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Bias in favour of self-selected hypotheses is associated with delusion severity in schizophrenia

Jennifer C. Whitman[1,2], Mahesh Menon[1,3,4], Susan S. Kuo[1,2], and Todd S. Woodward[1,2]

[1]Department of Psychiatry, University of British Columbia, Vancouver, BC, Canada
[2]BC Mental Health & Addictions Research Institute, Vancouver, BC, Canada
[3]Schizophrenia Program and PET Centre, Centre for Addiction & Mental Health, Toronto, Canada
[4]Department of Psychiatry, University of Toronto, Toronto, Canada

Introduction. Delusions are typically characterised by idiosyncratic, self-generated explanations used to interpret events, as opposed to the culturally normative interpretations. Thus, a bias in favour of one's own hypotheses may be a fundamental aspect of delusions.
Methods. We tested this possibility in the current study by comparing judgements of self-selected hypotheses to judgements of externally selected ones in a probabilistic reasoning task. This allowed us to equate self- and externally selected hypotheses in terms of objectively quantifiable supporting evidence. It is normal to be biased in favour of self-selected hypotheses, but we expected this bias to be exacerbated in schizophrenia patients relative to healthy and psychiatric controls, and to be correlated with the severity of delusions in the schizophrenia sample.
Results. As expected, all groups showed the self-selection bias. Although this bias was not increased in schizophrenia patients relative to the control groups, it was significantly correlated with the severity of delusions in the schizophrenia sample.

Correspondence should be addressed to Todd S. Woodward, Room A3-A116, BC Mental Health & Addictions Research Institute, Translational Research Building, 3rd Floor, 938 W. 28th Avenue, Vancouver, British Columbia, Canada V5Z 4H4. Email: Todd.S.Woodward@gmail.com

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Conclusions. These results fit with an account holding that the hypersalience of an individual's own interpretations of events, relative to culturally normative interpretations, may manifest in a self-selection bias, contributing to the delusional state in schizophrenia.

Keywords: Delusions; Hypersalience; Probabilistic reasoning; Schizophrenia; Self-selection bias.

INTRODUCTION

Delusions in schizophrenia are typically characterised by self-generated, idiosyncratic explanations used to interpret events, as opposed to the culturally normative interpretation (Mullen, 1979). Cognitive accounts of delusions in schizophrenia (reviewed in Bell, Halligan, & Ellis, 2006; Garety & Freeman, 1999) have focused on probabilistic reasoning biases (Garety, Hemsley, & Wessely, 1991; Moritz & Woodward, 2005), theory of mind deficits (Frith, 1994), attributional biases (Bentall, 1994), and incorrect attribution of salience to benign external stimuli and internal percepts (Kapur, 2003; McKenna, 1991; van Os, 2009). However, despite its face validity, whether a cognitive bias towards self-generated hypotheses may be associated with delusions in schizophrenia has not been empirically tested to our knowledge.

In past work on healthy participants it has been noted that a bias towards overrating the plausibility of one's own hypotheses, relative to those suggested by others, is a characteristic of healthy human cognition (Koehler, 1994; Ronis & Yates, 1987; Sieck, 2003; Sieck & Yates, 2001; Sniezek, Paese, & Switzer, 1990). These early studies confounded self-selection with a variety of other material-based cognitive variables (e.g., familiarity of subject matter, fluency in memory retrieval, completeness of memory retrieval), but work in our laboratory using a probabilistic reasoning paradigm demonstrated that even if self- and externally selected hypotheses are exactly equated in terms of objectively quantifiable supporting evidence, self-selected focal hypotheses were judged to be more probable than externally selected ones (Whitman & Woodward, 2012). In the current study, we extend this work by administering this task to a sample of schizophrenia patients, and comparing their performance to psychiatric and healthy control groups.

The probabilistic reasoning paradigm used here is a variation of the beads-from-a-jar probabilistic reasoning task (Huq, Garety, & Helmsley, 1988; Moritz & Woodward, 2005). The traditional probabilistic reasoning task involves judging the likelihood that a series of beads is drawn from Jar A rather than Jar B, based on the colours of the beads in Jars A and B, and on the colours in the series of beads being drawn. We have developed versions of this task involving a fisherman fishing from one of two lakes (Speechley, Whitman, & Woodward, 2010; Woodward, Munz, LeClerc, &

Lecomte, 2009) or downstream jumping fish originating from one of two or more upstream lakes (Whitman & Woodward, 2011, 2012). The version of the task used here involved judging the probability that a single jumping fish originated from one of three lakes (Whitman & Woodward, 2012). Specifically, participants judged the probability that the fish originated from a given self- or externally selected lake rather than being drawn from either of the two alternatives. The self- or externally selected lake is referred to as the *focal hypothesis*, and the other two lakes are referred to as *alternative hypotheses*. On all trials, participants were required to indicate the likelihood that the focal hypothesis (rather than the two alternatives) was true. The self-selected hypotheses were tracked, and computer-selected hypotheses were produced that exactly matched the self-selected hypotheses in terms of supporting evidence.

Based on our past work, we predicted a self-selection bias for all participants, whereby probability ratings of the focal hypothesis would be higher if it was self-selected than if it was externally selected (Whitman & Woodward, 2012). Based on the self-generated nature of delusions and the centrality of the delusional state to schizophrenia, we expected this bias to be exacerbated in schizophrenia patients relative to healthy and psychiatric controls, and to be correlated with the severity of delusions in the schizophrenia sample.

METHODS

Participants

Thirty-six participants with schizophrenia and 16 psychiatric controls (diagnosed with bipolar disorder) were recruited from psychiatric hospitals and community health agencies in and around Greater Vancouver, British Columbia, Canada. All diagnoses were based on DSM-IV-R criteria (American Psychiatric Association, 2000). Diagnoses were confirmed with the Mini-International Neuropsychiatric Interview (MINI; Sheehan et al., 1998), which was administered on the date of testing. Psychopathology was assessed using the Signs and Symptoms of Psychotic Illness scale (SSPI; Liddle, Ngan, Duffield, Kho, & Warren, 2002), a schedule gauging symptom severity using 20 symptom items scored 0–4. Item 7 from the SSPI was used to quantify the severity of delusions. The possible values on this item are: 0 (“absent”), 1 (“vague idea which might be delusional”; “peculiar ideas which do not conflict with evidence in a clear-cut manner”), 2 (“belief contrary to evidence, but patient has partial insight in the unrealistic nature of the belief”), 3 (“definite delusions, but the delusional beliefs do not have a pervasive influence on thinking or behaviour”), and 4 (“definite delusions which have pervasive influence on thinking and/or influence observable

behaviour''). Any or all of delusions of guilt, grandiose delusions, paranoid delusions, delusions of reference, or Schneiderian delusions can be rated on this item. All bipolar patients had SSPI delusions scores of 0.

Participants were excluded if they reported a head injury resulting in a loss of consciousness for 10 minutes or more, and for current and past substance abuse and alcoholism. Substance abuse was assessed by chart review and by interview, and participants were excluded 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 two patients, all patients with schizophrenia were stabilised with antipsychotic medications, with 27 on atypical antipsychotics and nine on typical antipsychotics. Of the 16 patients in the bipolar group, seven were on antidepressants only, seven were on antidepressants and atypical antipsychotics, one was on antidepressants and typical antipsychotics, and one was on typical antipsychotics only. All schizophrenia patients were either currently experiencing delusions, or had in the past. Eight of the 16 bipolar patients had some history of psychotic features.

Thirty-three healthy control participants were recruited via posters on the University of British Columbia campus and in community centres in the greater Vancouver area, and also via postings on electronic bulletin boards. All participants were reimbursed $10 per hour for their time plus parking and transportation expenses. The healthy control group had no history of psychiatric illness as determined by a medical questionnaire. Additional exclusion criteria were the same as those employed for the patient groups.

All participants were fluent in English. Intelligence estimates were made using the Kaufman Brief Intelligence Test (K-BIT; Kaufman & Kaufman, 1997) for verbal and nonverbal intelligence, and the Ammons Quick Test (QUICK; Ammons & Ammons, 1962) for an assessment of current intelligence quotient (IQ). Socioeconomic status was estimated using the Amherst Modification of the Hollingshead–Redlich Two-Factor Index of Socioeconomic Status (Hollingshead & Redlich, 1958; Watt, 1976) using highest parental occupation and education level.

The probabilistic reasoning task used in this study allows exclusion of data that is characteristic of poor performance, or a lack of understanding of task instructions. Namely, the lake that is chosen as a self-selected hypothesis should be the mathematically most likely origin of the downstream jumping fish. In accordance with our methodology on healthy participants (Whitman & Woodward, 2012), in order to ensure that participants clearly understood the instructions, we excluded their data if their accuracy in selecting the most probable hypothesis as the focal hypothesis was less than 81% (more than five errors out of 27 selection trials). As a result, the groups described earlier consisted of the participants remaining after 14 of the original 99 participants (one healthy control, two bipolar patients, and 11 schizophrenia patients) were excluded due to evidence that they did not understand

the task. In our experience, comprehension in probabilistic reasoning tasks is very important for reducing noise in the dataset (Balzan, Delfabbro, Galletly, & Woodward, 2012; Moritz & Woodward, 2005; Speechley et al., 2010), and for interpretation of the measures of interest (in this case the self-selection bias). If a participant is not meeting the basic reasoning requirements, the measured cognitive processes cannot be known.

Materials and procedure

Each trial of our probabilistic reasoning task involved a scene depicting four blue lakes (see Figure 1), three of which were upstream from the fourth. On all trials participants were required to rate the relative probability that the focal hypothesis, rather than its alternatives, was true. For the self-selected focal hypothesis trials, participants were required to select the lake that they

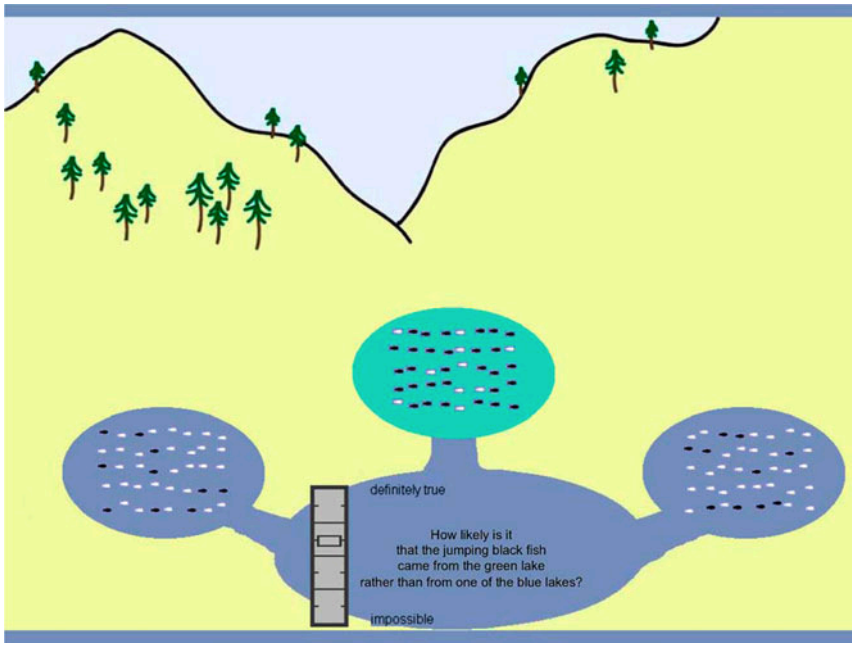

Figure 1. Display presented during a typical trial of this experiment. At the start of each trial, a single black or white fish was shown to jump in the downstream lake. If the trial involved a self-selected focal hypothesis, the participant indicated the upstream lake from which the jumping fish was most likely to have migrated, which then turned green. Otherwise, the green lake was selected by the computer. Next, the participant rated the probability of that fish having migrated downstream from the green lake (the focal hypothesis) rather than either of the blue upstream lakes (the alternative hypotheses).

preferred prior to making the probability rating. In contrast, for the externally selected trials, the to-be-rated focal hypothesis was selected by the computer. Unknown to the participant, the computer-selected lakes were matched precisely to the self-selected lakes by computerised yoking based on the participants' pattern of responding. A more detailed description of the methodology follows, and the full description has been published elsewhere (Whitman & Woodward, 2012). The probabilistic reasoning task employed here was identical to Experiment 2 of the previously published paper, with the exception that participants completed only one-third as many experimental blocks in the current study.

At the start of each trial, a single black or white fish was seen to jump in the downstream lake. The colour of this jumping fish, referred to hereafter as the relevant colour, was randomised across trials. Next, the contents of each of the three upstream lakes became visible. Each contained a mixture of black and white fish (40 fish in total per lake), which remained in view until a rating had been made. Participants were told that the fish in the downstream lake originated from one of the upstream lakes. Thus, each upstream lake corresponded to a hypothesis about the origin of the jumping fish. The upstream lake with the most fish of the relevant colour was the most likely origin of the fish in the downstream lake.

Next, if the trial was in the self-selected condition, participants indicated the lake they deemed to be the most likely origin of the jumping fish by moving the mouse cursor (a red square) over their preferred lake and clicking with the left mouse button. This lake, referred to hereafter as the focal lake, then turned green. If the trial was in the computer-selected condition, the focal lake was selected by the computer to match the choice made by the participant on an equivalent trial in a preceding block with self-selected focal hypotheses. The focal lake turned green immediately after the fish in the bottom lake jumped, at the same time as the fish in the upstream lakes became visible.

Once the focal lake was selected (self- or computer-selected), participants were required to rate the relative probability that the focal hypothesis, rather than its alternatives, was true. Ratings were made on a vertical scale, with the labels "definitely true" at the top end and "impossible" at the bottom end. Participants used a mouse to move the slider smoothly up and down the scale and clicked the left mouse button when it was in the desired location. The vertical position of the slider, in pixels, was then recorded. In the results section, ratings are reported as a percentage of the total height of the response scale. At the beginning of each trial, the slider was set at the midpoint of the response scale. Trials with self-selected and externally selected focal hypotheses occurred in separate blocks. In total there were six blocks of nine trials each, alternating between blocks in which the focal hypothesis was self-selected and blocks in which it was externally selected.

The first block always consisted of trials in which the focal hypothesis was self-selected.

Strength of support for the focal hypothesis was manipulated, as was the strength of support for its alternatives, via control of the percentage of fish of the relevant colour in each lake. Details of these manipulations are reported in previously published work (Whitman & Woodward, 2012). As the self-selection bias found in healthy individuals does not vary as a function of support for the focal hypothesis or the two alternatives, all analyses in the current paper were collapsed across these factors. We simply assessed the magnitude of the self-selection bias for each group of participants, and assessed whether the bias correlated with the severity of delusions in the schizophrenia group.

Strategy of data analysis

We excluded from data analysis any error trials (i.e., trials on which the selected "focal hypothesis" was actually less probable than one of its alternatives). Self-selection bias scores were calculated as the difference between the mean probability rating for self-selected focal hypotheses and the mean rating for externally (i.e., computer) selected ones. Note that, as the objective probabilities were identical in these two conditions, an ideal mathematically normative rater would have a self-selection bias score of zero. Based on past work, we expected the self-selection bias score to be positive for all groups (Whitman & Woodward, 2012). For the current study, we hypothesised that the schizophrenia group would show an increased self-selection bias relative to the bipolar group and the healthy control group, and that the selection bias would correlate positively with the present severity of delusions in the schizophrenia group. Each of the statistical tests reported below was also repeated with rank-transformed scores, in order to adjust for potential skew in the data often inherent to ratings made on a probability scale (Conover & Iman, 1981). The rank transformation did not change the significance of any of the reported effects, so is not reported here.

RESULTS

Patient demographics

The sociodemographic and psychopathological characteristics of the sample are summarised in Table 1. Fisher's exact tests indicated no significant differences for gender between groups. A t-test comparing the two patient groups also revealed a significantly longer illness duration, $t(47) = 2.08$, $p < .05$, in the schizophrenia group ($M = 11.83$ years) than in the bipolar

TABLE 1
Psychopathological and socio-demographic characteristics of the participants

	Group; mean (standard deviation)[a]		
Characteristic	*Healthy n = 33*	*Bipolar n = 16*	*Schizophrenia n = 36*
Age, yrs	29.70 (9.44)	35.31 (12.14)	34.36 (9.66)
Range	19–51	19–52	19–53
Sex, male:female	18:15	7:9	21:15
Education, yrs	15.90 (1.74)	14.19 (2.04)[b]	13.49 (2.63)[c]
Parental socioeconomic status	65.88 (20.69)	70.13 (24.91)	80.94 (25.00)[d]
Quick Test IQ score	98.00 (13.18)	99.00 (9.90)	97.61 (10.15)
K-BIT IQ score			
Vocabulary	102.42 (13.72)	98.93 (11.10)	100.56 (13.54)
Matrices	110.55 (12.09)	104.00 (13.98)	104.80 (14.74)
Composite	107.45 (9.62)	101.80 (11.77)	103.06 (14.37)
Illness duration, yrs	n/a	6.79 (4.63)	11.83 (8.55)[g]
Delusions	n/a	0.0 (0.0)	1.94 (1.49)[e]
Guilt or worthlessness	n/a	0.0 (0.0)	0.36 (0.83)[g]
Grandiose	n/a	0.0 (0.0)	0.75 (1.18)[e]
Paranoid	n/a	0.0 (0.0)	1.46 (1.56)[e]
Schneiderian	n/a	0.0 (0.0)	1.06 (1.41)[e]
Hallucinations	n/a	0.0 (0.0)	1.77 (1.82)[e]
Thought disorder	n/a	0.0 (0.0)	0.31 (0.79)[g]
Underactivity	n/a	0.88 (0.81)	1.19 (1.06)
Poverty of speech	n/a	0.0 (0.0)	0.42 (0.81)[f]
Flattened affect	n/a	0.50 (0.89)	1.19 (0.92)[g]

[a]Symptom scores are derived from the Signs and Symptoms of Psychotic Illness rating scale. [b]Healthy vs. bipolar $p = .01$, [c]healthy vs. schizophrenia $p < .001$, [d]healthy vs. schizophrenia $p = .01$, [e]bipolar vs. schizophrenia $p < .001$, [f]bipolar vs. schizophrenia $p < .01$, [g]bipolar vs. schizophrenia $p < .05$.

control group ($M = 6.79$ years). Univariate analyses of variance (ANOVAs) comparing groups on demographic and IQ measures indicated significant differences between groups on years of education, $F(2, 82) = 10.45$, $MSE = 51.23$, $p < .001$, and socioeconomic status, $F(2, 78) = 3.56$, $MSE = 1936.86$, $p < .05$. Post hoc t-tests based on Fisher's least-significant difference (LSD) correction were conducted to determine which groups differed significantly from each other and are reported in Table 1. Where adjustments were required for unequal variances on t-tests, the conclusions were unchanged.

Hypothesis comparison task

Mean probability ratings are displayed as a function of self- versus computer-selected focal hypotheses in Table 2. Contrary to one of our

TABLE 2
Mean rating of the relative probability that the focal hypothesis (rather than its alternatives) was true, displayed as a function of self- and computer-selected focal hypothesis conditions (standard errors in parentheses)

Conditions	*Healthy controls (H; n = 33)*	*Schizophrenia patients (S; n = 36)*	*Bipolar patients (B; n = 16)*	*Statistics (ANOVA; post hoc means comparisons)*
Self	58.28 (2.21)	63.19 (1.88)	68.04 (2.72)	$F(2, 82) = 3.92$, $p < .05$; B > H ($p < .01$)
Computer	54.79 (1.86)	59.56 (1.74)	64.15 (2.40)	$F(2, 82) = 4.66$, $p < .05$; B > H ($p < .01$)
Self-selection bias (self-computer)	3.48 (0.93)	3.63 (1.13)	3.88 (2.15)	$F(2, 82) = 0.87$, *ns*

Note that the self-selected hypotheses were tracked, and computer-selected hypotheses were exactly matched to the self-selected hypotheses in terms of supporting evidence. Post hoc means comparisons were carried out with Fisher's least significant difference (LSD) test.

predictions, the ANOVA on the self-selection bias showed no significant effect of group, $F(2, 82) = 0.02$, $MSE = 0.87$, with the bias being present for schizophrenia and bipolar patients and in healthy controls equally (means = 3.63, 3.88, and 3.48, respectively). However, within the group of schizophrenia patients, self-selection bias was correlated significantly with delusion severity as assessed by the SSPI, $r(35) = .42$, $p = .01$. The self-selection bias was not correlated with any other SSPI symptom rating scores (all $ps > .09$), with the exception of auditory hallucinations, for which a strong correlation was also observed, $r(35) = .52$, $p < .01$. To assess the possible impact of confounding variables on this correlation, we inspected the correlations between the self-selection bias measure, the delusions item on the SSPI, and each of the characteristics in Table 1. None of the correlations were significant, so could not be confounding the relationship between the self-selection bias and delusions (the same was observed when the delusions item was replaced by the hallucinations item).

DISCUSSION

Delusions are typically characterised by idiosyncratic, self-generated explanations used to interpret events, as opposed to the culturally normative interpretations. In past work on healthy participants, it has been noted that a bias towards overrating the plausibility of one's own hypotheses, relative to those suggested by others, is a characteristic of healthy human cognition. In the current study we test whether or not such a bias is exaggerated in schizophrenia patients compared to bipolar patients and healthy controls,

and whether it is related to delusions. To achieve this, we employed a probabilistic reasoning task for which self- and externally selected hypotheses were equivalent in terms of objectively quantifiable supporting evidence. On each trial, participants rated their acceptance of a focal hypothesis relative to two alternatives, with the most probable focal hypothesis selected either by the participant, or by the stimulus presentation software. All groups showed an equivalent self-selection bias, but within the schizophrenia group, this bias was correlated with the current severity of delusions. An increased self-selection bias likely contributes to the delusional state in schizophrenia, as delusions are typically based on an individual's own interpretations of events as opposed to culturally normative interpretations.

Although an overall difference between the groups did not manifest, within the schizophrenia group severity of delusions and hallucinations correlated with the magnitude of the self-selection biases, suggesting that this bias is a state, rather than a trait aspect of the illness. This apparent discrepancy arose because the asymptomatic schizophrenia patients scored lower than the control groups on the self-selection bias, although this bias increased in a linear manner with symptom severity ($M = 0.96$, 1.18, 2.69, 3.11, 10.25; $M = 0.60$, 0.96, 1.70, 5.68, 8.44; for SSPI scores of 0, 1, 2, 3, and 4 on delusions and hallucinations items, respectively). The sample sizes are small, hampering efforts to carry out analysis of these subsets of patients with specific levels of symptom severity, and future research would be required to determine whether the decreases and increases in the self-selection bias at specific levels of severity are reliable. In the current study, the linear "dose–response" relationship between the self-selection bias and symptoms reached significance, but evidence for a trait-related group difference was absent.

A relatively large number of participants did not understand the task instructions, as they did not select the most plausible lake in the self-selection condition at a rate substantially higher than chance. This rendered the study of a self-selection bias impossible for these participants, as the reasons why they performed this way can be based on speculation only, but likely reflects some form of reasoning impairment that is not related to the self-selection bias. Exclusion was no more frequent in schizophrenia (23% excluded) than in bipolar disorder (26% excluded), although healthy controls had better comprehension (13% excluded). The excluded and retained participants for each group did not differ significantly on any demographic variable including IQ. This task may be suboptimal as a general tool for investigation of schizophrenia due to task difficulty, but when the self-selection bias is to be measured, the ability to check for accuracy is important. However, it is possible that the participants who were "left" in the analyses are unique in some way, and that their results may not generalise to the population at large.

In a previous study, also using a probabilistic reasoning paradigm, we suggested that hypersalience of evidence-hypothesis (EVH) matches (Speechley et al., 2010) may contribute to delusions in schizophrenia, such that delusional schizophrenia patients overrated the plausibility of hypotheses for which supporting evidence was provided, but did not do so for hypotheses for which supporting evidence was absent. We have also documented a bias against disconfirmatory evidence (BADE) in delusional patients (Woodward, Moritz, & Chen, 2006; Woodward, Moritz, Cuttler, & Whitman, 2006), which may be secondary to an impairment in integrating new evidence, which amounts to hypersalience of self-selected and previously endorsed interpretations of scenarios (Speechley, Moritz, Ngan, & Woodward, 2011). Thus, the BADE, hypersalience of EVH matches, and increased self-selection bias may all be related though a common cognitive bias, namely hypersalience of matches between self-selected hypotheses and evidence, possibly contributing to delusion formation and maintenance.

The correlation reported here with auditory hallucinations as well as delusions is not unexpected. Although hallucinations and delusions are clearly different, they are known to co-occur (Liddle, 1987; van der Gaag et al., 2006; Pearson's $r = .43$ in the current sample), so likely share underlying cognitive processes. A greater weighting of self-generated concepts and percepts, hypersalience of EVH matches, an impairment in integrating new evidence, and a BADE have all been identified as playing a role in the formation and maintenance of delusions. Hallucinations fit into this account, as they are partially caused by hyperactivity in voice-selective regions of the cortex (Allen et al., 2012; Rapin et al., 2012), but also by a number of more clearly top-down influences, one of which could be hypersalience of a match between evidence (vivid thoughts) and a self-selected hypothesis ("I will hear voices"). In addition, both delusions and hallucinations are affected by other top-down personalising factors which must interact with hypersalience, such as expectations, hypervigilance, imagination/fantasy, and memories/trauma (Waters et al., 2012). Thus, an increased self-selection bias could contribute to hallucinations in a top-down fashion; namely, hypersalience of a match between evidence (vivid thoughts) and a self-selected hypothesis ("I will hear voices").

A potential limitation of this study is that group differences were present on a number of variables such as general cognitive ability and length of illness. However, overall group differences were absent on the self-selection bias measure, suggesting that these confounds did not affect the results. Moreover, in a check for confounds produced no potential confound for the relationship between self-selection bias and delusions (or hallucinations).

The self-selection bias reported here, and possibly a number of other measurable cognitive biases (e.g., hypersalience of EVH matches, BADE),

may contribute to delusion formation and maintenance. This study provides further confirmation that the cognitive biases in delusions extend beyond material congruent with an individual's specific delusions to neutral, unrelated content, and as such, may reflect a pervasive reasoning deficit predisposing individuals with schizophrenia towards the formation and maintenance of delusional ideation. Such increased understanding of the cognitive biases underlying delusions is important in light of the clinical applications of this work, where it has been demonstrated that sharing information with patients about the cognitive biases underlying delusions leads to reduction of the severity and impact of these symptoms (Moritz et al., 2011; Moritz & Woodward, 2007a, 2007b; Ross, Freeman, Dunn, & Garety, 2011; Waller, Freeman, Jolley, Dunn, & Garety, 2011).

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