this question in settings where contingencies are more concrete and familiar to the participants. The stylized and abstract setting of this study allows us to have a well-grounded benchmark in the literature and easily vary conditions over rounds; however, it might have also amplified the difficulty of imaging hypothetical contingencies. Another potential avenue involves integrating contingent belief updating with nudging or training. For example, one could stress the importance of carefully imagining the proposed contingencies and encourage participants to contrast their answers across contingencies before proceeding. A novel paper by Ashraf et al. (2024) shows that the ability to imagine the forward-oriented scenario can be trained, and it is linked to improved economic outcomes. Enhancing such training to promote contrast reasoning may boost this effect further.

References

- Agranov, Marina, Utteeyo Dasgupta, and Andrew Schotter (2024) “Trust me: Communication and Competition in a Psychological Game,” *Journal of the European Economic Association*, jvae012.
- Aina, Chiara (2024) “Tailored Stories.”
- Aina, Chiara, Pierpaolo Battigalli, and Astrid Gamba (2020) “Frustration and anger in the Ultimatum Game: An experiment,” *Games and Economic Behavior*, 122, 150–167.
- Alan, Sule and Seda Ertac (2018) “Fostering patience in the classroom: Results from randomized educational intervention,” *Journal of Political Economy*, 126 (5), 1865–1911.
- Ali, S Nageeb, Maximilian Mihm, Lucas Siga, and Chloe Tergiman (2021) “Adverse and advantageous selection in the laboratory,” *American Economic Review*, 111 (7), 2152–2178.
- Alós-Ferrer, Carlos, Ernst Fehr, and Nick Netzer (2021) “Time will tell: Recover-

ing preferences when choices are noisy,” *Journal of Political Economy*, 129 (6), 1828–1877.

Ambuehl, Sandro and Shengwu Li (2018) “Belief updating and the demand for information,” *Games and Economic Behavior*, 109, 21–39.

Ashraf, Nava, Gharad Bryan, Alexia Delfino, Emily A Holmes, Leonardo Iacovone, and Ashley Pople (2024) “Learning to See the World’s Opportunities: Memory, Mental Experiencing and the Economic Lives of the Vulnerable.”

Augenblick, Ned, Eben Lazarus, and Michael Thaler (2024) “Overinference from Weak Signals and Underinference from Strong Signals*,” *The Quarterly Journal of Economics*, qjae032.

Ba, Cuimin, J Aislinn Bohren, and Alex Imas (2024) “Over-and Underreaction to Information.”

Becker, Christoph K, Tigran Melkonyan, Eugenio Proto, Andis Sofianos, and Stefan T Trautmann (2024) “Reverse Bayesianism: Revising beliefs in light of unforeseen events.”

Benjamin, Daniel J (2019) “Errors in probabilistic reasoning and judgment biases,” *Handbook of Behavioral Economics: Applications and Foundations* 1, 2, 69–186.

Bohren, J Aislinn and Daniel N Hauser (2024) “The Behavioral Foundations of Model Misspecification: A Decomposition.”

Bordalo, Pedro, Giovanni Burro, Katherine Coffman, Nicola Gennaioli, and Andrei Shleifer (2024) “Imagining the Future: Memory, Simulation, and Beliefs,” *The Review of Economic Studies*, rdae070.

Bordalo, Pedro, John J Conlon, Nicola Gennaioli, Spencer Yongwook Kwon, and Andrei Shleifer (2023) “How People Use Statistics.”

Bordalo, Pedro, Nicola Gennaioli, and Andrei Shleifer (2022) “Salience,” *Annual Review of Economics*, 14 (1), 521–544.

Brandts, Jordi and Gary Charness (2003) “Truth or consequences: An experiment,” *Management Science*, 49 (1), 116–130.

——— (2011) “The strategy versus the direct-response method: a first survey of experimental comparisons,” *Experimental Economics*, 14 (3), 375–398.

Brosig, Jeannette, Joachim Weimann, and Chun-Lei Yang (2003) “The hot versus

- cold effect in a simple bargaining experiment,” *Experimental Economics*, 6, 75–90.
- Byrne, Ruth (2016) “Counterfactual Thought,” *Annual Review of Psychology*, 67.
- Casari, Marco and Timothy N Cason (2009) “The strategy method lowers measured trustworthy behavior,” *Economics Letters*, 103 (3), 157–159.
- Charness, Gary, Uri Gneezy, and Vlastimil Rasocha (2021a) “Experimental methods: Eliciting beliefs,” *Journal of Economic Behavior & Organization*, 189, 234–256.
- Charness, Gary, Ryan Oprea, and Sevgi Yuksel (2021b) “How do people choose between biased information sources? Evidence from a laboratory experiment,” *Journal of the European Economic Association*, 19 (3), 1656–1691.
- Cipriani, Marco and Antonio Guarino (2009) “Herd behavior in financial markets: an experiment with financial market professionals,” *Journal of the European Economic Association*, 7 (1), 206–233.
- Cohen, Shani (2024) “What You Can’t See: Contingent Thinking Failures in Dynamic Markets.”
- Cohen, Shani and Shengwu Li (2023) “Sequential Cursed Equilibrium.”
- Danz, David, Lise Vesterlund, and Alistair J Wilson (2022) “Belief elicitation and behavioral incentive compatibility,” *American Economic Review*, 112 (9), 2851–83.
- Dube, Oeindrila, Sandy Jo MacArthur, and Anuj K Shah (2023) “A cognitive view of policing,” Technical report, National Bureau of Economic Research.
- Enke, Benjamin, Uri Gneezy, Brian Hall, David Martin, Vadim Nelidov, Theo Offerman, and Jeroen van de Ven (2023a) “Cognitive Biases: Mistakes or Missing Stakes?,” *The Review of Economics and Statistics*, 105 (4), 818–832.
- Enke, Benjamin and Thomas Graeber (2023) “Cognitive uncertainty,” *Quarterly Journal of Economics*, 138 (4), 2021–2067.
- Enke, Benjamin, Thomas Graeber, and Ryan Oprea (2023b) “Confidence, self-selection, and bias in the aggregate,” *American Economic Review*, 113 (7), 1933–1966.
- Epstude, Kai and Neal Roese (2008) “The Functional Theory of Counterfactual Thinking,” *Personality and Social Psychology Review*, 12, 168–92.

- Esponda, Ignacio and Emanuel Vespa (2014) “Hypothetical thinking and information extraction in the laboratory,” *American Economic Journal: Microeconomics*, 6 (4), 180–202.
- (2023) “Contingent preferences and the sure-thing principle: Revisiting classic anomalies in the laboratory,” *Review of Economic Studies*.
- Esponda, Ignacio, Emanuel Vespa, and Sevgi Yuksel (2024) “Mental models and learning: The case of base-rate neglect,” *American Economic Review*, 114 (3), 752–782.
- Farina, Agata and Mario Lecce (2024) “Hiding a Flaw: A Lab Experiment on Multi-Dimensional Information Disclosur.”
- Ferrante, Donatella, Vittorio Girotto, Marta Stragà, and Clare Walsh (2012) “Improving the Past and the Future: A Temporal Asymmetry in Hypothetical Thinking,” *Journal of Experimental Psychology: General*, 142.
- Frederick, Shane (2005) “Cognitive reflection and decision making,” *Journal of Economic Perspectives*, 19 (4), 25–42.
- Gandhi, Linnea, Anoushka Kiyawat, Colin Camerer, and Duncan J Watts (2023) “Hypothetical nudges provide misleading estimates of real behavior change.”
- Gerstenberg, Tobias (2022) “What would have happened? Counterfactuals, hypotheticals and causal judgements,” *Philosophical Transactions of the Royal Society B: Biological Sciences*, 377 (1866), 20210339.
- Gonçalves, Duarte, Jonathan Libgober, and Jack Willis (2024) “Retractions: Updating from Complex Information.”
- Grether, David M (1980) “Bayes rule as a descriptive model: The representativeness heuristic,” *Quarterly Journal of Economics*, 95 (3), 537–557.
- Hoppe, Eva I and David J Kusterer (2011) “Behavioral biases and cognitive reflection,” *Economics Letters*, 110 (2), 97–100.
- Hossain, Tanjim and Ryo Okui (2013) “The binarized scoring rule,” *Review of Economic Studies*, 80 (3), 984–1001.
- John, Anett and Kate Orkin (2022) “Can simple psychological interventions increase preventive health investment?” *Journal of the European Economic Association*, 20 (3), 1001–1047.

- Kahneman, Daniel and Amos Tversky (1982) *The Simulation Heuristic*, 201–208: Cambridge University Press.
- Karni, Edi and Marie-Louise Vierø (2013) ““Reverse Bayesianism”: A choice-based theory of growing awareness,” *American Economic Review*, 103 (7), 2790–2810.
- (2017) “Awareness of unawareness: A theory of decision making in the face of ignorance,” *Journal of Economic Theory*, 168, 301–328.
- Kozakiewicz, Marta (2022) “Belief-Based Utility and Signal Interpretation.”
- Krajbich, Ian, Björn Bartling, Todd Hare, and Ernst Fehr (2015) “Rethinking fast and slow based on a critique of reaction-time reverse inference,” *Nature Communications*, 6 (1), 7455.
- Li, Shengwu (2017) “Obviously strategy-proof mechanisms,” *American Economic Review*, 107 (11), 3257–3287.
- Lilley, Matthew and Brian Wheaton (2024) “Are Preconceptions Postconceptions? Evidence on Motivated Political Reasoning.”
- Martínez-Marquina, Alejandro, Muriel Niederle, and Emanuel Vespa (2019) “Failures in contingent reasoning: The role of uncertainty,” *American Economic Review*, 109 (10), 3437–74.
- Mitzkewitz, Michael and Rosemarie Nagel (1993) “Experimental results on ultimatum games with incomplete information,” *International Journal of Game Theory*, 22, 171–198.
- Ngangoué, M Kathleen and Georg Weizsäcker (2021) “Learning from unrealized versus realized prices,” *American Economic Journal: Microeconomics*, 13 (2), 174–201.
- Niederle, Muriel and Emanuel Vespa (2023) “Cognitive Limitations: Failures of Contingent Thinking,” *Annual Review of Economics*, 15, 307–328.
- Oechssler, Jörg, Andreas Roider, and Patrick W Schmitz (2009) “Cognitive abilities and behavioral biases,” *Journal of Economic Behavior & Organization*, 72 (1), 147–152.
- Paolacci, Gabriele and Quentin André (2023) “Probabilistic outcomes are valued less in expectation, even conditional on their realization,” *Management Science*.

- Pearl, Judea (2009) *Causality: Models, Reasoning and Inference*, USA: Cambridge University Press, 2nd edition.
- Piermont, Evan (2024) “Hypothetical Expected Utility.”
- Piermont, Evan and Peio Zuazo-Garin (2024) “Failures of contingent thinking.”
- Samuelson, Larry and Jakub Steiner (2024) “Constrained Data-Fitters,” *Yale University and University of Zurich, CERGE-EI, and CTS*.
- Schipper, Burkhard C (2024) “Predicting the unpredictable under subjective expected utility.”
- Schlag, Karl H, James Tremewan, and Joël J Van der Weele (2015) “A penny for your thoughts: A survey of methods for eliciting beliefs,” *Experimental Economics*, 18 (3), 457–490.
- Schotter, Andrew and Isabel Trevino (2014) “Belief elicitation in the laboratory,” *Annu. Rev. Econ.*, 6 (1), 103–128.
- (2021) “Is response time predictive of choice? An experimental study of threshold strategies,” *Experimental Economics*, 24, 87–117.
- Toussaert, Séverine (2017) “Intention-based reciprocity and signaling of intentions,” *Journal of Economic Behavior & Organization*, 137, 132–144.
- Woodford, Michael (2014) “Stochastic choice: An optimizing neuroeconomic model,” *American Economic Review*, 104 (5), 495–500.
- (2020) “Modeling imprecision in perception, valuation, and choice,” *Annual Review of Economics*, 12 (1), 579–601.
- Zultan, Ro'i, Aniol Llorente-Saguer, and Santiago Oliveros (2024) “Beyond Value: on the Role of Symmetryin Demand for Information.”

A Appendix

A.1 Bias

Table A1: Bias with SGP \times Contingency fixed effects

	I	II	III
All-Contingency	0.022* (0.009)	0.010 (0.011)	0.026 (0.013)
One-Contingency	0.038*** (0.009)	0.045*** (0.011)	0.054*** (0.015)
Asymmetric	0.014 (0.012)		
All-Contingency \times Asymmetric	0.020* (0.009)		
One-Contingency \times Asymmetric	-0.012 (0.010)		
High CRT			-0.043*** (0.009)
All-Contingency \times High CRT			-0.002 (0.017)
One-Contingency \times High CRT			-0.026 (0.017)
Constant	0.057*** (0.010)	0.061*** (0.011)	0.080*** (0.012)
<i>N</i>	6000	6000	6000
adj. <i>R</i> ²	0.027	0.028	0.056
Clusters	450	450	450

Notes. OLS estimates. Individual-level clustered standard errors. SGP \times contingency fixed effects. Contingency refers to the realized signal in *Conditional* and to the relevant contingency in *One-Contingency* and *All-Contingency*. The dependent variable is defined as the absolute value of the difference between the reported posterior and the Bayesian benchmark; * p<.05, ** p<.01, *** p<.001.

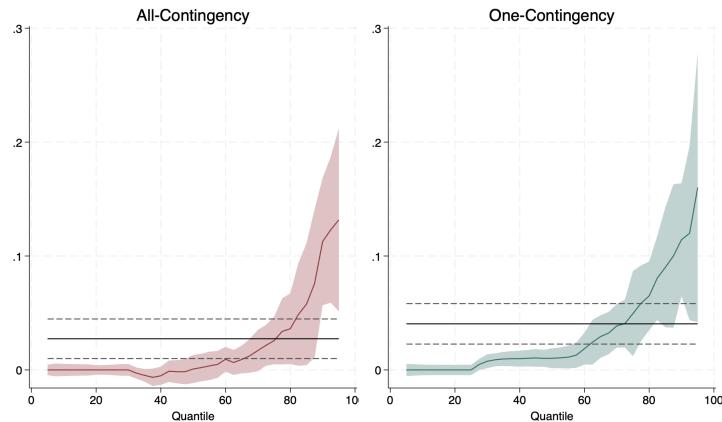


Figure A1: Bias: Quantile Regressions

Notes. Quantile regressions of the bias on treatment indicators, with *Conditional* as the baseline. Individual-level clustered standard errors. Shaded regions indicate 95% confidence intervals. Horizontal lines indicate the coefficient for the standard OLS model, with the dotted lines indicating the 95% confidence interval of the estimated coefficient.

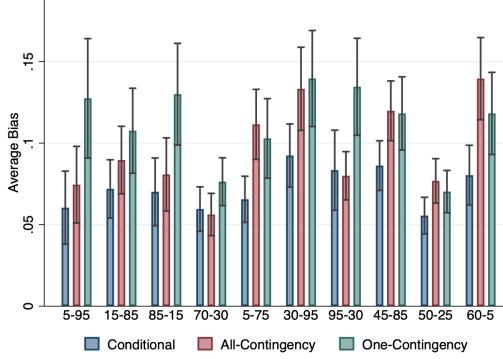


Figure A2: Treatment Effect in Bias by SGP

Notes. Each triplet of histograms represents the average bias by treatment and SGP. SGPs labels, reported on the x-axis, report the number of blue balls in the first and second bag, respectively (e.g., “5-75” indicated that for that SGP the first bag contained 5 blue balls and the second 75). Error bars indicate 95% confidence intervals.

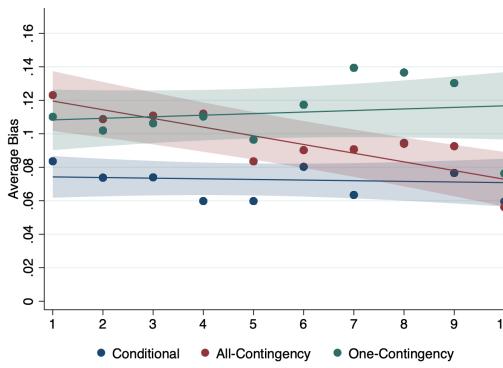


Figure A3: Trend in Average Bias by Round

Notes. Each point represents the average bias by treatment and round number. Lines indicate the linear predictions of the average bias by treatment, the shaded regions indicate 95% confidence intervals of these predictions.

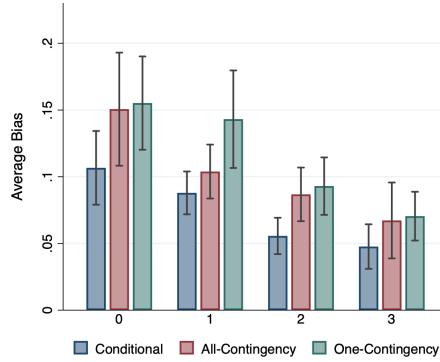


Figure A4: Treatment Effect in Bias by CRT scale

Notes. Each triplet of histograms represents the average bias by treatment and CRT level. Specifically, the latter is measured as the number of CRT questions correctly answered by participants, indicated on the x-axis label. Error bars indicate 95% confidence intervals.

Table A2: Bias and Treated as Symmetric

	I
Treated as Symmetric	-0.078*** (0.013)
Degree of Asymmetry	-0.033 (0.017)
Treated as Symmetric \times Degree of Asymmetry	0.243*** (0.036)
Constant	0.127*** (0.012)
<i>N</i>	3000
adj. R^2	0.052
Clusters	150

Notes. OLS estimates. Individual-level clustered standard errors. The dependent variable is defined as the absolute value of the difference between the reported posterior and the normative (Bayesian) benchmark; * $p < .05$, ** $p < .01$, *** $p < .001$.

A.2 Underinference

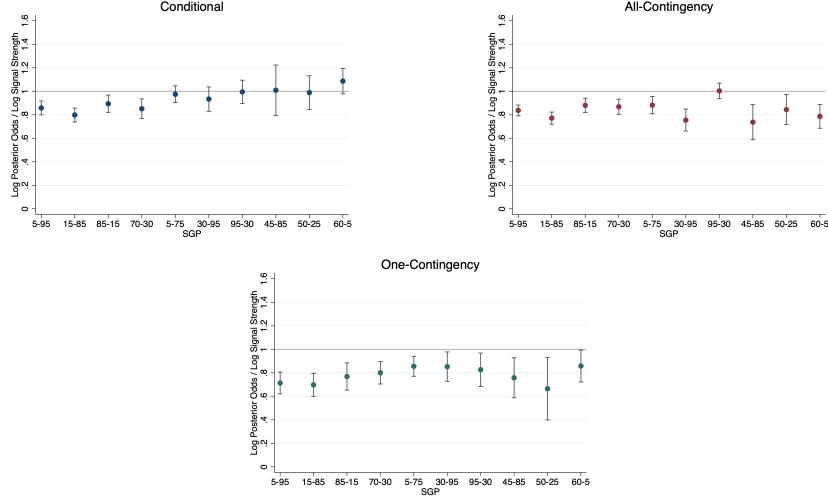


Figure A5: Underinference by SGP and Treatment

Notes. Each figure plots the estimated degree of underinference, measured as the average ratio of the reported log posterior-odds to the log signal strength for each SGP in a given treatment. The horizontal line at value one serves as the Bayesian benchmark: ratios below one indicate evidence of underinference, while ratios above one suggest evidence of overinference. Error bars indicate 95% confidence intervals.

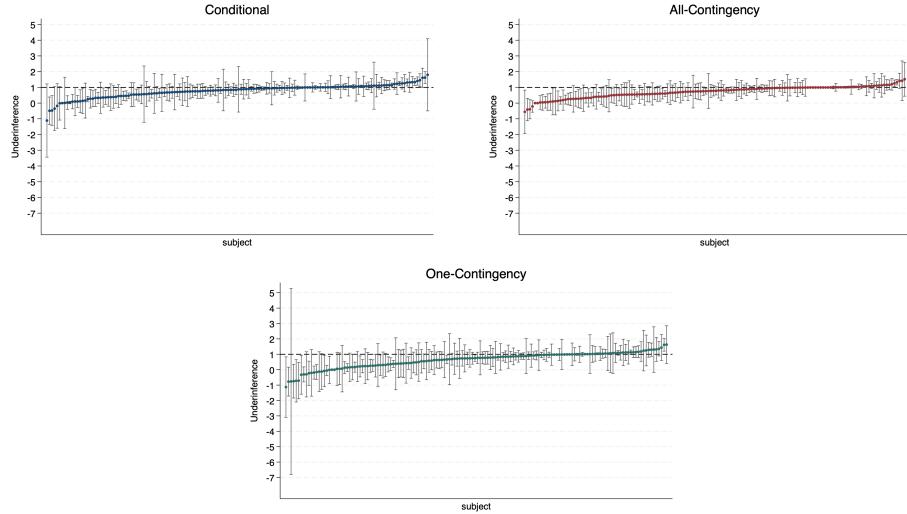


Figure A6: Underinference per Individual

Notes. Each figure plots the estimated degree of underinference, measured as the average ratio of the reported log posterior-odds to the log signal strength for each individual in a given treatment. The horizontal line at value one serves as the Bayesian benchmark: ratios below one indicate evidence of underinference, while ratios above one suggest evidence of overinference. Error bars indicate 95% confidence intervals.

A.2.1 Relative Signal Strength

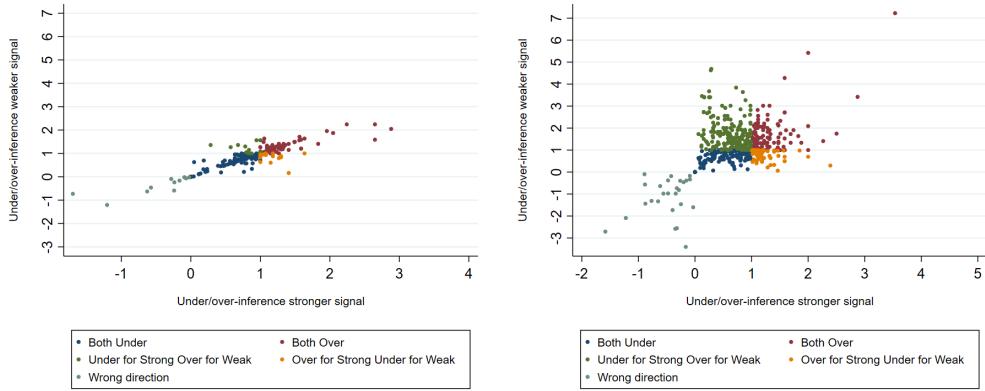


Figure A7: Relative Underinference Within Task: All-Contingency

Notes. Each point represents the estimated degree of underinference for the stronger (x-axis) and the weaker signal (y-axis), measured as the average ratio of the reported log posterior-odds to the log signal strength for each individual in a given task in *All-Contingency*; for symmetric SGPs, signals are equally diagnostic and we classified the blue ball as stronger arbitrarily.

Table A3: Relative Underinference

	I	II	III
Stronger Signal	-0.171*** (0.033)	0.021 (0.035)	-0.203*** (0.055)
All-Contingency	-0.108* (0.048)	-0.008 (0.043)	-0.075 (0.086)
One-Contingency	-0.133* (0.054)	-0.100 (0.051)	-0.103 (0.096)
Stronger Signal \times All-Contingency	0.036 (0.042)	-0.007 (0.040)	0.019 (0.075)
Stronger Signal \times One-Contingency	0.001 (0.051)	-0.012 (0.063)	-0.065 (0.086)
Asymmetric		0.274*** (0.049)	
Stronger Signal \times Asymmetric		-0.303*** (0.062)	
Stronger Signal \times All-Contingency \times Asymmetric		0.054 (0.079)	
Stronger Signal \times One-Contingency \times Asymmetric		0.003 (0.120)	
High CRT			0.108 (0.067)
Stronger Signal \times High CRT			0.063 (0.067)
Stronger Signal \times All-Contingency \times High CRT			0.019 (0.088)
Stronger Signal \times One-Contingency \times High CRT			0.104 (0.102)
Constant	1.018*** (0.033)	0.841*** (0.031)	0.962*** (0.057)
N	6000	6000	6000
adj. R ²	0.016	0.026	0.021
Clusters	450	450	450

Notes. OLS estimates. Individual-level clustered standard errors. The dependent variable is calculated as the ratio of the log posterior-odds and log signal strength for a given signal; * p<.05, ** p<.01, *** p<.001.

A.3 Individual Measures

Table A4: Individual Measures

	Time	Bias	Bias	Challenge	Bias	Log Odds
All-Contingency	18.719*** (2.913)	0.027** (0.009)	0.028** (0.010)	0.380* (0.172)	0.028* (0.013)	0.049 (0.055)
One-Contingency	3.819 (2.386)	0.041*** (0.009)	0.038*** (0.011)	0.540** (0.172)	0.055*** (0.015)	0.092 (0.115)
Time		-0.000** (0.000)	-0.000* (0.000)			
All-Contingency × Time			-0.000 (0.000)			
One-Contingency × Time			0.000 (0.000)			
High CRT				-0.043*** (0.009)	-0.001 (0.087)	
All-Contingency × High CRT					-0.002 (0.017)	-0.137 (0.116)
One-Contingency × High CRT					-0.024 (0.018)	-0.162 (0.142)
Log Signal Strength					0.683*** (0.049)	
Log Signal Strength × All-Contingency					-0.070 (0.073)	
Log Signal Strength × One-Contingency					-0.214* (0.084)	
Log Signal Strength × High CRT					0.165* (0.067)	
Log Signal Strength × All-Contingency × High CRT					-0.001 (0.093)	
Log Signal Strength × One-Contingency × High CRT					0.120 (0.108)	
Constant	33.330*** (3.179)	0.069*** (0.008)	0.069*** (0.009)	4.407*** (0.122)	0.085*** (0.010)	0.199*** (0.067)
N	6000	6000	6000	6000	6000	6000
adj. R^2	0.037	0.027	0.027	0.016	0.053	0.262
Clusters	450	450	450	450	450	450

Notes. OLS estimates. Individual-level clustered standard errors. SGP fixed effects. The dependent variable in Column I is the response time measured in seconds, in Column II, III and V the absolute bias, in Column IV the perceived degree of being challenged, and in Column VI the logarithm of the ratio of the elicited posterior belief for a given signal; * p<.05, ** p<.01, *** p<.001.

A.4 Additional Measures

A.4.1 Within-Consistency

To construct the within-consistency measure in our dataset, we proceed as follows.

First, for each pair of mirrored SGPs, all posteriors were reported in terms of one SGP (15-85 for symmetric and 30-95 for asymmetric). Second, we keep only the observation for which we can construct this measure. In *Conditional* and *One-Contingency*, the desired measure could only be constructed if the participant's posterior was elicited for the *same* signal for both mirrored SGPs (approximately in half of all cases, for each color of the ball). In *All-Contingency*, participants' beliefs are always elicited conditional on both signals for each SGP. Therefore, we keep 156 and 148 observations, respectively, in *Conditional* and in *One-Contingency*, and 600 in *All-Contingency*. Third, we calculate the difference between the posteriors conditional on the same signal. For any signal s and for any two mirrored SGPs M1 and M2, the dependant variable is defined as

$$\Delta \text{Posteriors} = |\Pr^{M1}(A|s) - \Pr^{M2}(A|s)|.$$

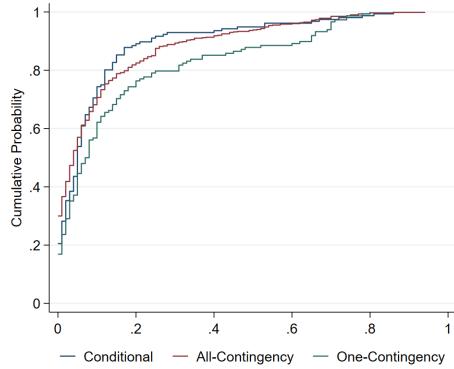


Figure A8: Cumulative Distribution of Δ Posteriors

A.4.2 Between-Consistency

To construct the between-consistency measure, we look at vectors of posteriors: $(\Pr(A|\text{blue}), \Pr(A|\text{orange}))$. Given the method of belief elicitation, these are available for all SGPs in *All-Contingency*. For *Conditional* and *One-Contingency*, we construct the vectors of posteriors exploiting the mirrored SGPs as follows.

First, for each pair of mirrored SGPs, all posteriors were reported in terms of one SGP (15-85 for symmetric and 30-95 for asymmetric). This part overlaps

with the construction of Δ Posteriors. Then, we keep only the observations of the participants whose posteriors were elicited conditional on the *different* signal realizations for the mirrored SGPs (around half of the times, for each color of the ball). Therefore, we have 144 and 152 observations, respectively, in *Conditional* and in *One-Contingency*, and 600 in *All-Contingency*.

Distance from Bayesian Vector of Posteriors We complement our between-consistency analysis by examining a more nuanced measure. We calculate the squared distance between the reported vector of posteriors and the Bayesian one:

$$\text{Distance} = \sqrt{\left(\Pr(A|\text{blue}) - \hat{\Pr}(A|\text{blue})\right)^2 + \left(\Pr(A|\text{orange}) - \hat{\Pr}(A|\text{orange})\right)^2}.$$

The results presented in Table A5 align with the findings of Section 4.3.2.

Table A5: Distance

	I	II
All-Contingency	0.022 (0.019)	0.009 (0.014)
One-Contingency	0.067** (0.025)	0.042* (0.021)
Constant	0.149*** (0.015)	0.116*** (0.011)
<i>N</i>	896	817
adj. <i>R</i> ²	0.016	0.013
Clusters	375	360

Notes. OLS estimates. Individual-level clustered standard errors. SGP symmetry fixed effects. The dependent variable is defined as the squared distance between the reported posterior and the Bayesian benchmark. Column I includes all samples of vectors of posteriors, while Column II excludes vectors of posteriors that are not Bayes-consistent. * p<.05, ** p<.01, *** p<.001.

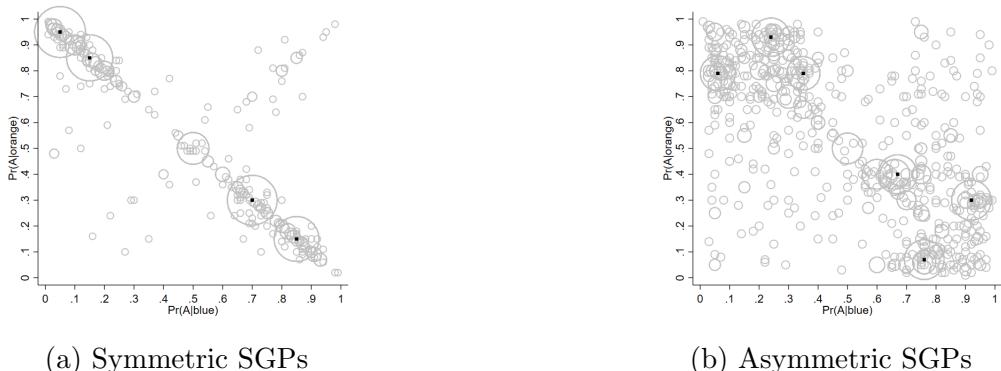


Figure A9: Vector of Posteriors: All-Contingency

Notes. Each circle represents the frequency of the corresponding vector of posterior beliefs in a given task across SGPs: the bigger the circle, the higher the frequency. Each black square corresponds to the Bayesian vector of posteriors associated with an SGP.

Online Appendix 1 Alternative Measures

Online Appendix 1.1 Overinference as in Ba et al. (2022)

Ba et al. (2024) introduce an alternative measure of underinference, which we use as a dependent variable as a robustness check. Their measure is defined in terms of overinference in the following manner. For a contingency-specific reported guess $\hat{\Pr}(A|s)$, the ratio used is defined as:

$$\frac{|\hat{\Pr}(A|s) - 0.5| - |\Pr(A|s) - 0.5|}{|\Pr(A|s) - 0.5|}$$

The higher the ratio, the higher the degree of observed overinference.

Table A1 replicates our main analysis using this ratio as a dependent variable.

Table A1: Overinference as defined in Ba et al. (2024)

	I	II	III
All-Contingency	-0.039 (0.023)	-0.006 (0.026)	-0.015 (0.034)
One-Contingency	-0.084** (0.026)	-0.051 (0.027)	-0.084 (0.045)
Asymmetric		0.129*** (0.026)	
All-Contingency \times Asymmetric		-0.055* (0.026)	
One-Contingency \times Asymmetric		-0.055 (0.028)	
High CRT			0.050 (0.033)
All-Contingency \times High CRT			-0.046 (0.046)
One-Contingency \times High CRT			-0.003 (0.053)
Constant	-0.074*** (0.018)	-0.098*** (0.019)	-0.100*** (0.027)
<i>N</i>	6000	6000	6000
adj. <i>R</i> ²	0.033	0.033	0.034
Clusters	450	450	450

Notes. OLS estimates. Individual-level clustered standard errors. The dependent variable is calculated as the difference of the absolute distances of (i) the elicited posterior and prior and, (ii) the Bayesian posterior and the prior, divided by the absolute difference of the Bayesian posterior and the prior; * p<.05, ** p<.01, *** p<.001.

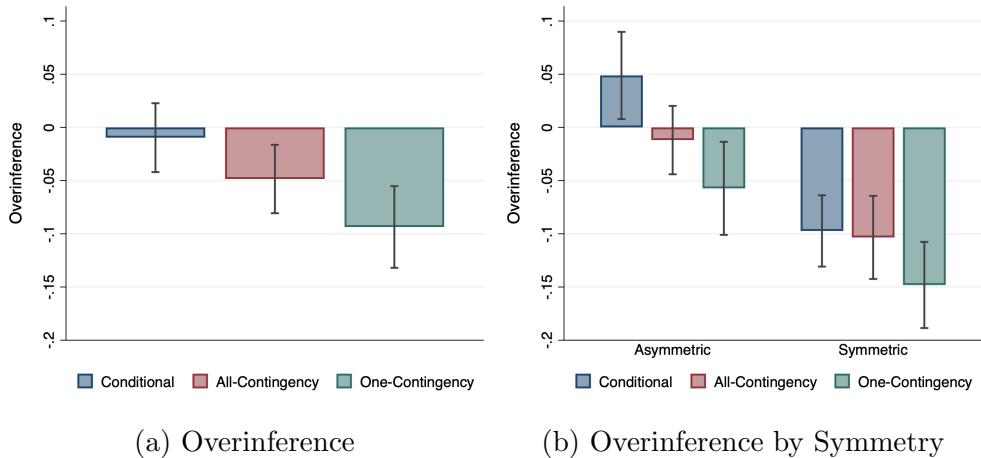


Figure A1: Overinference (Ba et al., 2024) by Treatment and Symmetry

Notes. Panel (a) shows the average overinference, defined as the difference of the absolute distances of (i) the elicited posterior and prior and, (ii) the Bayesian posterior and the prior, divided by the absolute difference of the Bayesian posterior and the prior, by treatment. Panel (b) shows this average overinference measure by treatment and symmetry of the SGP. Error bars indicate 95% confidence intervals, clustered at the individual level.

Online Appendix 1.2 Alternative Degree of Asymmetry

This section proposes an alternative measure of the degree of asymmetry and replicates the findings in the main text using this measure.

An alternative measure of degree of asymmetry for an SGP can be quantified by the absolute distance between the posterior across signals and bags:

$$|\Pr(A|s) - \Pr(B|s')|.$$

This difference is always zero for symmetric SGPs, and positive for asymmetric SGPs. The larger the difference in posteriors, the more asymmetric the SGP.

These two measures are conceptually similar, but not identical. The main difference is that this measure also captures the role of the prior, even if this is not relevant with equal prior. Another difference is that the measure used in the text better captures relative differences rather than absolute ones.

Table A2: Bias and Underinference with Alternative Measure of Asymmetry

	I	II
All-Contingency	0.010 (0.010)	0.012 (0.068)
One-Contingency	0.041*** (0.011)	0.044 (0.089)
Alternative Degree of Asymmetry	0.098* (0.041)	2.756*** (0.554)
All-Contingency \times Alternative Degree of Asymmetry	0.154** (0.055)	-0.336 (0.715)
One-Contingency \times Alternative Degree of Asymmetry	-0.006 (0.063)	-0.435 (0.921)
Log Signal Strength		0.886*** (0.038)
Log Signal Strength \times All-Contingency		-0.023 (0.052)
Log Signal Strength \times One-Contingency		-0.152* (0.069)
Log Signal Strength \times Alternative Degree of Asymmetry		-1.268*** (0.354)
Log Signal Strength \times All-Contingency \times Alternative Degree of Asymmetry		-0.408 (0.441)
Log Signal Strength \times One-Contingency \times Alternative Degree of Asymmetry		0.218 (0.592)
Constant	0.064*** (0.006)	-0.067 (0.054)
<i>N</i>	6000	6000
adj. <i>R</i> ²	0.020	0.256
Clusters	450	450

Notes. OLS estimates. Individual-level clustered standard errors. The dependent variable is defined as the absolute value of the difference between the reported posterior and the Bayesian benchmark in Column I and as the ratio of the log posterior-odds and log signal strength for a given signal in Column II; * p<.05, ** p<.01, *** p<.001.

Online Appendix 2 Expert Survey

Online Appendix 2.1 Survey Design & Data Collection

Our expert survey has three parts. First, we provide all relevant information on the experiment. The survey began with a short description of the goal of the study for which participants were asked to report predictions. After consenting to participate in our survey, we clarified that the experiment was already preregistered but not run yet; we informed the experts that the preregistration link was available at the end of the survey. Then, they read a detailed description of our experimental design. To keep the survey brief and focused on our main objective, we only describe two treatments: *Conditional* and *All-Contingency*. The survey participants could access further details on the design in linked documents, such as the instructions and control questions of these two treatments and information on the used SGPs. We also include information about the target sample, randomization, and incentives. Finally, we highlight as the key outcome of interest the bias as defined in Section 4.

In the second part, we elicited the experts' predictions. This was followed by two sets of questions. First, we elicited the expected direction of the treatment effect: the participants reported whether they expected the bias in *Conditional* to be significantly smaller, higher, or not statistically significant than in *All-Contingency*. The participants also reported their confidence (1-7 scale) in their answers. Second, we elicited the participants' opinions on the heterogeneity of the treatment effect along two dimensions: CRT and the symmetry of SGPs. Also, for this set of questions, the participants reported their confidence in their previous answers (1-7 scale). Finally, the participants were asked how they classify their research (theoretical, experimental, and/or empirical). The pre-registration link was also available on the final screen.

The Qualtrics survey was distributed in February 2023 using the Social Science Prediction Platform (Study ID: sspp-2023-0007-v1) by invitation (the survey was not publicly accessible). We compiled a distribution list including researchers that we considered knowledgeable about topics related to expectations or contingent thinking for a total of 135 experts. We purposefully excluded colleagues who were aware of pilot results through conversations with us.

Online Appendix 2.2 Predictions

Sample In total, we gathered 38 responses (28% completion rate). Our final sample includes 17 faculty members, 6 postdocs, and 12 PhD students (with 3 participants not reporting their position). 89% described their research as experimental, 29% as theoretical, and 26% as empirical (these categories were not mutually exclusive). 83% include behavioral economics as one of their main fields; other fields include experimental economics, microeconomics theory, game theory, development economics, and political economics, among others.

Main Prediction Figure B1a illustrates how experts expect the bias in *Conditional* to change compared to *All-Contingency*. Compared to Conditional, 14 participants predicted a significantly smaller bias in *All-Contingency*, and only one predicted a significantly higher bias in *All-Contingency*. 23 experts predicted no significant difference between *Conditional* and *All-Contingency*. These percentages do not vary much depending on the research field. Also, there does not seem to be a difference in confidence in the expected direction of the treatment, as shown in Figure B1b.

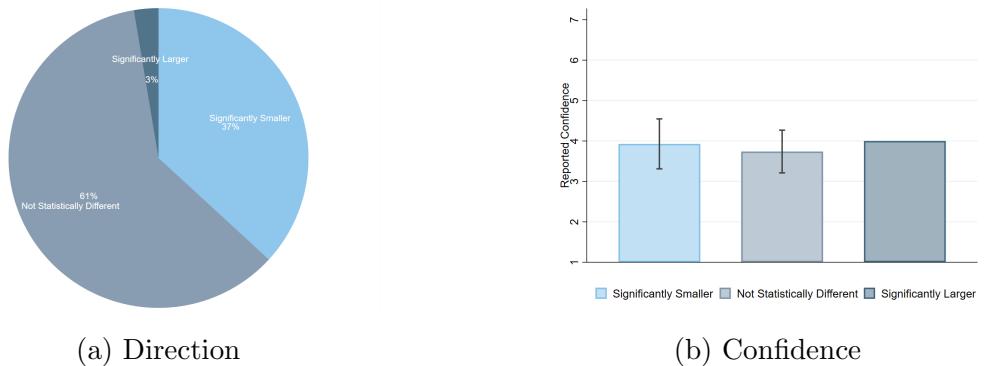


Figure B1: Main Prediction

Notes. Panel (a) shows the shares of experts predicting a significantly higher, significantly lower, and no significantly different bias in *All-Contingency* compared to *Conditional*. Panel (b) shows for each possible prediction the confidence of the experts in their answers on a Likert scale (1-7).

Heterogeneous Effect of SGP Symmetry In Figure B2a, we report the expectations of the change in the bias for symmetric SGPs compared to the change for asymmetric SGPs. 58% predicted no significant difference in the change in the bias between asymmetric and symmetric SGPs. 26% expects a significantly higher change in the bias and 16% expects a significantly lower change in the bias for asymmetric SGPs compared to symmetric SGPs. The predictions do not seem different by the expected treatment effect (Figure B3).

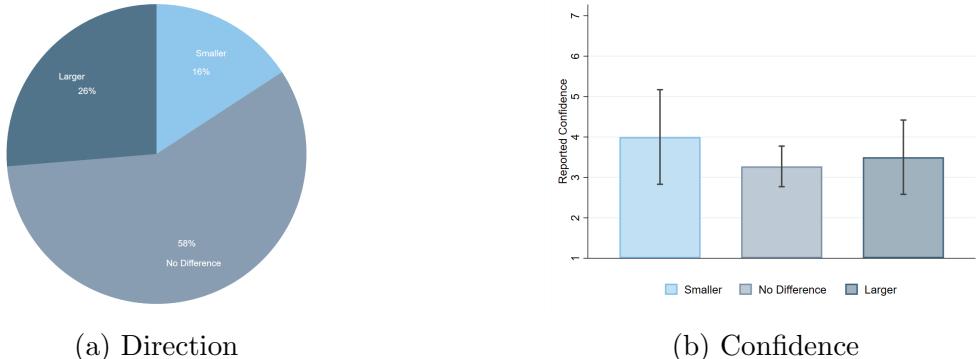


Figure B2: Prediction about SGP Symmetry

Notes. Panel (a) shows the shares of experts predicting a significantly higher change in the bias, a significantly lower change in the bias, and no significantly different change in the bias for asymmetric compared to symmetric SGPs. Panel (b) shows for each possible prediction the confidence of the experts in their answers on a Likert scale (1-7).

Heterogeneous Effect of CRT Figure B4a summarizes how participants expect the change in bias for individuals who score low on the CRT to vary compared to individuals who score high on the CRT. 55% predicted no significant difference in the change in the bias between individuals who scored low and high on the CRT. 29% expect a significantly smaller change in the bias, and 16% expect a higher change in the bias for individuals with high CRT scores compared to individuals with low CRT scores. The predictions do not seem different from the expected treatment effect (Figure B5).

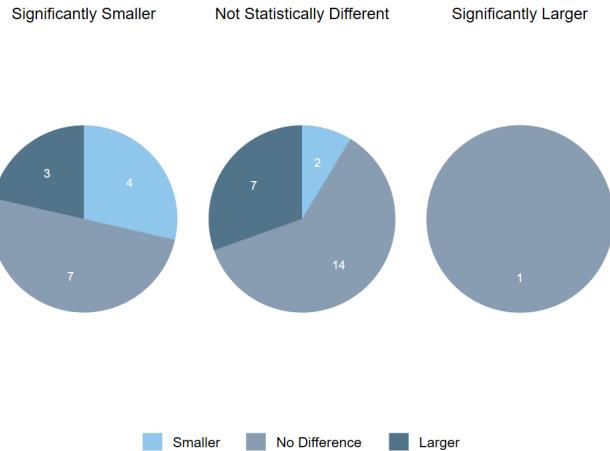


Figure B3: Prediction about SGP Symmetry, by Expected Treatment Effect

Notes. Shares of experts predicting a significantly higher change in the bias, a significantly lower change in the bias, and no significantly different change in the bias for asymmetric compared to symmetric SGPs by possible answers on the expected treatment effect.

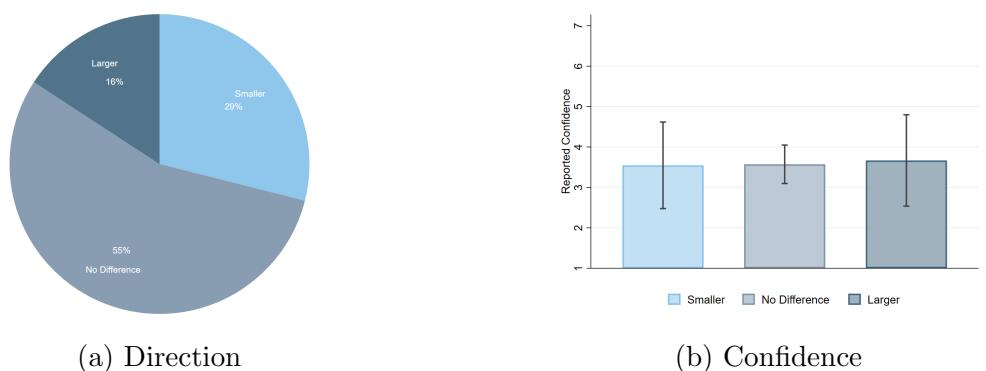


Figure B4: Prediction about CRT

Notes. Panel (a) shows the shares of experts predicting a significantly higher change in the bias, a significantly lower change in the bias, and no significantly different change in the bias for individuals with high compared to low CRT. Panel (b) shows for each possible prediction the confidence of the experts in their answers on a Likert scale (1-7).

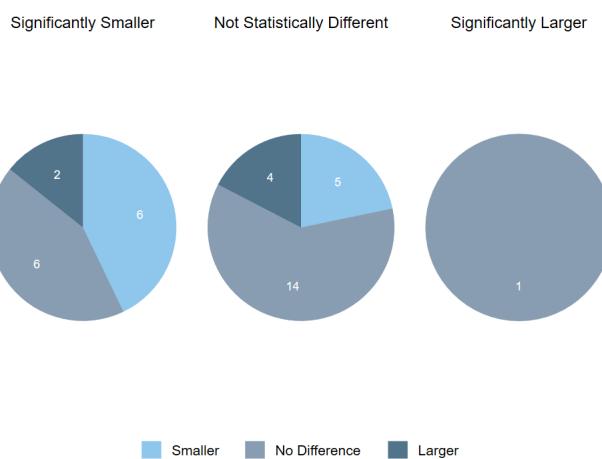


Figure B5: Prediction about CRT, by Expected Treatment Effect

Notes. Shares of experts predicting a significantly higher change in the bias, a significantly lower change in the bias, and no significantly different change in the bias for individuals with high compared to low CRT by possible answers on the expected treatment effect.

Online Appendix 3 Instructions & Interface

Online Appendix 3.1 Instructions

Online Appendix 3.1.1 General Instructions

WELCOME!

Thank you for participating in this study. You are guaranteed to receive GBP 2 for completing the study. If you follow the instructions carefully, you may earn an additional bonus of GBP 2, as explained later. Your earnings will depend on your decisions and chance.

Please read the instructions carefully. **There will be two checks of your understanding of these instructions, for which you have three attempts.** If you provide three incorrect answers in either set of these questions about the instructions, you will not be eligible for a bonus payment. You always have to complete the study to receive the guaranteed payment.

There will be two parts to the experiment. The first part is the main part of the experiment and will take up most of the time. The second part will be introduced after you have finished the first part. In total, this study should take around 30 minutes.

PART ONE

In the first part, you will be asked to make a series of choices that can impact your bonus payment. Most of these choices will be of a similar format: You have to guess the chance that a bag was selected based on the available information.

In each task, you are asked to consider two bags, bag A and bag B. In each bag, there are several balls. The total number of balls can be either 60 or 80. The balls are either **orange** or **blue**. The number of **orange** and **blue** balls in each bag varies across tasks. You will be informed about the number of **orange** and the number of **blue** balls in each bag.

The task proceeds as follows:

- You start by clicking 'Select the bag'.
- The computer randomly flips a **fair coin** to select bag A or bag B. It is **equally likely** that the computer selects bag A or bag B.
- You do not know whether bag A or bag B was selected.
- When you click 'Draw the ball', the computer draws either an **orange** ball or a **blue** ball from the selected bag.
- The computer draws one ball from the selected bag.

Your task is to guess the chance (in %) that the computer chose bag A or bag B.

You will repeat this task ten times. For each task, the computer selects a new bag and then draws a new ball from the selected bag. **So you should think about which bag was selected in each task independently of all other tasks.**

Online Appendix 3.1.2 Control Questions 1

TESTING YOUR UNDERSTANDING OF THE INSTRUCTIONS

On the slider, please indicate the chance (in %) that a fair coin flip selects bag A.

Chance of bag A (in %): Please click on the slider

When you click 'Draw the ball', the computer draws a ball from the previously selected bag.

True

False

When you click 'Draw the ball', you know which bag was previously selected.

True

False

Online Appendix 3.1.3 Conditional Instructions

YOUR CHOICE

The computer draws either an **orange** ball or a **blue** ball. You observe the color of the ball.
You will be asked to guess the chance that the ball was drawn from bag A or bag B.

You make your guess by selecting the chance between 0% and 100%. Higher numbers mean that you think it is more likely that this bag was selected. The guess for the chance that the ball was drawn from bag A and the chance that the ball was drawn from bag B will automatically sum up to 100%.

YOUR CHOICE: EXAMPLE

This is an example of the task. It is not relevant for your payment. Please familiarize yourself with the interface, then proceed with the instructions. **You can hover over the elements of the screen to see the explanations of each part of the screen.**

Remember:

- Bag A** contains **60 blue balls** and **40 orange balls**.
- Bag B** contains **40 blue balls** and **60 orange balls**.

Make your guesses below.

A **blue ball** was drawn.

What is the chance (in %) that the ball was drawn from each bag?

Chance of bag A (in %): **Click on the slider**

Chance of bag B (in %): **Click on the slider**

PAYMENT

For your bonus payment, one of the ten tasks will be randomly selected for payment.
Your bonus payment will depend on your guesses in the selected task. Your guesses do not influence which task is selected for payment.

We have carefully chosen the payment rule such that you maximize the chance of winning a bonus of GBP 2 if you give your best guesses in all questions. To maximize the chance of winning the bonus, **it is in your best interest to always give a guess that you think is the true chance. The closer your guess is to the true chance, the higher is your probability of receiving the bonus.** If you are interested, further details on the payment are provided here.

► [Click here for further details](#)

Online Appendix 3.1.4 All-Contingency Instructions

YOUR CHOICE

The computer draws either an **orange** ball (case **orange**) or a **blue** ball (case **blue**). You do not observe the color of the ball when making your guesses.

For each of the two possible cases (orange and blue), you will be asked to guess the chance that the ball was drawn from bag A or bag B.

For each case, you make your guess by selecting the chance between 0% and 100%. Higher numbers mean that you think it is more likely that this bag was selected. The guesses for the chance that the ball was drawn from bag A and the chance that the ball was drawn from bag B will automatically sum up to 100%.

YOUR CHOICE: EXAMPLE

This is an example of the task. It is not relevant for your payment. Please familiarize yourself with the interface, then proceed with the instructions. **You can hover over the elements of the screen to see the explanations of each part of the screen.**

Remember:

Bag A contains **60 blue balls** and **40 orange balls**.

Bag B contains **40 blue balls** and **60 orange balls**.

Make your guesses below for **Case Blue** and **Case Orange**.

Case Orange:

Suppose the computer drew an **orange ball**

What is the chance (in %) that the ball was drawn from each bag?

Chance of **bag A** (in %): Click on the slider

Chance of **bag B** (in %): Click on the slider

Case Blue:

Suppose the computer drew a **blue ball**

What is the chance (in %) that the ball was drawn from each bag?

Chance of **bag A** (in %): Click on the slider

Chance of **bag B** (in %): Click on the slider

PAYMENT

For your bonus payment, one of the ten tasks will be randomly selected for payment.
Your bonus payment will depend on your guesses in the selected task. Your guesses do not influence which task is selected for payment.

We have carefully chosen the payment rule such that you maximize the chance of winning a bonus of GBP 2 if you give your best guesses in all questions. To maximize the chance of winning the bonus, **it is in your best interest to always give a guess that you think is the true chance. The closer your guess is to the true chance, the higher is your probability of receiving the bonus.** If you are interested, further details on the payment are provided here.

► [Click here for further details](#)

You are asked about your guesses for case **orange** and case **blue**. Depending on the color of the ball drawn from the bag, only your guesses for that case will matter for your bonus payment. As you do not know the color of the ball when making your guess, it is therefore in **your best interest to give your best guesses for each case.**

As an example, imagine that the computer draws a **blue** ball. Then, only your guesses for case **blue** matter for your bonus payment.

Online Appendix 3.1.5 One-Contingency Instructions

YOUR CHOICE

The computer draws either an **orange** ball (case **orange**) or a **blue** ball (case **blue**). You do not observe the color of the ball when making your guesses.

You will be asked to guess the chance that the ball was drawn from bag A or bag B for one of the two possible cases (**orange** or **blue**). It is equally likely that you will be asked about each case. This does not depend on the actual color of the ball drawn by the computer.

You make your guess by selecting the chance between 0% and 100%. Higher numbers mean that you think it is more likely that this bag was selected. The guess for the chance that the ball was drawn from bag A and the chance that the ball was drawn from bag B will automatically sum up to 100%.

YOUR CHOICE: EXAMPLE

This is an example of the task. It is not relevant for your payment. Please familiarize yourself with the interface, then proceed with the instructions. You can hover over the elements of the screen to see the explanations of each part of the screen.

Remember:

Bag A contains **60 blue balls** and **40 orange balls**.
Bag B contains **40 blue balls** and **60 orange balls**.

Make your guesses below.

Suppose the computer drew a **blue ball**.

What is the chance (in %) that the ball was drawn from each bag?

Chance of bag A (in %): Click on the slider

Chance of bag B (in %): Click on the slider

PAYMENT

For your bonus payment, one of the ten tasks will be randomly selected for payment.
Your bonus payment will depend on your guesses in the selected task. Your guesses do not influence which task is selected for payment.

We have carefully chosen the payment rule such that you maximize the chance of winning a bonus of GBP 2 if you give your best guesses in all questions. To maximize the chance of winning the bonus, **it is in your best interest to always give a guess that you think is the true chance. The closer your guess is to the true chance, the higher is your probability of receiving the bonus.** If you are interested, further details on the payment are provided here.

► [Click here for further details](#)

You are asked about your guess for one case, either case **orange** or case **blue**. If the color of the ball drawn from the bag matches the case you considered **your guess matters for your bonus**. Otherwise, you will receive a fixed payment of GBP 1. As you do not know the color of the ball when making your guess, it is therefore in **your best interest to give your best guess**.

As an example, imagine that you are asked about case **orange**. If an **orange** ball was drawn, your guess matters for the bonus payment. If a **blue** ball was drawn, you receive the fixed payment.

Online Appendix 3.1.6 Control Questions 2

TESTING YOUR UNDERSTANDING OF THE INSTRUCTIONS

The bonus payment will be implemented for one randomly selected task.

True

False

It is in your best interest to give your best guess of the chance that the ball was drawn from bag A or bag B.

True

False

We will ask you about the guess of the chance that the ball was drawn from bag A or bag B

before you get to know the color of the ball.

once you get to know the color of the ball.

Online Appendix 3.2 Task Interface

Online Appendix 3.2.1 Conditional

Part One: Task 1/10

Please click on the right arrow if you are ready to proceed to the next task.



Bag A contains **9 orange balls** and **51 blue balls**.
Bag B contains **51 orange balls** and **9 blue balls**.

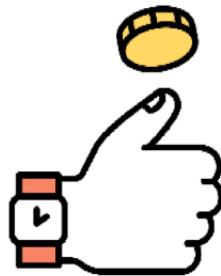


Next:

The computer randomly selects one bag by flipping a fair coin.

Select the bag

Flipping the coin to select the bag...



The coin was flipped and a bag was selected.



Next:

The computer will draw a ball from the bag that was previously selected.

[Draw the ball](#)

The computer draws a random ball from the bag that was previously selected...



Remember:

Bag A contains **9 orange balls** and **51 blue balls**.
Bag B contains **51 orange balls** and **9 blue balls**.

Make your guesses below.

A blue ball was drawn.

What is the chance (in %) that the ball
was drawn from each bag?

Chance of bag A (in %): Click on the slider

Chance of bag B (in %): Click on the slider

Online Appendix 3.2.2 All-Contingency

Part One: Task 1/10

Please click on the right arrow if you are ready to proceed to the next task.



Bag A contains **42 orange balls** and **18 blue balls**.
Bag B contains **3 orange balls** and **57 blue balls**.

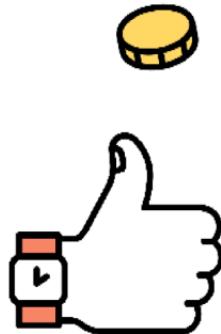


Next:

The computer randomly selects one bag by flipping a fair coin.

Select the bag

Flipping the coin to select the bag...



The coin was flipped and a bag was selected.



Next:

The computer will draw a ball from the bag that was previously selected.

[Draw the ball](#)

The computer draws a random ball from the bag that was previously selected...



Remember:

Bag A contains **42 orange balls** and **18 blue balls**.

Bag B contains **3 orange balls** and **57 blue balls**.

Make your guesses below for **Case Blue** and **Case Orange**.

Case Orange:

Suppose the computer drew an **orange ball**.

What is the chance (in %) that the ball
was drawn from each bag?

Chance of bag A (in %): Click on the slider

Chance of bag B (in %): Click on the slider

Case Blue:

Suppose the computer drew a **blue ball**.

What is the chance (in %) that the ball
was drawn from each bag?

Chance of bag A (in %): Click on the slider

Chance of bag B (in %): Click on the slider

An **orange ball** was drawn.



Online Appendix 3.2.3 One-Contingency

Part One: Task 1/10

Please click on the right arrow if you are ready to proceed to the next task.



Bag A contains **68 orange balls** and **12 blue balls**.
Bag B contains **12 orange balls** and **68 blue balls**.

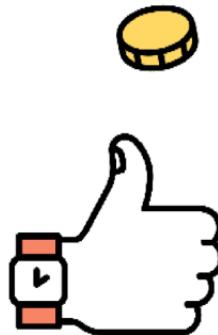


Next:

The computer randomly selects one bag by flipping a fair coin.

Select the bag

Flipping the coin to select the bag...



The coin was flipped and a bag was selected.



Next:

The computer will draw a ball from the bag that was previously selected.

[Draw the ball](#)

The computer draws a random ball from the bag that was previously selected...



Remember:

- Bag A** contains **68 orange balls** and **12 blue balls**.
- Bag B** contains **12 orange balls** and **68 blue balls**.

Make your guesses below.

Suppose the computer drew an orange ball.

What is the chance (in %) that the ball
was drawn from each bag?

Chance of bag A (in %): Click on the slider

Chance of bag B (in %): Click on the slider

A blue ball was drawn.



Online Appendix 3.3 Modified Cognitive Reflection Test

We modified the original version of the Cognitive reflection test (Frederick, 2005) to avoid previous experiences or cheating, asking the following three questions.

1. Milk and a cookie cost GBP 3.20 in total. Milk costs GBP 2 more than the cookie. How much does the cookie cost?
2. If it takes 50 workers 50 minutes to pick 50 apples, how long would it take 1000 workers to pick 1000 apples?
3. A runner doubles the number of kilometers he runs every month. After one year, he runs a marathon, 42 km. After how many months did he run a half marathon, 21 km?