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The contribution of hypersalience to the "jumping to conclusions" bias associated with delusions in schizophrenia

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Background: Previous schizophrenia research involving the "beads task" has suggested an association between delusions and 2 reasoning biases: (1) "jumping to conclusions" (JTC), whereby early, resolute decisions are formed on the basis of little evidence and (2) overadjustment of probability estimates following a single instance of disconfirmatory evidence. In the current study, we used a novel JTC-style paradigm to provide new information about a cognitive operation common to these 2 reasoning biases. **Methods:** Using a task that required participants to rate the likelihood that a fisherman was catching a series of black or white fish from Lake A and not Lake B, and vice versa, we compared the responses of 4 groups (healthy, bipolar, nondelusional schizophrenia and delusional schizophrenia) when we manipulated 2 elements of the Bayesian formula: incoming data and prior odds. **Results:** Regardless of our manipulations of the Bayesian formula, the delusional schizophrenia group gave significantly higher likelihood ratings for the lake that best matched the colour of the presented fish, but the ratings for the nonmatching lake did not differ from the other groups. **Limitations:** The limitations of this study include a small sample size for the group of severely delusional patients and a preponderance of men in the schizophrenia sample. **Conclusion:** Delusions in schizophrenia are associated with hypersalience of evidence–hypothesis matches but normal salience of nonmatches. When the colour of the incoming data is uniform (fish of only one colour), this manifests as JTC early in a series, and when the colour of incoming data varies (both black and white fish), this manifests as an overadjustment midseries. This account can provide a unifying explanation for delusion-associated performance patterns previously observed in the beads task in schizophrenia.

Introduction

An influential and well-supported cognitive reasoning model in schizophrenia research is the "jumping-to-conclusions" (JTC) bias.[1,2] It describes a reasoning style in patients with delusions that is characterized by early, resolute decisions made on the basis of little evidence. This reasoning bias has been frequently identified by use of the beads task. Typically, 2 jars of beads are presented to participants, one containing substantially more pink than green beads and the other containing the reverse.[1] One by one, beads are taken from a single hidden jar and presented to the participants who are required to guess from which jar the experimenter is taking beads. In some JTC tasks, the dependent measure is the number of beads drawn before the participant indicates readiness to decide on a jar (draws to decision). Other tasks involve a rating comparing the jars after each bead is drawn (graded estimates). Participants with delusions tend to make firm decisions as to the identity of the jar much sooner than controls, occasionally after the very first bead is presented. In addition to the JTC bias, the beads literature has also reported what has been referred to as either an "overadjustment bias"[3,4] or a "bias toward disconfirmatory evidence"[2] in people with delusions. This effect has been suggested because of evidence of

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downward overadjustments in probability estimates following a single instance of disconfirmatory evidence.

Delusions research involving the beads task has its roots in Hemsley and Garety's theoretical examination of the Bayesian formula as a tool for characterizing the reasoning of patients with delusions.[5] This hypothesis paper was followed up by Huq, Garety and Hemsley's seminal paper using the beads task with delusional patients.[1] In addition to noting the tendency of delusional patients to make firm decisions on the basis of relatively little evidence, this research suggested that the apparently hasty decision-making style of deluded participants was actually closer to rationality, according to Bayes' theorem, with controls appearing overly cautious in their assessments of probabilities on the beads task.

Although the Bayesian model presents the mathematically optimal strategy for probabilistic inferences, it is not expected that any group will follow this pattern of responding because, irrespective of mental health status, people do not necessarily reason logically.[6–9] Indeed, reasoning in a more Bayesian manner may not even be the most ecologically valid strategy, such that the more Bayesian earlier decisions of people with delusions may predispose this group toward making more erroneous decisions under certain everyday circumstances. In this regard, the relative conservatism of controls may contribute to resistance to delusion formation in real-world settings. Nevertheless, normative frameworks, such as Bayes' theorem, provide a useful gauge against which the reasoning of different groups can be compared.[10] The Bayesian model of probabilistic reasoning is a particularly suitable framework given the incorporation of prior beliefs and the relative influence of new information on these beliefs.

Surprisingly, despite the consideration given by Hemsley and Garety[3] to how reasoning biases in delusions could occur given deviations from the Bayesian model at one or more of the formula's various stages, explicit manipulation of or attention to elements of the Bayesian formula in the beads and JTC literature has been neglected. In the current study, we considered individual components of the Bayesian formula to develop a more precise understanding of the nature of the JTC reasoning bias in patients with delusional schizophrenia.

Previous studies of JTC have either not compared delusional to nondelusional patients or have included too few participants with schizophrenia to investigate the impact of severe delusions. In this study, we attempted to recruit a large enough sample of participants with schizophrenia to set relatively high cut-offs for delusion severity for inclusion in the delusions group. In addition, we collected data about a group of people diagnosed with bipolar disorder as a psychiatric control group, to provide a way to check that performance differences between people with schizophrenia and healthy controls would not extend to a different diagnostic category of mental illness. We used manipulations based on the Bayesian formula with a variant of the beads task designed to decrease the abstract nature of the task to compare deviations from Bayesian reasoning between healthy controls, people with bipolar disorder and people with schizophrenia.[11] Instead of 2 jars containing different proportions of 2 different coloured beads, our task involved 2 lakes containing different coloured fish, with a fisherman sequentially presenting catches from one of the lakes.

We expected to observe evidence for a JTC-type bias in the delusions group in the form of much higher ratings after viewing the initial fish than for the other groups. We also anticipated that the delusions group would peak sooner in their ratings of the more likely lake, and/or would continue to give higher ratings than the other groups for the duration of each session.

Methods

Participants

All participants who took part in the study gave written informed consent after a full explanation of the study and the procedures involved. All experimental procedures were approved by the University of British Columbia Clinical Research Ethics Board.

We recruited 37 people with schizophrenia and 41 bipolar, psychiatric controls from psychiatric hospitals and community health agencies in and around greater Vancouver, British Columbia. All diagnoses were based on DSM-IV-R criteria[12] and were taken from a chart review. These diagnoses were based on a multidisciplinary team conference during the first month of admission when the diagnosis is reviewed using all sources of information. If a diagnosis had not been finalized at the time of recruitment, the Mini-International Neuropsychiatric Interview (MINI)[13] was administered on the date of testing to provide a final diagnosis.

Psychopathology was assessed using the Signs and Symptoms of Psychotic Illness scale (SSPI)[14] method of gauging symptom severity using 20 symptom items scored 0–4. The SSPI has a separate item for delusions, with subscales for specific delusion types, making it a particularly suitable tool for the current study. Another advantage of the SSPI is that disorganized and impoverished mental activity are better separated.[14,15] The SSPI delusion item was used to divide the schizophrenia group into a severely delusional subgroup ($n = 7$, delusions item = 4) and a mildly or nondelusional subgroup ($n = 30$, delusions item < 4). For simplicity, the 2 groups are referred to in this study as the delusional group and the nondelusional group.

The bipolar group recruited for this study experienced low levels of delusions (no bipolar participants had SSPI delusions scores greater than 2). Participants were excluded if they had ever suffered a head injury or a concussion resulting in a loss of consciousness for 10 minutes or more. We also excluded participants for current and past substance abuse and alcoholism. Substance abuse was assessed by chart review and interview, and we excluded participants if they met the DSM-IV-R criteria for an Axis I diagnosis of a substance-related disorder (e.g., polysubstance dependence). With the exception of 4 individuals, the condition of all patients with schizophrenia was stabilized with antipsychotic medications, with most taking atypical antipsychotics. Of the patients in the bipolar group, 11 of 41 were taking atypical antipsychotics, 2 were taking typical antipsychotics and the

remainder were not taking any antipsychotic medication. Chlorpromazine equivalent values are listed in Table 1.[16]

We recruited 40 healthy controls through advertisement and word-of-mouth. Screening with a medical questionnaire ensured that none of the healthy participants had any current or prior history of psychiatric illness. Additional exclusion criteria were the same as those used for the patient groups.

We excluded participants based on their performance on a control series with uniform fish catches (either all black or all white fish) and 50% black and 50% white fish in both lakes. Participants whose ratings for Lake A and Lake B for the final catch (the tenth fish) did not fall within the 4-point range spanning 3 and 7 (on a scale of 0–10) were excluded from the analysis because we considered this to indicate either a lack of understanding of the task or a failure to adequately attend to the task requirements. We excluded 2 delusional patients with schizophrenia, 5 nondelusional patients with schizophrenia, 4 bipolar controls and 5 healthy controls because of evidence of not understanding or not engaging with the task. Of the 5 participants retained in the delusional patient group, 1 showed severe grandiose delusions and 4 showed severe paranoid delusions.

All participants were fluent in English. Intelligence estimates were made using the Kaufman Brief Intelligence Test (K-BIT)[17] for verbal and nonverbal intelligence and the Ammons Quick Test (QUICK)[18] for an assessment of current IQ. Socio-economic status was estimated using the Hollingshead Two-Factor Index of Social Position[19] using highest parental occupation and education level.

The model

We used a computerized task in which, instead of jars of beads, participants saw 2 lakes containing black and white fish in different ratios. Participants were told that they would see a series of fish caught from only 1 of the 2 lakes, with each fish replaced after each catch so as not to alter the ratio of black to white fish in the lake. After each fish in the sequence, participants were instructed to rate on 2 separate scales the likelihood that the fish were being caught exclusively from Lake A and the likelihood that they were being caught exclusively from Lake B (Fig. 1). The initial prior odds in the Bayesian formula were altered by varying the ratio of one colour fish to the other in each lake across series. Previous research has shown that people with delusions vary their responses in line with changes in the prior odds, indicating that JTC cannot be accounted for by impulsivity.[20]

We also manipulated the incoming data by presenting mixed and uniform fish series. Mixed series showed fish

Table 1: Psychopathological and socio-demographic characteristics of the study participants

Characteristic	Group; mean (SD)*			
	Healthy, *n* = 35	Bipolar, *n* = 37	Nondelusional schizophrenia, *n* = 25	Delusional schizophrenia, *n* = 5
Age, yr	35.1 (10.0)†	40.9 (9.5)	37.3 (11.6)	31.2 (10.0)
Range	19–55	20–56	21–56	18–43
Sex, male:female	16:19	24:13‡	17:8	4:1
Education, no. of years	15.4 (2.4)†§	15.3 (4.0)¶**	13.0 (3.1)	11.6 (1.7)
Quick Test IQ score	107.3 (12.1)	112.2 (11.1)**	102.2 (11.6)	101.6 (7.3)
K-BIT IQ score				
Vocabulary	107.0 (17.3)†§	109.4 (18.7)¶**	96.4 (10.6)	90.4 (12.5)
Matrices	105.8 (18.2)§	99.8 (9.8)	96.4 (12.5)	98.6 (15.8)
Composite	107.0 (16.2)	103.7 (9.9)	100.2 (20.8)	94.0 (15.8)
Social status	36.0 (13.7)	30.4 (15.5)	27.2 (14.0)	46.0 (18.4)
Illness duration, yr	N/A	14.2 (9.6)	14.8 (10.9)	13.4 (7.1)
Chlorpromazine equivalent, mg	N/A	28.1 (90.2)‡	204.7 (401.3)	114.5 (121.9)
Delusions	N/A	0.4 (0.7) **††	1.2 (1.1)‡‡	4 (0)
Guilt or worthlessness	N/A	0 (0.2)	0.1 (0.3)	0 (0)
Grandiose	N/A	0 (0) **††	0.3 (0.5)‡‡	1.6 (1.8)
Paranoid	N/A	0.3 (0.6)**	0.5 (1.1)‡‡	3.8 (0.4)
Schneiderian	N/A	0.2 (0.5)**	0.4 (0.9)¶¶	1.4 (1.3)
Hallucinations	N/A	0.3 (0.8)¶	0.5 (1.2)	1.4 (1.9)
Thought disorder	N/A	0.2 (0.5)‡¶	0.8 (1.0)	1.0 (1.4)
Flat affect	N/A	0.7 (1.0)	0.7 (1.0)	0.2 (0.4)
Poverty of speech	N/A	0.4 (0.9)	0.3 (0.9)	0 (0)
Underactivity	N/A	1.0 (1.1)	0.7 (0.9)	0 (0)

K-BIT = Kaufman Brief Intelligence Test;[20] SD = standard deviation.
*Unless otherwise indicated. Symptom scores are derived from the Signs and Symptoms of Psychotic Illness rating scale.[17]
†Delusional schizophrenia v. healthy, $p < 0.05$.
‡Nondelusional schizophrenia v. bipolar, $p < 0.05$.
§Nondelusional schizophrenia v. healthy, $p < 0.05$.
¶Delusional schizophrenia v. bipolar, $p < 0.05$.
**Nondelusional schizophrenia v. bipolar, $p < 0.01$.
††Delusional schizophrenia v. bipolar, $p < 0.01$.
‡‡Delusional schizophrenia v. nondelusional schizophrenia, $p < 0.01$.
¶¶Delusional schizophrenia v. nondelusional schizophrenia, $p < 0.05$.

catches of both colours, whereas uniform series showed fish catches of only one colour for the duration of the series. The uniform condition is a useful addition to the more typical mixed series approach, because it reduces any interference arising from cognitive differences in the integration of disconfirming and confirming evidence across a series.

Previous beads-task research has used a single rating scale with choice A at one end of the scale and choice B at the other. This approach artificially forces estimates of the probabilities associated with each choice to be reciprocal, and, although optimally they should be, participants may not actually rate the choices this way. This imposed reciprocity results in a loss of information and provides poorer estimates of the ratings for each option when comparing responses to those anticipated by the Bayesian formula, because it is impossible to know whether a movement in one direction represents a downward rating adjustment for one option, an upward rating for the other, or both. For these reasons, we used a separate rating scale for each lake, allowing independence of probability estimates and no loss of information because of imposed reciprocity.

In Bayesian terms, our task can be considered as follows. On viewing the first fish, the initial proportions are the proportion of fish in each lake that match the colour of the viewed fish. On viewing the second fish, the proportions corresponding to the first fish are multiplied by the proportions corresponding to the second fish, which are again simply the proportions of fish of that colour in each lake. The ideal Bayesian reasoner would accurately (1) compute the proportions of fish in each lake that match the colour of the viewed fish, (2) multiply these proportions by those arrived at following the most recent catch and (3) translate those multiplications into a ratio or estimated probability comparing the likelihoods of the 2 lakes.

We provide the following numerical example that illustrates the influence of our incoming data manipulation. These computations are derived from Bayes' theorem, which can be viewed elsewhere.[5,21,22] The simplified formulas used were

$$p(A \sim B) = \frac{p(A)}{p(A) + p(B)} \quad \text{and} \quad p(B \sim A) = \frac{p(B)}{p(A) + p(B)}$$

where *A* refers to Lake A, *B* refers to Lake B, and *p(A)* and *p(B)* refer to the probability of that the entire current series of fish is being caught independently from Lake A and Lake B, respectively. In the following example, the proportions of fish in each lake are as follows: Lake A contains 80% black fish and 20% white fish, and Lake B contains 30% black fish and 70% white fish. The probability of each lake (and not the other) being correct, after seeing the first fish (black for this example), is computed in 4 steps:

1. Determine the probability of a black fish being caught from Lake A: 0.8, *p(A)*.
2. Determine the probability of a black fish being caught from Lake B: 0.3, *p(B)*.
3. Compute the probability that the black fish came from Lake A and not Lake B, *p(A~B)*, by dividing 0.8, *p(A)*, by the total of 0.8 + 0.3, *p(A)* + *p(B)*, which is 0.8/1.1 = 0.73.
4. Compute the probability that the black fish came from Lake B and not Lake A by dividing 0.3 by the total of 0.8 + 0.3, which is 0.3/1.1 = 0.27.

This means that with 80% black fish and 20% white fish in Lake A and 30% black fish and 70% white fish in Lake B, after viewing the first fish and seeing that it is black, the ideal Bayesian reasoner would compute the probability that the fisherman is fishing from Lake A and not B as 0.73 and the probability that he is fishing from Lake B and not A as 0.27.

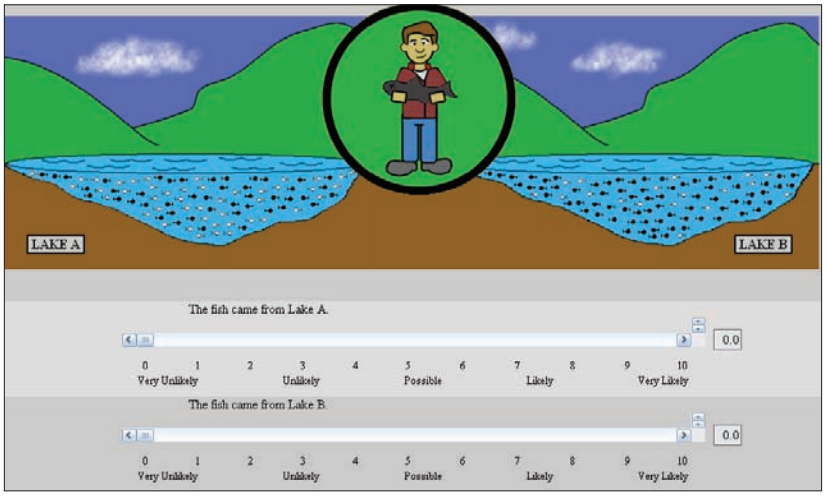

Fig. 1: Sample screen shot of the fishing task. Differences in ratios of black to white fish in each lake for each series were represented graphically. The fisherman was updated for each catch to display the colour of the current fish catch. Following each catch, participants were instructed to make separate ratings using the 2 sliding scales of the likelihood that the fish were being caught exclusively from Lake A and the likelihood that they were being caught exclusively from Lake B.

After viewing a second fish, also black, the probabilities must be adjusted to account for the entire series of fish, as follows:

1. Determine the probability of a second black fish being caught from Lake A: $0.8 \times 0.8 = 0.64$.
2. Determine the probability of a second black fish being caught from Lake B: $0.3 \times 0.3 = 0.09$.
3. Compute the probability that the black fish came from Lake A and not Lake B by dividing 0.64 by the total of 0.64 + 0.09, which is $0.64/0.73 = 0.88$.
4. Compute the probability that the black fish came from Lake B and not Lake A by dividing 0.09 by the total of 0.64 + 0.09, which is $0.09/0.73 = 0.12$.

This means that with 80% black fish and 20% white fish in Lake A and 30% black fish and 70% white fish in lake B, after viewing the first 2 fish and seeing that they are both black, the ideal Bayesian reasoner would compute the probability that the fisherman is fishing from Lake A and not Lake B as 0.88 and the probability that he is fishing from Lake B and not Lake A as 0.12. Any sequence of fish colours and lake proportions can be incorporated using these 4 steps. Viewing a third black fish would lead to the following computations:

1. $0.64 \times 0.8 = 0.512$
2. $0.09 \times 0.3 = 0.027$
3. $0.512/(0.512 + 0.027) = 0.95$
4. $0.027/(0.512 + 0.027) = 0.05$

In contrast, viewing a third fish and seeing that it was white would lead to the following computations:

1. $0.64 \times 0.2 = 0.128$
2. $0.09 \times 0.7 = 0.063$
3. $0.128/(0.128 + 0.063) = 0.67$
4. $0.063/(0.128 + 0.063) = 0.33$

In addition to the experimental manipulations carried out with respect to the sequence of the fish catches, the proportion of black to white fish in each lake, and the use of independent rating scales for the 2 lakes, further changes to the paradigm were made to improve the accuracy of our results compared with previous JTC research. We introduced a control condition to assist in our ability to screen out participants who either did not fully understand the task or were not paying full attention. This condition took the form of a series of catches in which the percentages of fish in the 2 lakes were 50% black and 50% white, with uniform fish catches. Individuals who showed large deviations in responses from the anticipated estimated probability of 0.5 (50/[50 + 50]) by the end of the series of catches were excluded from further analysis.

Experiment

A computerized beads task variant, using estimates made on a graded response scale,[23] was presented offline using Microsoft Internet Explorer 6.0. This task was written in JavaScript/html, with graphics (stimuli) prepared in Adobe Photoshop CS3. Instead of beads and containers, participants were presented with fish and lakes (Fig. 1). An image of a fisherman stood between 2 lakes, with each lake containing a different ratio of black fish to white fish. The lake on the left was designated "Lake A" and the lake on the right, "Lake B." Each trial consisted of a series of 10 fish being caught, with ratings made after each fish. Participants were told that the fisherman was fishing from only 1 of the 2 visible lakes and that he was returning the fish to the same lake after each catch, such that the total ratio of black to white fish did not change across the series. The ratios of black to white fish in each lake were not stated by the experimenter, but they were graphically represented on the screen, to be estimated by the participants.

Each series began with the fisherman holding his current catch (a black or white fish). Participants were instructed to rate how likely they thought it was that he was fishing from Lake A and how likely it was that he was fishing from Lake B following each fish catch in a series. Ratings were made using sliders on 2 horizontal probability scales, one for each lake, ranging from 0 to 10 (labels were placed below the sliders as follows: 0 = very unlikely, 2.5 = unlikely, 5 = possible, 7.5 = likely, 10 = very likely). The ratings for each lake were independent of each other, such that high ratings for Lake A did not preclude the possibility of giving high ratings for Lake B. A brief practice session was used to familiarize participants with the 2 sliding rating scales before the experiment began.

The experiment consisted of 6 series, each comprising 10 fish catches. The ratios of black to white fish in each lake were different for each session (Table 2). For series 2, 3, 4 and 6, all 10 fish caught were the same colour. Fish colour varied across series 1 and 5 in the following order (B = black; W = white):

- Series 1: B-W-B-W-W-B-W-B-B-W
- Series 5: B-W-B-B-B-B-W-B-B-B

Lake positions and fish colour for both catches and lake ratios were counterbalanced across series and participants.

Data analysis

For the purpose of data analysis, we took counterbalancing into account by transforming the data such that black fish represented the constant fish colour for series 2, 3, 4 and 6 and the predominant colour in series 5. For series 1, in which an equal number of black and white fish were caught, we transformed the data such that the first fish catch was black for all randomizations. We organized the lakes such that the

Table 2: The percentage ratio of black to white fish in Lake A and Lake B and the sequence of fish catch colours for series 1 to 6*

Series, catch	Lake A, B:W	Lake B, B:W
1. B-W-B-W-W-B-W-B-B-W	50:50	20:80
2. B-B-B-B-B-B-B-B-B-B	80:20	20:80
3. B-B-B-B-B-B-B-B-B-B	80:20	50:50
4. B-B-B-B-B-B-B-B-B-B	50:50	20:80
5. B-W-B-B-B-B-W-B-B-B	80:20	50:50
6. B-B-B-B-B-B-B-B-B-B	50:50	50:50

B = black fish; W = white fish
*Lake positions and fish colour for both catches and lake ratios were counterbalanced across series and participants. Counterbalancing was taken into account here and elsewhere (e.g., data analysis) by transforming the data such that black fish represented the constant fish colour for series 2, 3, 4 and 6, and the predominant colour in series 5. For series 1, where an equal number of black and white fish were caught, the data were transformed such that the first fish caught was set to black. Additionally, the lakes were organized such that the lake with the higher proportion of black fish was designated "Lake A" and the other "Lake B."

lake with the higher proportion of black fish was designated Lake A and the other Lake B. We performed an additional transformation for series 1 and 5, in which we transformed the data to be equivalent to that of series 2, 3, 4 and 6, with Lake A representing the lake that best matched the catches and Lake B representing the nonmatching lake.

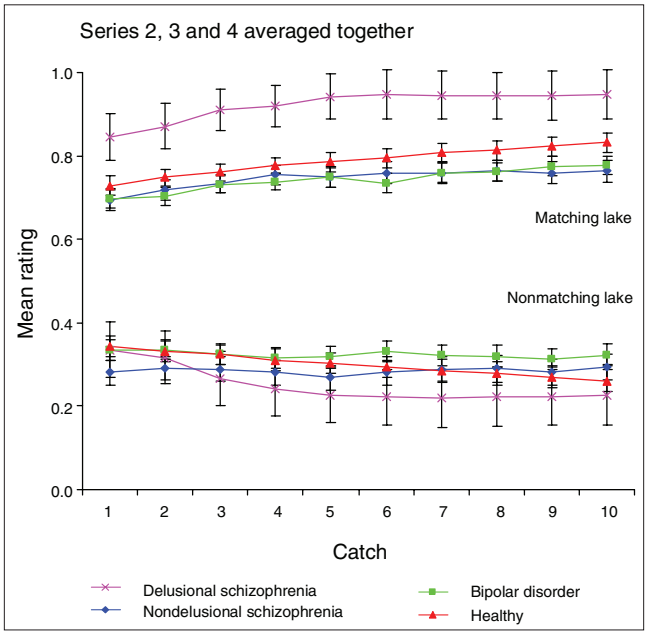

Fig. 2: Average matching lake (top) and nonmatching lake (bottom) ratings for series 2, 3 and 4. A "match" is a situation in which the ratio of fish in one lake makes it the best choice with regards to the colour of the current fish catch. Error bars represent the standard error of the mean.

The main analyses were carried out separately for uniform and mixed fish series and separately for the ratings of the single lake of the pair that most closely matched the fish colour presented on a given trial, and the nonmatching lake (i.e., the other lake). These analyses were carried out by way of two 3-way analyses of variance (ANOVAs), with lake ratings as the dependent variable. For the uniform fish series, the ANOVA was based on a $10 \times 3 \times 4$ mixed-model ANOVA, with catches (1–10) and series (2, 3 and 4) as the within-subjects factors and group (delusional schizophrenia patients, nondelusional schizophrenia patients, bipolar patients and healthy controls) as the between-subjects factor. For the mixed fish series, the ANOVA was a $10 \times 2 \times 4$ mixed model, with catches (1–10) and series (1 and 5) as the within-subjects factors and group (delusional schizophrenia patients, nondelusional schizophrenia patients, bipolar patients and healthy controls) as the between-subjects factor. We tested sphericity; it did not affect any of the results reported here, so the unadjusted degrees of freedom are reported in all cases. Series 6 was not analyzed because it was included in the study as a control condition used to identify and exclude participants who did not understand the task instructions or failed to attend to the task requirements.

Results

Patient demographics

Univariate ANOVAs comparing groups on demographic and IQ measures indicated significant differences between the groups for years of education ($F_{3,85} = 4.52$, $p < 0.01$; K-BIT Vocabulary, $F_{3,76} = 4.24$, $p < 0.01$; Quick Test, $F_{3,85} = 4.13$, $p = 0.01$). Sex also differed between groups ($\chi^2 = 8.53$, degrees

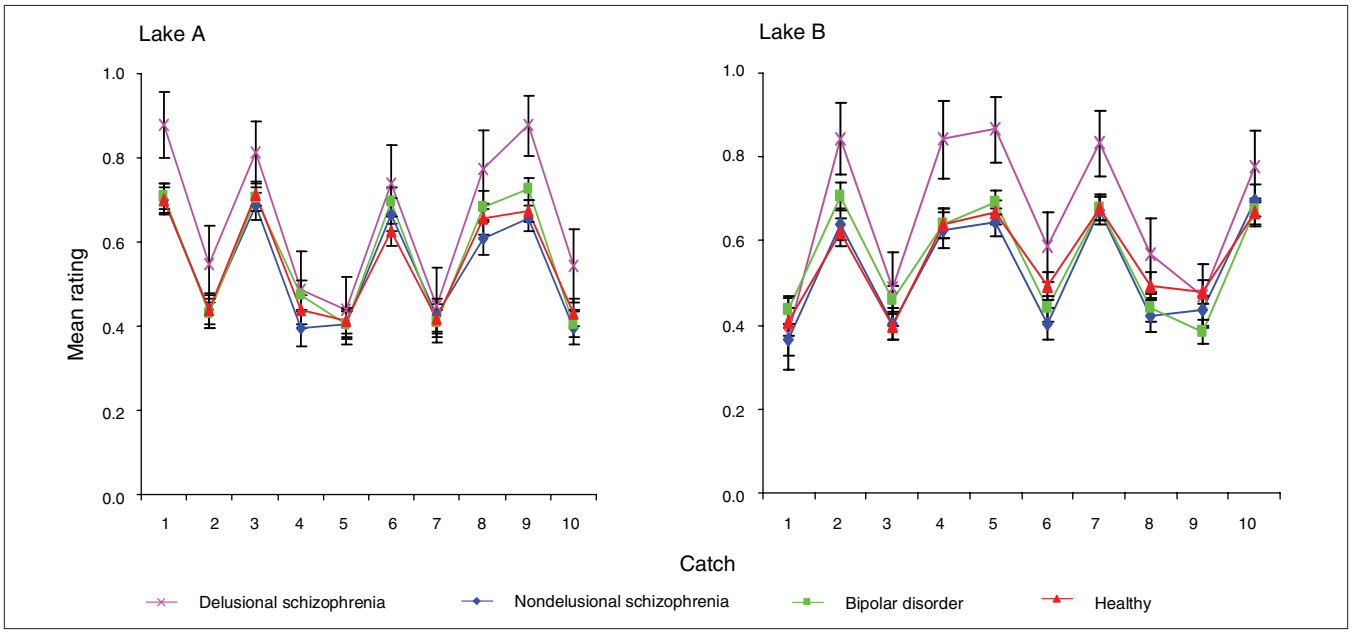

Fig. 3: Ratings for series 1 for Lake A and B, plotted as a function of catches. Counterbalancing was accounted for by designating Lake A as the lake best supported by the first fish catch. Error bars represent the standard error of the mean.

of freedom 3, $n = 102$, $p < 0.05$). The socio-demographic characteristics of the sample are summarized in Table 1. Note that the delusional and nondelusional schizophrenia groups did not differ significantly for any variable, with the exception of delusion-related symptom scores.

Uniform coloured fish series

For the matching lake ratings, there were significant main effects of catches ($F_{9–882} = 11.65$, $p < 0.001$) and series ($F_{2–196} = 14.13$, $p < 0.001$), but these factors did not interact, ($F_{18–1764} = 0.22$, $p = 1.00$). The catches effect was characterized by a strong linear increase over the 10 draws ($F_{1–98} = 15.29$, $p < 0.001$) combined with quadratic and cubic trends ($F_{1–98} = 8.75$, $p < 0.005$; $F_{1–98} = 4.36$, $p < 0.05$), such that the slope of the linear increase flattened with later draws, with no other trends being significant (all $p > 0.46$). The series effect was characterized by different average ratings for the matching lake over series 2, 3 and 4 (mean 0.85, 0.81 and 0.74). Although all 3 series had an 80:20 matching fish ratio, higher ratings for series 2 were expected because the competing lake had an 20:80 ratio as opposed to a 50:50 ratio for series 3 and 4.

The effects of catches and series did not interact with group (all $p > 0.76$); therefore, we averaged the group comparisons over catches and series. The group effect was highly significant ($F_{3–98} = 4.60$, $p < 0.005$). As can be seen in Fig. 2 (averaged over series 2–4), this effect was characterized by the rating of the matching lake being significantly higher for the delusional schizophrenia group (mean 0.92) compared with the averaged ratings of the nondelusional schizophrenia group (mean 0.75), bipolar group (mean 0.74) and healthy control group (mean 0.79) ($F_{1–98} = 10.44$, $p < 0.005$).

For the nonmatching lake ratings, there were significant main effects of catches ($F_{9–882} = 4.14$, $p < 0.001$) and series ($F_{2–196} = 10.45$, $p < 0.001$), but these factors did not interact ($F_{18–1764} = 0.62$, $p = 0.88$). The catches effect was characterized by a linear decrease over the 10 draws ($F_{1–98} = 5.00$, $p < 0.05$), combined with a quadratic trend ($F_{1–98} = 6.91$, $p < 0.01$) such that the slope of the linear decrease flattened with later draws, with no other trends being significant (all $p > 0.11$). The series effect was characterized by different average ratings for the matching lake over the series, with series 2 (mean 0.24) having lower ratings than either series 3 or 4 (mean 0.29, 0.34, respectively). Lower ratings for series 2 were expected because the nonmatching lake had a 20:80 ratio as opposed to 50:50 for series 3 and 4. The effects of catches and series did not interact with group (all $p > 0.15$); therefore, we averaged the group comparison over catches and series, and it was not significant ($F_{3–98} = 0.63$, $p = 0.58$).

Mixed-colour fish series

The progression of ratings for series 1 and 5 (Fig. 3, Fig. 4) suggests that the delusional schizophrenia group rated the plausibility of the lake that matched the presented fish (with respect to the more dominant colour of fish in the lake) higher than did the other groups in any given trial, with no group difference for ratings of lakes that did not match the presented fish in any given trial. Therefore, as with series 2, 3 and 4, series 1 and 5 were analyzed separately for matching and nonmatching lakes.

For the matching lake ratings, there was a significant main effect of catches ($F_{9–882} = 5.97$, $p < 0.001$) and this interacted with the series ($F_{9–882} = 14.13$, $p < 0.001$). The source of this interaction was that there was no significant effect of catches for series 1 ($F_{9–882} = 1.33$, $p = 0.22$) but there was for series 5 ($F_{9–882} = 15.29$,

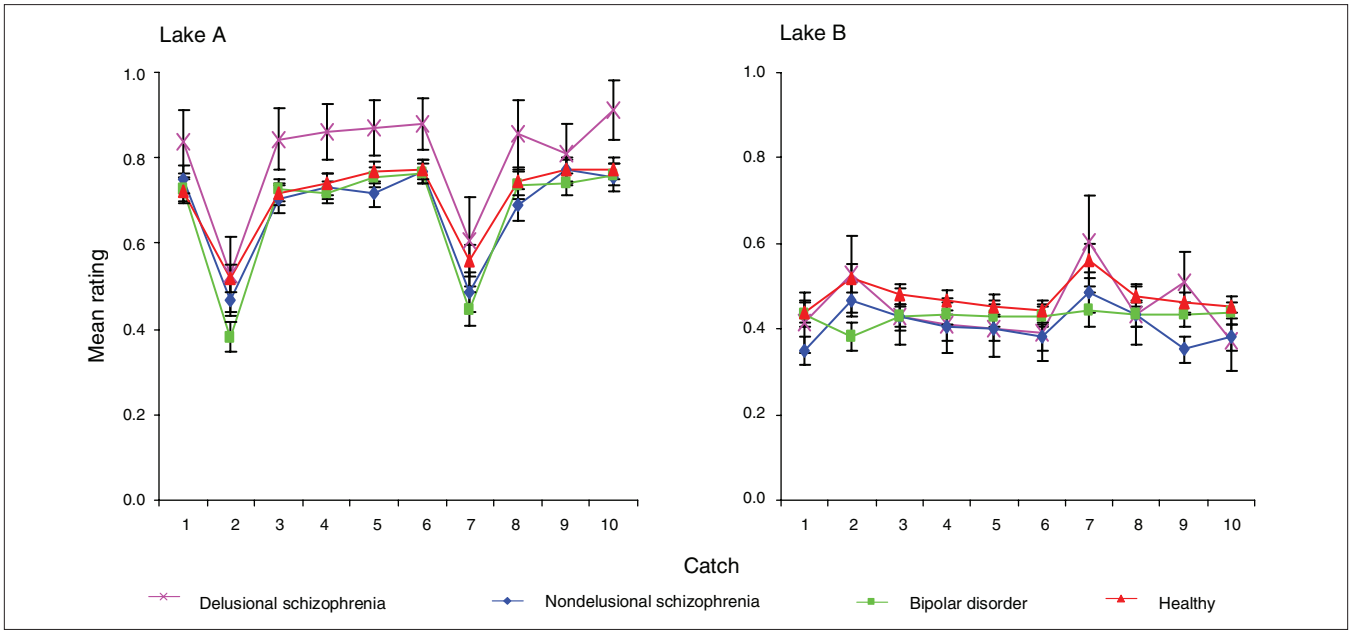

Fig. 4: Ratings for series 5 for Lake A and B, plotted as a function of catches. Counterbalancing was accounted for by designating Lake A as the lake best supported by the majority of the fish catches. Error bars represent the standard error of the mean.

$p < 0.001$). For series 5, the linear effect was significant ($F_{1–98} = 6.03$, $p < 0.05$), reflecting increasing ratings over the 10 catches, as was observed for the uniform coloured fish matching lakes. Five higher-order effects for catches were also significant, describing a pattern whereby lower ratings were observed for the matching lake for the less frequently presented colour relative to those for the more frequently presented colour. This was not the case for series 1.

The effects of catches and series did not interact with group (all $p > 0.63$); therefore, we averaged group comparisons over catches and series. The group effect was significant ($F_{3–98} = 2.84$, $p < 0.05$). This effect was characterized by the rating of the matching lake being significantly higher for the delusional schizophrenia group (mean 0.83) compared with the averaged ratings of the nondelusional schizophrenia group (mean 0.68), bipolar group (mean 0.70) and healthy control group (mean 0.69) ($F_{1–98} = 7.90$, $p < 0.01$).

For the nonmatching lake ratings, there were significant main effects of catches ($F_{9–882} = 2.62$, $p < 0.01$), and this interacted with series ($F_{9–882} = 14.13$, $p < 0.001$). The source of this interaction was that there was no significant effect of catches for series 1 ($F_{9–882} = 1.67$, $p = 0.09$), but there was for series 5 ($F_{9–882} = 4.20$, $p < 0.01$). For series 5, the linear effect was not significant, but 4 higher-order effects for catches were significant. These describe the following pattern: in the 2 trials of series 5 in which the fish caught should lead to a decrease in the rating of the matching lake (trials 2 and 7), participants' ratings were higher than would be expected given the evidence. The effects of catches and series did not interact with group (all $p > 0.07$); therefore, we averaged the group comparison over catches and series, and it was not significant ($F_{3–98} = 1.54$, $p = 0.21$).

Ratings averaged over all series

We also performed an analysis of ratings averaged over series 1–5, with separate variables computed for matching and nonmatching lakes (Fig. 5). One-way ANOVA showed a significant group effect for the matching lakes ($F_{3–98} = 4.71$, $p < 0.005$) but not for the nonmatching lake ($F_{3–98} = 0.52$, $p = 0.67$). The results of t tests on the matching lake ratings suggested that the delusional group differed significantly from all other groups (all $p < 0.01$), but none of the other groups differed from one another (all $p > 0.23$). Within the schizophrenia group, we observed a significant correlation between the SSPI delusions item and the matching lake ratings ($r_{28} = 0.47$, $p < 0.01$) but not for the nonmatching lake ratings ($r_{28} = –0.04$, $p = 0.83$). No comparisons were significant when the schizophrenia group was divided into patients with high and low hallucinations (all $p > 0.12$). We could not test parallel high–low splits for other symptoms owing to the small numbers of participants with ratings in the high-to-severe range (Table 1).

Discussion

Typically, JTC has been measured by use of the beads task, in which a single bipolar rating scale is used to measure the likelihood that beads are being drawn from one jar and not the other. Using a variant of this task, we provided separate rating scales for 2 options. This approach indicated that the delusional group could be differentiated from the other groups by increased trial-by-trial likelihood ratings for whichever lake matched the current evidence. For example, if a black fish was shown, the delusions group gave a higher rating to the lake with the higher proportion of black fish than did members of the other groups. This trial-by-trial group difference was only seen for the matching lake and not the nonmatching lake. In other words, although the delusional group showed an exaggerated increase in likelihood ratings for whichever lake matched the current fish, this did not translate to correspondingly greater decreases in ratings for the lake that was not supported by the current catch. This suggests that delusions in schizophrenia are associated with a reasoning bias characterized by hypersalience of evidence–hypothesis matches, but with reasoning that appears comparable to that of control groups for evidence–hypothesis nonmatches. This effect was not found when we subdivided the schizophrenia group on the basis of hallucinations, suggesting that the hypersalience effect is specific to delusions.

Our results are compatible with accounts that suggest that the JTC bias is associated with delusions. Increased likelihood ratings for evidence–hypothesis matches for the delusional group may be expected to translate to a premature termination of data collection using the draws-to-decision procedure.[9] However, the current set of results takes the JTC theory one step further by describing why the delusional group shows a premature termination of data collection: the hypersalience of an hypothesis–evidence match may translate into sufficient evidence for the early acceptance of an option.

Hypersalience is consistent with the aberrant salience account of psychosis,[24] which posits that dysregulated dopamine transmission in schizophrenia may result in context inappropriate salience attributions, exaggerating the importance of percepts. However, to integrate this account with the current data, hypersalience must be extended only to hypothesis–evidence matches and not to any type of neutral material (notably not to

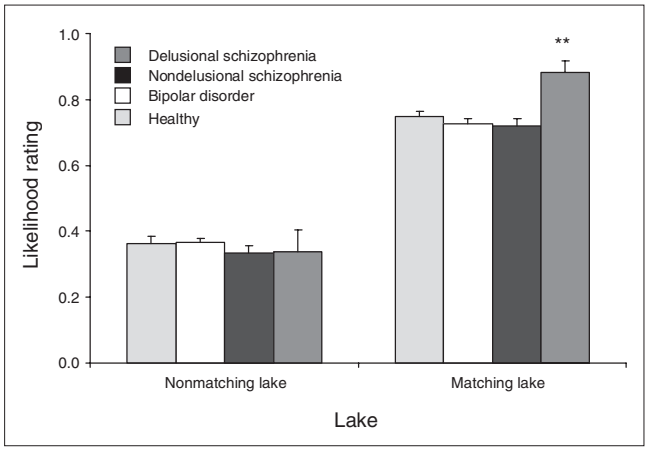

Fig. 5: The average ratings for series 1–5 plotted as a function of group and whether the presented fish matched the lake being rated. Error bars represent the standard error of the mean. $^{**}p < 0.01$ for adjacent bars.

hypothesis–evidence nonmatches). Given that neurotransmission in the ventral striatal dopamine pathway is thought to reinforce stimulus–response or stimulus–stimulus associations,[25–27] and, combined with the hippocampus, has the capacity to reinforce patterns of cerebral activity associated with a particular mental event,[28,29] it can be speculated that evidence–hypothesis matches were hypersalient for severely delusional patients in the current study owing to dysregulated dopamine transmission in the ventral striatal dopamine pathway.

In addition to JTC bias, the beads literature contains frequent reports of what has been referred to as either an "overadjustment bias"[3,4] or a "bias toward disconfirmatory evidence"[2] in people with delusions. This effect refers to downward overadjustments in probability estimates following a single instance of disconfirmatory evidence. Our results are directly compatible with this effect but provide an additional piece of important information: "overadjustment" applies only to the upward rating of the matching lake or jar and not to the downward rating of the nonmatching lake or jar. Thus, it is only movement toward the currently favoured option that differentiates the delusional group from the others. That such an effect is evident even on the first trial in a series, and on every trial of a series of uniform fish colours, suggests that JTC and overadjustment may both be behaviours resulting from the hypersalience of evidence–hypothesis matches. Describing the same behaviour (high ratings on evidence–hypothesis matches) as JTC when it occurs at the beginning of a series and as overadjustment when it occurs midseries may be adding an unnecessary level of complexity. Put simply, our results suggest that people with delusions show a greater preference for whichever option is supported by the current incoming data, while simultaneously showing normal ratings for the less supported option. Whether the evidence confirms a recent judgment is irrelevant to understanding this effect.

The notion of a disconfirmatory bias has been of interest to our group given our well-supported work on the "bias against disconfirmatory evidence" (BADE) in schizophrenia,[30,31] which some evidence suggests is stronger for currently delusional individuals.[32,33] The apparent irreconcilability of the 2 concepts (i.e., that delusions are associated with a bias toward disconfirmatory evidence in the JTC literature and a bias against disconfirmatory evidence in the BADE literature) could be resolved by accepting that what is described by other groups as a disconfirmatory bias in JTC should perhaps be reconceptualized as a hypersalience of evidence–hypothesis matches, because the hypersalience reported here does not extend to an enhanced tendency to disconfirm previously supported outcomes.

One of our motivations for the current study was to assess how close to optimal Bayesian reasoning the different groups were using our probabilistic reasoning paradigm. Optimal Bayesian reasoning involves the integration of incoming information with the current state of knowledge, such that the resulting probability estimates for a given trial appropriately integrate the entire series of data. At the other extreme are probability ratings that take into account the current trial, effectively ignoring previously encountered data. This could be considered decidedly non-Bayesian reasoning. Figure 6 shows

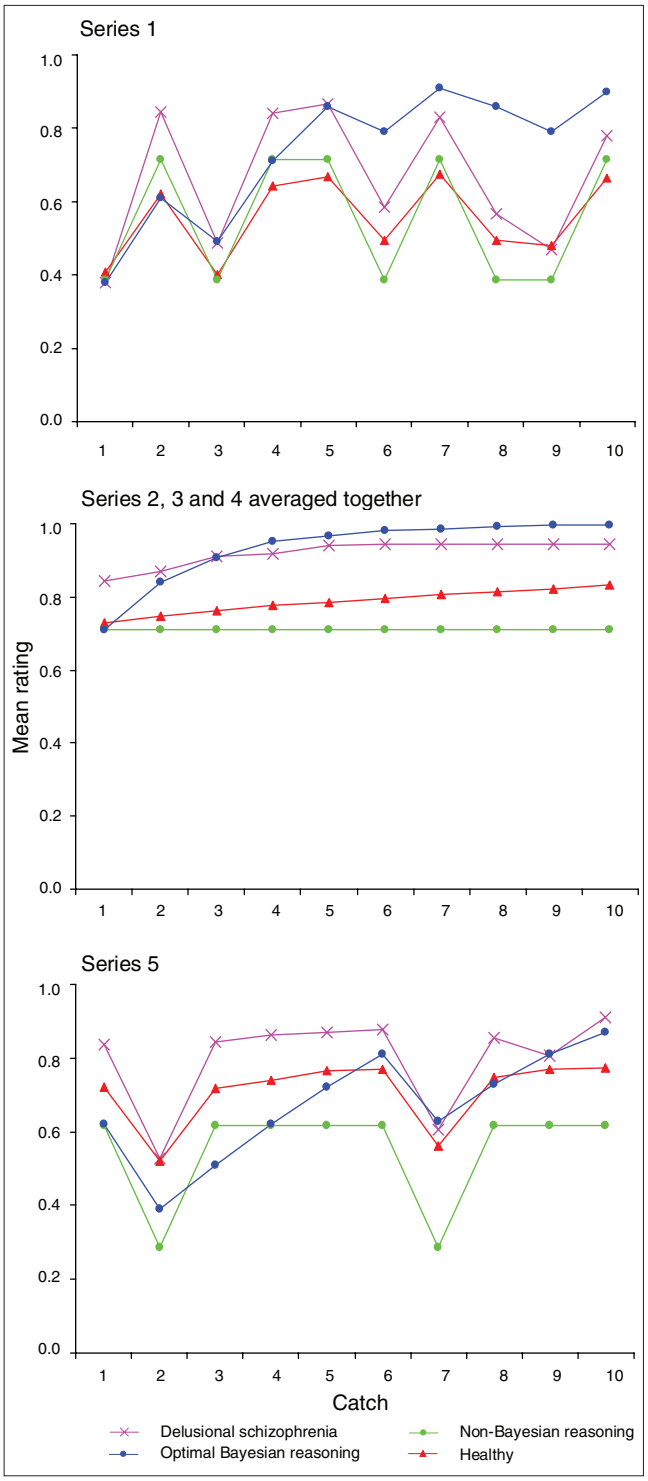

Fig. 6: Ratings for matching lakes compared with the optimal Bayesian reasoning pattern expected if the information presented over the whole series of catches is taken into account, and the opposite, non-Bayesian reasoning pattern in which individual catches are rated as independent events. Probabilities were computed as the probability of the focal hypothesis (i.e., the lake best supported by the fish catches or "matching lake") being true and not the alternate hypothesis.

a comparison of responses anticipated by these 2 contrasting modes of responding with the actual responses of participants.

It has been previously stated that the performance pattern displayed by delusional schizophrenia patients is more Bayesian than that of healthy controls.[1,34] However, as shown in Figure 6, it may not be accurate to characterize the delusional group's responses as being closer to optimal Bayesian reasoning than the other groups. For the uniform incoming data conditions, the optimal Bayesian reasoning curve shows a sharp increase in probability estimates initially, reaching a plateau after sufficient evidence has been collected. None of the groups showed this pattern of responding. All showed a considerably more modest influence of cumulative data across catches, with the delusional group being more confident from the outset, registering a higher baseline. The delusional group can be considered closer to optimal Bayesian responders in that their maximal level of confidence is closer to the maximal level predicted by the Bayesian formula, but, at the same time, they would be considered the least Bayesian group after only 1 catch, with the Bayesian formula predicting the more conservative ratings shown by the other groups.

For the mixed conditions (series 1 and 5), in which the incoming evidence is relatively less persuasive, it appears that trial-by-trial information is much more salient than series information, with the responses of all groups more closely matching the expected response for non-Bayesian reasoning, with each catch being considered an independent event. The undue influence of individual trial evidence on the ratings of all groups in a mixed condition is in accordance with past research.[3,35] In summary, it is not accurate to say that the delusional group generally shows more Bayesian reasoning than the other groups.

Limitations

One limitation of the current study is the small sample size associated with the delusional group. However, achieving a modest sample of severely delusional patients would require recruitment of a reasonably large number of people with schizophrenia, because people with this symptom profile are difficult to find. Scoring a 4 on the SSPI delusions item implies not only that a delusion is held but also that the delusion has such a pervasive influence on thinking that little else occupies the individual's thoughts. If definite delusions are present but do not have a pervasive influence on thinking, in that topics of discussion untouched by delusional thought are readily accessible, this person would rate a 3 on the SSPI delusions item. The present results suggest that these cognitive biases may only be present if delusions are very severe and that, in states of relative remission, delusions may be more memory-based than caused by active cognitive biases.

Another limitation is that other symptoms and measures of chlorpromazine-equivalent medication differed between the delusional and nondelusional schizophrenia group, although none of these were significantly different. Delusion-related symptom scores were the only variables that differed significantly between the 2 schizophrenia groups. The bipolar group rated lower on a number of positive symptoms than did either schizophrenia group, but since the bipolar group did not differ from the nondelusional schizophrenia group on any of the experimental measures, this would not directly affect the interpretation of the current set of results. With respect to level of medication, the direction of the medication differences were such that the performance of the more medicated group was equivalent to that of the healthy controls in all conditions, implying that higher levels of medication could not have caused the aberrant performance of those in the delusional group.

Conclusion

In this study, a number of adaptations of previous studies appeared to clarify the source of the JTC bias observed in patients with delusions. First, we separated the ratings for lakes A and B, instead of using an integrated A–B continuous scale, allowing the observation that JTC is caused by hypersalience of evidence–hypothesis matches and does not extend to nonmatching situations. Second, the use of a control condition with a ratio of 50% black fish to 50% white fish allowed for the exclusion of participants using cognitive strategies that were not the target of our investigation. Third, recruitment of a sample of patients large enough to allow severely delusional patients to be grouped separately allowed for the observation of the hypersalience effect.

The conclusion of our study is that delusions in schizophrenia appear to be associated with the hypersalience of evidence–hypothesis matches, although reasoning appears comparable to that of control groups for nonmatches. This effect appears robust, occurring regardless of manipulations of the incoming data, although it may only be present when delusions are in their most severe form.

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