Delusion-Like Beliefs and Data Quality: Are Classic Cognitive Biases Artefacts of Carelessness?

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We have no conflicts of interest to disclose. An online repository of data, materials, analyses and preregistrations is at <https://osf.io/fvkcq>. Correspondence concerning this article should be addressed to Justin Sulik, Cognition Values & Behaviour LMU, Gabelsbergerstr 26, Munich 81333, Germany. Email: justin.sulik@gmail.com.

Abstract

There is widespread agreement that delusions in clinical populations and delusion-like beliefs in the general population are, in part, caused by cognitive biases. Much of the evidence comes from two influential tasks: the Beads Task and the Bias Against Disconfirmatory Evidence (BADE) Task. However, research using these tasks has been hampered by conceptual and empirical inconsistencies. In an online study, we examined relationships between delusion-like beliefs in the general population and reasoning biases associated with these tasks. Our study had four key strengths: a new animated Beads Task designed to reduce task miscomprehension, several data-quality checks to identify careless responders, a large sample ($n = 1,002$), and a pre-registered analysis plan. When analysing the full sample, our results replicated classic relationships between cognitive biases and delusion-like beliefs. However, when we removed 82 careless participants from the analyses (8.2% of the sample) we found that these relationships were severely diminished and, in many cases, disappeared entirely. These results suggest that seemingly well-established relationships between cognitive biases and delusion-like beliefs might be artefacts of careless responding.

Keywords: *Beads Task; bias against disconfirmatory evidence (BADE); cognitive bias; continuum model; delusion; jumping to conclusions (JTC)*

General Scientific Summary (GSS)

Research suggests that cognitive biases play a key role in the development of delusion-like beliefs. For instance, participants who endorse such beliefs have been reported to “jump to conclusions” when performing abstract data-gathering tasks and to display a “bias against disconfirmatory evidence” when determining the best explanation for a scenario. However, the present study suggests that seemingly well-established relationships between cognitive biases and delusion-like beliefs might, in fact, be spurious—driven by careless responding by a subset of research participants.

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Research points to the existence of a psychosis continuum such that clinical delusions in patients with psychotic disorders appear in less severe forms as delusion-like beliefs in the general population (Linscott & van Os, 2013; van Os et al., 2009). Moreover, a large body of evidence suggests that cognitive biases are implicated in the development and maintenance of delusions are also involved in delusion-like beliefs (Dudley et al., 2016; Livet et al., 2020; McLean et al., 2017; Ross et al., 2015; So et al., 2016). However, there is reason to be cautious when interpreting this research. Notably, much of the evidence for an association between cognitive biases, delusions and delusion-like beliefs comes from research using two influential tasks—the Beads Task and the bias against disconfirmatory evidence (BADE) Task—but as we shall argue, this research suffers from a range of conceptual and empirical issues.

In the Beads Task (Huq et al., 1988), participants are shown two urns filled with beads in complementary colours: for instance, one labelled “mainly pink” and the other labelled “mainly green”. The experimenter hides the urns and ostensibly draws beads from one of them. After each draw, participants are asked if they are ready to guess which urn the beads are being drawn from or if they would like to see another bead. Three cognitive biases have been identified using this task. First, delusions and delusion-like beliefs are associated with requesting fewer beads before making a decision about which urn the beads are being drawn from, suggesting a “jumping to conclusions” (JTC) bias (Dudley et al., 2016; McLean et al., 2017; Ross et al., 2015; So et al., 2016). Second, when participants are asked to rate how likely it is that the beads are coming from each urn after each successive draw, delusions and delusion-like beliefs are associated with “overadjusting” to a newly revealed bead that contradicts the previously favoured hypothesis, suggesting an “overadjustment bias” (Garety

et al., 1991; Rodier et al., 2011). Third, when participants are asked to rate their confidence in their decision about which urn the beads are being drawn from once they have made the decision to stop drawing beads, delusions and delusion-like beliefs are associated with relatively low subjective confidence, suggesting a “liberal acceptance bias” (Moritz et al., 2006; Moritz et al., 2007).

In the BADE Task (Woodward et al., 2006), participants read four competing explanations of a scenario. At each stage of the task, they are provided with additional information about the scenario and are asked to rate the plausibility of the competing explanations: two “lure” explanations which initially seem plausible, but become less plausible as more information is revealed; a “true” explanation which becomes the most plausible as more information is revealed; and an “absurd” explanation which is consistently implausible. Two cognitive biases are routinely studied using this task. First, delusions and delusion-like beliefs have been associated with favouring the initially plausible lure explanations even as evidence against them mounts, suggesting a “bias against disconfirmatory evidence” (BADE, (McLean et al., 2017; Menon et al., 2013). Second, delusions and delusion-like beliefs have been associated with overrating the plausibility of the absurd explanation, also termed “liberal acceptance bias” (Woodward et al., 2006).

A point of concern with this research is that appeals to cognitive biases as drivers of delusions and delusion-like beliefs lack explanatory depth. For instance, it has been argued that “portrayal of people with delusions as having a JTC bias is a redescription rather than an explanation” (Corlett & Fletcher, 2014, p. 399). An analogous criticism can be applied to the other aforementioned biases. For example, that people with delusions display a bias against disconfirmatory evidence seems true almost by definition—the American Psychiatric Association defines delusions as “fixed beliefs that are not amenable to change in light of

conflicting evidence” (APA, 2013, p. 87). One potential path forward is to situate proposed cognitive biases within a cognitive model of information processing (Coltheart, 2012).

Dual process theories of thinking are among the most influential cognitive models in cognitive science. These theories distinguish two broad types of thinking (Evans & Stanovich, 2013): Type 1 or “intuitive” processing, which is typically relatively fast and effortless, and which has been characterised as a “machine for jumping to conclusions” (Kahneman, 2011, p. 79); and Type 2 or “analytic” processing, which is typically relatively slow and effortful. It has been proposed that dual process theories provide a useful cognitive model for understanding delusions (Aimola Davies & Davies, 2009; Bronstein, Pennycook, Joormann, et al., 2019; Freeman et al., 2014; Ross et al., 2016). In particular, people with delusions and delusion-like beliefs may fail to critically engage effortful Type 2 analytic processing to evaluate the outputs of Type 1 intuitive processing. Supporting this proposal, poor performance on a test of analytic thinking has been associated with (i) schizophrenia (Puveendrakumaran et al., 2020) in clinical research and with (ii) delusion-like beliefs (Bronstein, Pennycook, Bear, et al., 2019), the JTC bias (Ross et al., 2016), and the BADE (Bronstein, Everaert, et al., 2019) in general population studies.

In the present study, we had participants complete the Beads Task, the BADE Task, a test of analytic thinking, and a measure of delusion-like beliefs in order to rigorously examine relationships among the underlying constructs. Specifically, we aimed to address four key inconsistencies in the empirical literature.

First, there is mixed empirical evidence concerning the proposed integration between delusions, delusion-like beliefs and dual process theories of thinking. Although one large study found a relationship between delusion-like beliefs and analytic thinking (Bronstein, Pennycook, Bear, et al., 2019), another large study did not (Ross et al., 2016). And a further study found that analytic thinking predicted performance in the BADE Task in the general

population (Bronstein, Everaert, et al., 2019), but this study did not measure delusion-like beliefs (the focus of this study was paranoia). As dual process theories are meant to add explanatory depth when it comes to cognitive biases, we would expect that analytic thinking should predict the same biases that in turn predict delusion-like beliefs. Hence, *Research Question 1: Does analytic thinking predict the JTC bias and the BADE and, at the same time, do these biases predict delusion-like beliefs?*¹

Second, there is a striking tension between reasoning biases identified using the Beads Task and the BADE Task (Furl et al., 2021). As noted above, in the Beads Task, delusions and delusion-like beliefs are associated with a tendency to *over-accommodate* evidence that disconfirms a pre-established pattern (i.e., the overadjustment bias; Garety et al., 1991; Rodier et al., 2011). By contrast, in the BADE Task, delusions and delusion-like beliefs are associated with a tendency to *under-accommodate* disconfirmatory evidence (i.e., the BADE; McLean et al., 2017). It seems incongruous that delusions and delusion-like beliefs should be associated with over-accommodating evidence in one task and under-accommodating evidence in another, but we are not aware of any studies that examine whether these two biases are studied in the same sample. Hence, *Research Question 2: Are the overadjustment bias and the BADE associated with each other and with delusion-like beliefs?*

Third, although the Beads Task and BADE Task have been used together in a single study (e.g., Moritz et al., 2010), we are not aware of any studies that specifically examine whether the JTC bias and the BADE predict delusions or delusion-like beliefs when controlling for the other bias. Hence, *Research Question 3: Do the JTC bias and the BADE*

¹ This research question differs from that reported in our pre-registration. Our pre-registered research question was inspired by an analysis conducted by Ross et al. (2016) and asked whether analytic thinking predicts the JTC bias and BADE *while controlling for* delusion-like beliefs. However, with further reflection we have come to realise that this analysis does not test a cognitive model. For this reason, we have developed a new RQ1 and analysis plan that focuses on a sophisticated cognitive model recently developed by Bronstein et al. (2019). Our new Research Question 1 asks whether these cognitive biases *mediate* the relationship between analytic style and delusion-like beliefs. An analysis of the original pre-registered hypothesis is reported in our online material (<https://osf.io/fvkcw/>).

each predict unique variance in delusion-like beliefs, and if so, which is the stronger predictor?

Fourth, the liberal acceptance bias appears to be conceptualized in different ways in the Beads Task and the BADE Task.² Liberal acceptance bias_{BEADS} is operationalized as deciding to stop drawing beads while expressing low subjective confidence about which urn the beads are being drawn from (Moritz et al., 2016; Moritz et al., 2006; Moritz et al., 2007). By contrast, liberal acceptance bias_{BADE} is operationalized as overrating the plausibility of an absurd interpretation of events (McLean et al., 2017). It is not clear whether these operationalizations of a “liberal acceptance bias” measure the same underlying cognitive bias or if they are different biases that have been assigned the same name. Hence, *Research Question 4*: Are the liberal acceptance bias_{BEADS} and the liberal acceptance bias_{BADE} associated with each other and with delusion-like beliefs?³

In examining these hypotheses, our study includes four notable strengths that are particularly relevant when considering the four meta-analyses of the Beads Task and BADE Task literature (Dudley et al., 2016; McLean et al., 2017; Ross et al., 2015; So et al., 2016). First, to address concerns that misunderstanding of the Beads Task might be an important source of bias in research (Balzan, Delfabbro, & Galletly, 2012; Balzan, Delfabbro, Galletly, et al., 2012; Howe et al., 2018), we developed a new animated version of this task that specifically aims to facilitate comprehension⁴ and included a series of comprehension checks immediately after the demonstration. This is important because few—if any—of the Beads Tasks studies included in the four meta-analyses animated the task. A key advantage of our

² We use subscripts to distinguish between the two biases: “liberal acceptance bias_{BEADS}” and “liberal acceptance bias_{BADE}”.

³ For Hypothesis 4 we pre-registered an intention to test for an association between liberal acceptance bias_{BEADS} and the liberal acceptance bias_{BADE}, but an oversight was that we neglected to pre-register an intention to test for a relationship between these biases and delusion-like beliefs. Clearly, this hypothesis is central to our research, so we consider it with our pre-registered hypotheses although, strictly speaking, it is exploratory.

⁴ We invite the reader to examine our animated beads task and to consider how the animation clarifies task instructions (available at <https://osf.io/fvkcw/>).

animated task is that we *show* participants the entire process of setting up the urns and drawing beads. Non-animated presentations of the Beads Task can be considerably cognitively demanding and confusing because participants must read (or listen to) and understand complex descriptions without clear visual illustrations.

Second, we recruited a large sample, enabling us to detect small effect sizes. This is important because the meta-analyses are in agreement that effect sizes in this literature are small.

Third, we included multiple data-quality checks throughout the study to examine whether “careless responding” might have biased results in this literature. We follow Arthur et al. (2021) in using the term “careless responding” to include “inattentiveness, arbitrary response patterns, or unwillingness to comply with the task demands” (p. 106). This is important as careless responding can have a profound impact on results (Arthur et al., 2021), including in clinical research (Agley et al., 2021; Chandler et al., 2020; Moseley et al., 2021; Ophir et al., 2020; Zorowitz et al., 2021).

Fourth, we pre-registered our analysis plan, share our raw data, and report our analysis scripts to make our research maximally transparent and to protect against incorrect inferences (Tackett et al., 2019).

Methods

Participants

We pre-registered (<https://osf.io/fvkcw/>) a sample size of 1,000. We recruited from Amazon’s Mechanical Turk service, a platform which is regularly used in clinical studies (Chandler & Shapiro, 2016). Participation was managed by Turkprime (Litman et al., 2017) which overshot by two (hence $n = 1002$). In our sample, the mean age was 35.2 years ($SD = 10.8$), including 507 males, 482 females, 3 non-binary people, and 10 who opted out of the

gender question. The study was conducted in accordance with the APA ethical principles and it passed the internal ethics procedure at Royal Holloway, University of London.

Procedure

After providing informed consent, participants completed the following key tasks (for a full presentation of all tasks and measures and an interactive demonstration of the study, see <https://osf.io/fvkcw/>).

Beads Task (Huq et al., 1988). Participants were presented with two urns full of beads: for example, one “majority pink” urn (containing 60 pink beads and 40 green beads) and one “majority green” urn (60 green beads; 40 pink beads). One urn was randomly selected, and participants were told that beads would be drawn from that single urn one at a time with replacement (in reality, the sequence was fixed). Before seeing any beads being drawn, and again after each draw, participants provided confidence ratings on a 101-point scale ranging from 100% confidence in the “majority pink” urn at one end to 100% confidence in the “majority green” urn at the other. To avoid the high rates of miscomprehension shown in earlier studies (Balzan, Delfabbro, & Galletly, 2012; Balzan, Delfabbro, Galletly, et al., 2012; Howe et al., 2018), we animated the task so that participants could straightforwardly see that one urn was (ostensibly) picked at random and that beads were drawn with replacement from that single urn. In addition, as per standard practice, to minimize memory demands, previously drawn beads were displayed onscreen. Importantly, participants only proceeded to the trials once they scored 100% on a four-item comprehension test, otherwise the demonstration and test were repeated until this threshold was reached (85% of participants passed all four Beads Task comprehension check questions on their first attempt).

Participants completed two Beads Task trials. One was a “draws-to-decision” version of the Beads Task (Huq et al., 1988), where participants could draw as many beads they

wanted (up to a maximum of 30) before deciding the majority colour of the urn. Draws-to-decision was scored as the number of beads a participant drew, and the JTC bias was conceptualised in terms of fewer draws to decision. Liberal acceptance bias_{BEADS} was scored as a participant's confidence rating at the point they decided on the majority colour (Moritz et al., 2010), where lower confidence indicates more liberal acceptance. The other trial was a “graded-estimates” version of the Beads Task (Garety et al., 1991) where participants always drew ten beads, with beads of the minority colour appearing on draws 3, 6 and 9. The overadjustment bias was scored as the sum of the changes in a participant's confidence in the majority colour each time a bead of the minority colour was drawn.

Bias Against Disconfirmatory Evidence (BADE) Task (Woodward et al., 2006).

Participants completed eight focal trials plus three filler trials (Buchy et al., 2007). In each trial, participants were shown four candidate explanations of a given scenario. Over three stages, more information was revealed about the scenario. After each reveal, participants rated how likely each explanation was, given the current information. Focal trials were designed to have two “lure” explanations which initially seemed plausible, but became less plausible as more information was revealed; a “true” explanation which became the most plausible as more information was revealed; and an “absurd” explanation which was consistently implausible. Here, we scored the BADE using the method of Sanford et al. (2014). For further details about this scoring method and discussion of alternative scoring methods developed by Bronstein and Cannon (2018), see <https://osf.io/fvkc/>. Liberal acceptance bias_{BADE} was scored as the average of the ratings of absurd interpretations across all three stages of the task (Woodward et al., 2007) with a more positive score coded to indicate more bias (i.e., more readiness to accept implausible response options).

Peters et al. Delusions Inventory (PDI; Peters et al., 2004). Participants answered “yes” or “no” to 21 questions about delusion-like experiences, such as “Do you ever feel as if

people seem to drop hints about you or say things with a double meaning?”. For “yes” responses, three follow-up scales probed distress, preoccupation, and conviction on a five-point scale (scored from 1 to 5).⁵ Delusion-like beliefs were scored as the sum of all responses to the dichotomous scale (scored as 0 for “no” and 1 for “yes”) and the three follow-up scales. For exploratory purposes, in addition to the PDI items, we included items from a scale that overlaps heavily with the PDI—the positive-symptoms subscale of the Community Assessment of Psychic Experiences (CAPE; (Stefanis et al., 2002). We do not analyse these items here, though we make the data available in our online repository.

Cognitive Reflection Test (CRT; Frederick, 2005). The CRT consists of verbal puzzles with intuitively appealing but incorrect answers (e.g., “A bat and a ball cost \$1.10. The bat costs \$1.00 more than the ball. How much does the ball cost?” The intuitive answer is \$0.10; the correct answer is \$0.05). We combined a three-item (Shenhav et al., 2012) and four-item CRT (Thomson & Oppenheimer, 2016). Analytic thinking was indexed as the number of correct answers. Internal consistency reliability was estimated to be $\omega_t = 0.79$ and $\omega_h = 0.62$ (Revelle & Condon, 2019). We also included four verbal reasoning items (Condon & Revelle, 2014) that are similar in terms of content but do not have intuitively appealing incorrect answers and, thus, served as distractors. For exploratory purposes, after these questions were presented, we asked participants to rate on a five-point Likert scale whether they had seen any of these questions before.

WORDSUM Test (Malhotra et al., 2007). The WORDSUM test is a brief vocabulary test that consists of 10 target words in capital letters. Participants are asked to choose a word that most closely matches the meaning of the target word from five options. Data from this

⁵ In our implementation of the PDI, participants were informed that any endorsements of the dichotomous items would involve responding to the three follow-up scales. However, we designed the experiment script to only validate the follow-up scales (reminding participants to provide follow-up responses for any endorsed items) after all dichotomous items had been responded to. Thus, participants could not update their responses to “no” on dichotomous items in order to avoid the additional effort of responding to the follow-up scales.

test were collected for exploratory purposes and are not analysed here, though we make the data available in our online repository.

Demographic questions. Participants provided their age, gender, education level, and degree of belief in God. Finally, they indicated whether or not they were a native speaker of English and were asked if they had any comments about the study.

Each task was presented in the order listed above, except for the Beads Task and the BADE Task, which were always either first or second (order randomized). The order of trials and items in each task was randomized per participant. Table 1 summarises the variables mentioned in our pre-registered analyses.

Table 1

Description of the main variables

Variable name	Task/scale name	Interpretation of higher score
Analytic thinking	Cognitive Reflection Test (CRT)	More analytic cognitive style
Bias against disconfirmatory evidence (BADE)	BADE Task	More resistant to disconfirmatory evidence
Delusion-like beliefs	Peters et al. Delusions Inventory (PDI)	More delusion-like beliefs endorsed
Draws-to-decision	Beads Task	More beads drawn; less jumping to conclusions (JTC) bias
Liberal acceptance bias _{BADE}	BADE Task	More willing to endorse absurd explanations (<i>higher</i> liberal acceptance bias)
Liberal acceptance bias _{BEADS}	Beads Task	Higher subjective confidence when making decisions (<i>lower</i> liberal acceptance bias)
Overadjustment bias	Beads Task	Larger change in belief when a bead of the minority colour is drawn

Statistical analyses

Our analysis was pre-registered (<https://osf.io/kdyhn/>), and our data and analysis scripts are available online (<https://osf.io/fvkcw/>). These include model priors and model comparison. Our analyses depart from our pre-registration in that, in place of frequentist regressions, we employ Bayesian regressions built with package brms (Bürkner, 2017) in R (R Core Team, 2021). This allows us to quantify the strength of evidence for null effects (Dienes, 2014; Wagenmakers et al., 2016). Unless otherwise indicated, ranges in brackets represent 95% Credible Intervals (CIs). Bayes Factors (BFs) represent the weight of evidence in favour of a given hypothesis ($BF1 > 1$) or in favour of a null effect ($BF < 1$), with BFs between 0.33 and 3 representing merely anecdotal evidence (although we stress that Bayesian approaches eschew dichotomous cut-offs).

As per our pre-registration, we examined whether our results were influenced by careless participants using two pre-registered screening methods. First, we included three attention checks and participants who failed two or more of them were classified as “careless”. In the BADE Task, the attention-check trial looked like the other BADE trials except that the final revealed statement read “To show you are being careful, please set all response sliders to the minimum value.” In the PDI task, the attention-check item read, “Have you ever used the internet? Answer ‘five’ for all three scales on the right.” In the CRT task, the attention-check item read “How many days are there in two weeks? To show you’re reading this, enter double the actual number.” Second, participants who failed to move the sliders on more than a third of Beads Task and BADE Task questions that involved sliders were also classified as “careless”. In the Beads Task, questions that involved sliders were those that asked participants to rate how likely it was that one of two colours was the majority

colour of the urn. In the BADE Task, sliders were used to ask how probable the different scenarios were. Participants who passed both screening methods were classified as “diligent”. We pre-registered that we would report results both with and without careless participants included in the sample, so as to examine the influence of careless participants on results.

In addition to the analyses reported below, supplementary analyses in our online repository (<https://osf.io/fvkcw/>) examine in some detail the various response patterns that we call “careless”. This includes our argument for why these responses are better described as “careless” rather than, say, “extremely resistant to disconfirmatory evidence”. Further, because the first screening method involves failure to follow explicit instructions whereas the second screening method (failure to move sliders) is more of a behavioural criterion, the supplementary analyses also compare results with the pre-registered criteria (participants who fail either screening method are excluded) and results with weaker criteria (only participants who fail the first screening method are excluded).

Results

Data quality checks

8.2% of participants were classified as careless according to our pre-registered criteria because they failed at least one pre-registered screening method. Figure 1 shows differences between careless participants and diligent participants in terms of the number of delusion-like beliefs endorsed (21 dichotomous PDI items), draws-to-decision in the Beads Task, plausibility rating of the two lure explanations in the BADE Task, and CRT score. These plots clearly demonstrate markedly different response patterns in careless participants.

Figure 1

Responses for Four Key Variables

Note. Responses are split by data quality (blue = diligent, red = careless). (a) Histogram of the total number of delusion-like beliefs endorsed (21 dichotomous PDI items). (b) Histogram of beads drawn in the draws-to-decision version of the Beads Task. (c) Mean ratings of plausibility for the two lure explanations for each stage of the BADE Task. (d) Number of items correct on the 7-item CRT.

Pre-registered analyses

The analyses under Research Questions 1 and 4 depart from our pre-registration (see footnotes 1 & 3). In the interests of transparency, we include the pre-registered analysis for Research Question 1 in our project repository (<https://osf.io/fvkcw/>). This departure from our pre-registration does not alter our main conclusions. In the case of Research Question 4, the analysis below incorporates the pre-registered analysis, so we simply indicate at which point we go beyond the original.

Research Question 1

Does analytic thinking predict the JTC bias and BADE and, at the same time, do these biases predict delusion-like beliefs?

Hypothesis H1a. Analytic thinking predicts the JTC bias and in turn, the JTC bias predicts delusion-like beliefs.

Hypothesis H1b. Analytic thinking predicts the BADE and in turn, the BADE predicts delusion-like beliefs.

For H1a, we regressed draws-to-decision (i.e., the inverse of JTC bias) on analytic thinking using a Bayesian zero-truncated negative binomial regression (for an account of this choice of model, motivated by the distribution of this variable, see <https://osf.io/fvkcw/>). We simultaneously regressed delusion-like beliefs on draws-to-decision and analytic thinking using a negative binomial regression (again, see online repository for an account of this decision, given how the outcome variable was distributed). See Figure 2 for model structures. The resulting model is, in essence, a mediation model. With the full dataset, there was a positive association between analytic thinking and draws-to-decision ($b = 0.573$ [0.457, 0.695], Figure 2 top left) and a negative association between draws-to-decision and delusion-like beliefs ($b = -0.023$ [-0.033, -0.013]). Participants higher in analytic thinking drew more beads, and participants who drew more beads were less likely to report delusion-like beliefs (supporting H1a). However, even after accounting for draws-to-decision, analytic thinking had a negative association with delusion-like beliefs ($b = -0.682$ [-0.875, -0.491]).

Figure 2*Mediation Models Addressing Research Question 1*

Note. Bayesian regression coefficients (with 95% Credibility Intervals) regressing the cognitive biases (draws-to-decision and BADE, each in a separate model) on analytic thinking and simultaneously regressing delusion-like beliefs on analytic thinking and on the cognitive biases. The top row shows models with the full data set; the bottom row shows models with careless participants excluded. Pathways where the CIs include 0 are in grey and labelled in italics.

For H1b, we used the same model structure as H1a, but replaced draws-to-decision with BADE (Figure 2 top right). With the full dataset, there was a negative association between analytic thinking and BADE ($b = -0.611 [-0.785, -0.293]$), and a positive association between BADE and delusion-like beliefs ($b = 0.293 [0.238, 0.347]$). Participants higher in analytic thinking were less biased against disconfirming evidence, and people who were more biased against disconfirming evidence were more likely to report delusion-like beliefs (supporting H1b). Once more, even after accounting for the BADE, analytic thinking had a negative association with delusion-like beliefs ($b = -0.525 [-0.699, -0.347]$).

However, the results for both analyses changed when careless participants were excluded. Draws-to-decision was still positively—if more weakly—associated with analytic thinking ($b = 0.292$ [0.180, 0.404], Figure 2 bottom left), but *contra* H1a draws-to-decision was no longer associated with delusion-like beliefs ($b = 0.004$ [−0.007, 0.016], $BF = 0.01$). BADE was still positively associated with delusion-like beliefs ($b = 0.081$ [0.007, 0.155], Figure 2 bottom right), but *contra* H1b BADE was no longer associated with analytic thinking ($b = -0.022$ [−0.176, 0.129], $BF = 0.08$). In both cases, a direct association remained between analytic thinking and delusion-like beliefs (see Figure 2 bottom for details in each model). Thus, although dual process theories may be relevant for understanding delusion-like beliefs, this relevance is not because they explain the cognitive biases that are in turn associated with such beliefs: each bias is either associated with analytic thinking or with delusion-like beliefs, but not with both.

In the online material (<https://osf.io/fvkcn/>) we additionally report a model combining the pathways in Figure 2 (more in line with the proposal in (Bronstein, Pennycook, Joormann, et al., 2019)). This model is not included in the main text because it introduces issues of collinearity, which we address directly in Research Question 3 below. This alternative analysis does not alter our conclusion: analytic thinking does not explain biases associated with delusion-like beliefs. The only substantial difference is that draws-to-decision no longer has an association with delusion-like beliefs even when careless participants are included, once the relationship between BADE and delusion-like beliefs is included in the model.

Research Question 2

Are the overadjustment bias and the BADE associated with each other and with delusion-like beliefs?

Hypothesis H2a. Delusion-like beliefs are not associated with at least one of these biases; *or*

Hypothesis H2b. Delusion-like beliefs are associated with both biases, but they are not themselves related; *or*

Hypothesis H2c. Delusion-like beliefs are associated with both biases, and they are themselves related.

With the full dataset, H2b was supported. There was a positive correlation between delusion-like beliefs and the overadjustment bias ($\rho_s = 0.108$ [0.041, 0.172]) and a positive correlation between delusion-like beliefs and the BADE ($\rho_s = 0.194$ [0.129, 0.258], Figure 3), but there was strong evidence for no correlation between the BADE and the overadjustment bias ($\rho_s = 0.030$ [−0.040, 0.101], $BF = 0.04$).

Figure 3

Associations between Delusion-like Beliefs, Overadjustment and BADE (Research Question 2)

Note. Spearman correlation coefficients (ρ_s) with 95% Credibility Intervals.

This pattern changed dramatically when careless participants were excluded (Figure 3). The correlation between delusion-like beliefs and the overadjustment bias disappeared ($\rho_s = 0.060$ $[-0.007, 0.124]$, $BF = 0.14$). The correlation between the BADE and delusion-like beliefs became weaker ($\rho_s = 0.071$ $[0.007, 0.131]$, $BF = 0.27$). And the correlation between the BADE and the overadjustment bias remained null ($\rho_s = -0.042$ $[-0.107, 0.022]$, $BF = 0.06$).

Research Question 3

Do the JTC bias and the BADE each predict unique variance in delusion-like beliefs, and if so, which is the better predictor?

Hypothesis H3a. The JTC bias predicts delusion-like beliefs better than the BADE does; *or*

Hypothesis H3b. The BADE predicts delusion-like beliefs better than the JTC bias does; *or*

Hypothesis H3c. Neither bias is a better predictor of delusion-like beliefs.

We regressed delusion-like beliefs on draws-to-decision and BADE using a Bayesian zero-inflated negative binomial model (for an account of this choice of model, see <https://osf.io/fvkcn/>). With the full dataset, there was a negative coefficient for draws-to-decision ($b = -0.089$ $[-0.137, -0.040]$; model $R^2 = 0.097$ $[0.062, 0.139]$) and a positive coefficient for BADE ($b = 0.257$ $[0.209, 0.304]$, Figure 4). There was strong evidence ($BF > 100$) that the coefficient for BADE was larger than that for draws-to-decision. Thus, in the full dataset, the BADE was more closely associated with delusion-like beliefs than the JTC bias was (supporting H3b).

Figure 4

Regression Coefficients Addressing Research Question 3

Note. Bayesian regression coefficients (with 95% Credibility Intervals) for the predictor variables draws-to-decision and BADE and the outcome variable delusion-like beliefs.

With careless participants excluded, draws-to-decision was centred on 0 ($b = 0.002$ $[-0.051, 0.055]$; model $R^2 = 0.004$ $[0.000, 0.012]$) and the coefficient for BADE had a CI that *just* included 0 ($b = 0.049$ $[-0.001, 0.100]$). There was moderate evidence ($BF = 8.52$) that the coefficient for BADE was larger than that for draws-to-decision. Thus, with careless participants excluded, the BADE was a marginally better predictor of delusion-like beliefs than the JTC bias was (again supporting H3b, although more weakly).

Research Question 4

Are liberal acceptance bias_{BEADS} and liberal acceptance bias_{BADE} associated with each other and with delusion-like beliefs?

Hypothesis H4a. Liberal acceptance bias_{BEADS} and liberal acceptance bias_{BADE} are associated; *and*

Hypothesis H4b. Delusion-like beliefs are associated with at least one of these biases.

H4a was pre-registered; H4b was not, but it is important for our overall aim of understanding delusion-like beliefs. With the full dataset, liberal acceptance bias_{BEADS} and liberal acceptance bias_{BADE} were unrelated ($\rho_s = -0.046$ $[-0.109, 0.020]$, $BF = 0.07$). The same was true with careless participants excluded ($\rho_s = -0.036$ $[-0.102, 0.025]$, $BF = 0.05$). Thus, regardless of data quality, the liberal acceptance biases do not appear to capture the same (or a similar) underlying construct, *contra* H4a.

Regressing delusion-like beliefs on both versions of the liberal acceptance bias (using the same model family as for H3), analysis of the full data set indicated that liberal acceptance bias_{BEADS} was not predictive of delusion-like beliefs ($b = -0.045$ $[-0.096, 0.007]$, $BF = 0.12$), but there was a positive coefficient for liberal acceptance bias_{BADE} with participants who rated the absurd explanations as more plausible also having more delusion-like beliefs ($b = 0.253$ $[0.209, 0.297]$, Figure 5). Thus, analysis of the full dataset supports H4b. With careless participants excluded, neither variable was predictive of delusion-like beliefs (liberal acceptance bias_{BADE} $b = 0.035$ $[-0.017, 0.088]$, $BF = 0.06$; liberal acceptance bias_{BEADS} $b = -0.025$ $[-0.076, 0.027]$, $BF = 0.04$), *contra* H4b.

Figure 5*Regression Coefficients Addressing Research Question 4*

Note. Bayesian regression coefficients (with 95% Credibility Intervals) for each predictor (liberal acceptance bias_{BEADS} and liberal acceptance bias_{BADE}) for outcome variable delusion-like beliefs.

Discussion

According to continuum models of psychosis, cognitive biases that contribute to the formation and maintenance of clinical delusions are also implicated in delusion-like beliefs in the general population (Linscott & van Os, 2013; van Os et al., 2009). The primary sources of evidence for associations between cognitive biases, delusions, and delusion-like beliefs are studies that use the Beads Task and the BADE Task (Dudley et al., 2016; Livet et al., 2020; McLean et al., 2017; Ross et al., 2015; So et al., 2016), and these associations have been interpreted in terms of dual process theories of thinking (Aimola Davies & Davies, 2009; Bronstein, Pennycook, Joormann, et al., 2019; Freeman et al., 2014; Ross et al., 2016). In the present study, we addressed four research questions concerning relationships between cognitive biases, delusion-like beliefs (measured using the PDI), and analytic thinking (measured using the CRT).

Research Question 1 concerned relationships between delusion-like beliefs, analytic thinking, and the most widely studied biases from the Beads Task and the BADE Task literature—the JTC bias and the BADE. Irrespective of whether the full sample was used or careless participants were excluded, we found that analytic thinking was negatively associated with the JTC bias, which supports an earlier study (Ross et al., 2016). However, there was strong evidence that the JTC bias was not associated with delusion-like beliefs when careless participants were excluded. Analytic thinking was negatively associated with the BADE in the full sample, there was no association when careless responders were excluded, thus failing to replicate an earlier study (Bronstein, Everaert, et al., 2019). However, analytic thinking was still associated with delusion-like beliefs. These results could provide a useful impetus to refine models that seek to explain delusional beliefs from the context of dual-process theories of thinking as they confirm that dual process theories are relevant to understanding delusion-like beliefs, but show that neither bias is associated both with analytic thinking and with delusion-like beliefs.

Research Questions 2, 3, and 4 concerned relationships among a suite of five cognitive biases and delusion-like beliefs. When including all participants in the analyses, we typically replicated classic findings from the literature: with the Beads Task, delusion-like beliefs were associated with the JTC bias and the overadjustment bias (but not the liberal acceptance bias_{BEADS}); and with the BADE Task, delusion-like beliefs were associated with the BADE and the liberal acceptance bias_{BADE}. Strikingly, however, when careless participants were excluded, the picture changed dramatically: the extent to which cognitive biases predicted delusion-like beliefs was diminished severely; and in the case of the JTC bias, the overadjustment bias and the liberal acceptance bias_{BADE}, the association with delusion-like beliefs disappeared altogether.

Our study had several strengths and innovations. Some of these were general scientific strengths: for instance, our study was highly powered (our sample is among the very largest collected in this literature and, to the best of our knowledge, is the single largest study that includes both the Beads Task and the BADE Task) and our hypotheses and analysis plan were pre-registered (which is very rare in this literature). Others were more specific to the topic at hand. In particular, we developed an animated Beads Task to make the paradigm more readily understood. While it is rare for Beads Task studies to report any measure of comprehension, we identified three studies that did. Each of these studies was conducted in person and in each of them over 50% of participants misunderstood key features of the task (Balzan, Delfabbro, & Galletly, 2012; Balzan, Delfabbro, Galletly, et al., 2012; Howe et al., 2018). By contrast, in the present study we found that 85% of participants passed our four-items Beads Task comprehension check on their first attempt. Moreover, because participants could begin the first trial only after they had provided the correct response to all four items, comprehension levels during the task would have been near ceiling. Consequently, unlike earlier studies in the Beads Task literature, we can be confident that our results were not driven by miscomprehension.

A further strength of our study was that we included a series of data-quality checks to identify careless participants. Although only 8.2% of the sample were categorised as careless according to our pre-registered criteria, associations between thinking biases and delusion-like beliefs were severely attenuated—or disappeared entirely—when these careless participants were excluded from analyses. Data-quality checks are beginning to be used in clinical psychology research (Agle et al., 2021; Chandler et al., 2020; Moseley et al., 2021; Ophir et al., 2020; Zorowitz et al., 2021), but they are still very rare in the Beads Task and BADE Task literatures. In fact, we are aware of only one study with explicit data-quality checks and the removal of careless participants (Ross et al., 2016). That study was conducted

online and, notably, despite having a large sample ($n = 558$), it also failed to replicate the small association between the JTC bias and delusion-like beliefs that had been supported in an earlier meta-analysis (Ross et al., 2015). Given that participants in online studies have repeatedly been found to be at least as diligent—or even more diligent—than participants in the laboratory (Hauser & Schwarz, 2016; Kees et al., 2017; Moseley et al., 2021; Ramsey et al., 2016), these results suggest that in-person studies might have careless participants (including participants with low motivation, low effort, or low attentiveness), just as they have been shown to have high levels of miscomprehension (Balzan, Delfabbro, & Galletly, 2012; Balzan, Delfabbro, Galletly, et al., 2012; Howe et al., 2018). This is of some concern because carelessness in some participants and miscomprehension in others could be powerful drivers of spurious associations.

Why did careless participants drive spurious associations between reasoning biases and delusion-like beliefs in our study? We argue the answer is to be found by considering how careless participants respond to the PDI, the Beads Task, and the BADE Task. First, the PDI elicits low mean scores for attentive participants because they typically report holding few delusion-like beliefs (Peters et al., 2004). Consequently, if careless participants respond randomly then, on average, they will be coded as having particularly high levels of delusion-like beliefs compared to diligent participants. This is exactly what we find: the mean number of items endorsed on the PDI (recall that participants answer “yes” or “no” to each item) was 11 out of 21 for careless participants (i.e., very close to the value of 10.5 that would be expected if responses were entirely random) versus 3.7 for diligent participants; see Figure 1a.

Second, in the Beads Task, if a careless participant responds at random when deciding whether to see an additional bead (or aims to finish the task quickly by asking to see few beads) then, on average, they would ask to see fewer beads than diligent participants, which

would resemble a JTC bias. Again, this is exactly what we find: the mean number of beads was 2.7 for careless participants versus 9.6 for diligent participants; see Figure 1b.

Third, in the BADE Task, if a careless participant neglects to move sliders each time additional information about the scenario is revealed then their response would be coded as exhibiting a strong BADE. Indeed, among careless participants we found almost no change in the plausibility rating for lure explanations across stages of the task, whereas attentive participants decreased the plausibility rating as evidence accumulated; see Figure 1c.

Similar arguments can be made for the influence of random responding with the overadjustment biases and the liberal acceptance biases. Moreover, with the CRT we see that careless participants have a markedly lower mean number of correct responses compared to diligent participants (20% vs 58%); see Figure 1d. In summary, careless participants could drive entirely illusory relationships between the JTC bias, the BADE, other biases, and delusion-like beliefs that all but vanish when careless participants are excluded. These findings converge with the results of other recent studies which have found that heavily skewed response patterns in clinical symptom measures can drive spurious associations with task behaviours when participants are careless (Ophir et al., 2020; Zorowitz et al., 2021).

We see two potential concerns about our study that need to be addressed. First, it is possible that one of our approaches for screening out careless participants actually screened out diligent participants who are simply outliers who exhibit very strong cognitive biases. This screening criterion focused on extreme responding: participants who failed to move the slides on at least a third of Beads Task and BADE Task questions that involved sliders were classified as “careless”. In other words, these participants indicated that (i) being shown beads of different colours had no influence on their belief about which urn beads were being drawn from in the Beads Task and (ii) being shown more information about a scenario had no influence on their belief about the plausibility of lure explanations in the BADE Task (despite

the fact that these explanations were specifically designed to become increasingly implausible as additional information was revealed). It could be argued that these extreme responses to the Beads Task and BADE Task are sincere and that these participants are showing themselves to be highly resistant to evidence—or even entirely incorrigible—which is a core symptom of schizophrenia. We agree that this is *possible*, but we argue that this interpretation of these results is highly unlikely because a lack of engagement with the task is a more plausible interpretation than a total absence of belief updating. As mentioned previously, we conducted supplementary analyses which reveal that very similar results are found when this screening criterion is weakened, such that participants are only excluded out if they fail to comply with explicit instructions. Moreover, the supplementary analyses closely examine other patterns in the data which strongly suggest that these participants were careless rather than totally resistant to evidence.

A second potential concern with our study is that we did not have a clinical sample. Because of this, we cannot confidently make inferences about the relationship between clinical delusions, task comprehension, carelessness, and reasoning biases. Nonetheless, we argue that there is good reason to believe that clinical research will to be negatively impacted by careless responders too. Consider the following three issues. First, the only clinical study we have been able to identify that included comprehension checks for the Beads Task found even higher levels of miscomprehension of the task in the schizophrenia group (64%) compared to the two non-clinical groups (48% and 40%; Balzan, Delfabbro, & Galletly, 2012). Second, a large clinical study using a modified version of the Beads Task called the “Fishing Task” that was developed specifically to facilitate comprehension (Woodward et al., 2009) failed to find evidence for a relationship between delusions and the JTC bias (Pytlik et al., 2020). Third, a review of the schizophrenia literature found that avolition, decreased effort, dysfunctional attitude, stress, negative emotion, asociality and disorganisation can

explain poor performance in cognitive tasks in people diagnosed with schizophrenia (Beck et al., 2018); factors that we expect would be associated with task miscomprehension and careless responding. Indeed, a recent study found that when controlling for self-reported “momentary influences” (e.g., motivation, concerns about assessment, fear about poor outcome) the difference between clinical and control groups on several neurocognitive measures was substantially reduced (Moritz et al., 2017).

In discussing our results, we have focused on empirical concerns, suggesting that researchers need to pay more attention to measurement issues (including explicit measurement of data quality) when running new studies. Nonetheless, it is worth raising the possibility that problems with the Beads Task and BADE Task literature may, in fact, run deeper than measurement issues, with implications for theory. Consider that we did not find an association between delusion-like beliefs and JTC bias and only a weak association between delusion-like beliefs and the BADE. This could be interpreted as evidence against the hypothesis that shared cognitive biases are evidence for a psychosis continuum between clinical delusions and delusion-like beliefs.

In conclusion, the current study contributes to an emerging literature which demonstrates the importance of verifying that participants understand tasks and respond diligently to avoid spurious associations (Arthur et al., 2021), particularly when employing clinical measures with skewed distributions of responses (Agley et al., 2021; Chandler et al., 2020; Moseley et al., 2021; Ophir et al., 2020; Zorowitz et al., 2021).

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