Pathways to Paranoia: Analytic Thinking and Belief Flexibility

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Data Statement: Anonymized data have been made publicly available via the Open Science Framework and can be accessed at https://osf.io/6b2wf.

Abstract

Delusions have been repeatedly linked to reduced engagement in analytic (i.e., conscious and effortful) reasoning. However, the mechanisms underlying this relationship remain unclear. One hypothesis is that less analytic reasoning might maintain persecutory delusions by reducing belief flexibility. An important aspect of belief flexibility is the ability to revise beliefs in response to disconfirmatory evidence. The present study recruited 231 participants from the general population that represented a wide range of paranoid ideation. They completed tasks in which they encountered a series of ambiguous scenarios with initially-appealing explanations that were later disconfirmed by statements supporting alternative interpretations. Three types of scenarios were employed: two presented participants with emotionally valenced explanations (i.e., negative or positive) and one presented participants with emotionally neutral explanations. For? each type of reasoning scenario, impaired belief revision ability was found to partially mediate the relationship between reduced engagement in analytic reasoning and persecutory ideation. These results are consistent with the notion that reduced engagement in analytic reasoning may help maintain paranoid delusions by interfering with the ability to revise beliefs in the presence of disconfirmatory information.

Keywords: delusions; beliefs; paranoia; reasoning

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Potential Pathways to Paranoia: Analytic Thinking and Belief Flexibility

Belief inflexibility—the metacognitive capacity to reflect on one's beliefs, revise them in response to evidence, and generate and consider alternatives (Ward & Garety, 2017)—has been repeatedly observed in delusional individuals. Across studies, both interview and task-based measures of belief inflexibility are robustly associated with multiple dimensions of delusion severity, most notably with conviction in delusional beliefs (Zhu, Sun, & So, 2018). Interview-based measures suggest that individuals with delusions often fail to acknowledge the possibility that their delusional beliefs may be mistaken and seldom consider alternative accounts of the evidence that they perceive as supporting these beliefs (Freeman et al., 2004; Garety et al., 2005). Indeed, individuals with delusions exhibit a cognitive bias against revising even delusion-neutral beliefs in response to disconfirmatory evidence (McLean, Mattiske, & Balzan, 2017; Sanford et al., 2014).

Recent research suggests that belief inflexibility in individuals with persecutory delusions can be understood within the context of dual-process reasoning frameworks. These frameworks posit that human reasoning proceeds via two systems: one system (analytic reasoning) that is conscious, effortful, and dependent upon working memory, and another (experiential reasoning) that is autonomous, effortless, and utilizes associative learning processes (Evans, 2003). Although self-report studies examining experiential reasoning in relation to persecutory ideation have thus far been inconclusive, these studies suggest that individuals with persecutory delusions, as well as individuals experiencing more subclinical paranoia, may exhibit lower levels of analytic reasoning (Freeman, Lister, & Evans, 2014; Freeman, Evans, & Lister, 2012). Consistent with this suggestion, reasoning task performance in individuals with delusions is indicative of less engagement in analytic reasoning (Speechley, Woodward, & Ngan, 2013; Speechley, Murray, McKay, Munz, & Ngan, 2010).

While the link between delusions and less analytic reasoning has been well-supported, the mechanisms explaining this association remain unclear. One hypothesis is that reduced engagement in

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analytic reasoning might encourage belief inflexibility and thereby maintain persecutory delusions (Ward & Garety, 2017). Broadly consistent with this notion, the reduction in paranoia engendered by the Maudsley Review Training Program, a therapy that might encourage analytic reasoning,[1] may be partially mediated by an increase in individuals' willingness to acknowledge that their delusional beliefs may be mistaken (Garety et al., 2015). This notion is also consistent with theory positing that reduced modulation toward analytic reasoning in the face of cognitive conflict might promote a bias against disconfirmatory evidence (BADE; a specific facet of belief inflexibility) in delusional individuals (Speechley, 2012; Speechley & Ngan, 2008). Accordingly, belief inflexibility (BADE) may form part of the pathway from reduced engagement in analytic reasoning to paranoia.

The Present Study

The present study aimed to increase our understanding of this potential pathway to paranoia by testing whether lower levels of analytic reasoning engagement are related to higher levels of bias against disconfirmatory evidence (Hypothesis 1) and whether the relationship between reduced engagement in analytic reasoning and persecutory ideation is partially mediated by bias against disconfirmatory evidence (Hypothesis 2). These hypotheses were tested using both emotion-laden (negative and positive) and emotion-neutral variants of a popular belief revision task (the BADE task; original version: Woodward et al., 2006). This strategy allowed for three internal replication tests of Hypotheses 1 and 2. This strategy also facilitated an exploratory analysis inspired by previous research suggesting that delusion-prone individuals may exhibit similar impairments in the revision of emotion-laden and emotion-neutral beliefs (e.g., Buchy, Woodward, & Liotti, 2007; Riccaboni et al., 2012). This prior research implies that delusion-prone individuals may have a general belief revision deficit that manifests similarly regardless of the emotional valence of the initial belief and of corresponding disconfirmatory evidence. This possibility was examined using a post-hoc commonality analysis.

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Method

Participants and Sampling Strategy

Participants ($N = 343$) were recruited to participate in this study via Amazon's Mechanical Turk (MTurk). MTurk is a crowdsourcing internet marketplace where people from diverse backgrounds participate in research studies in exchange for financial compensation. People who are willing to participate in studies via MTurk are sufficiently diverse for research on clinical and mental health outcomes (Chandler & Shapiro, 2016).

Participants were only recruited if they were 18 or older and lived in the United States. Individuals meeting these specifications were recruited via a gradual oversampling strategy involving two waves of data collection. During the first wave, 219 individuals who completed the study were recruited without regard to their paranoid symptom severity (i.e., recruitment was unselected). During the second wave, participants were recruited on the basis of their endorsement of high levels of paranoia in a screening survey. In total, 742 individuals completed the Green et al. Paranoid Thoughts Scale-B. The 93 individuals endorsing the highest levels of paranoia were invited to complete the main study. Ultimately, 12 of these individuals completed the entire study, bringing the total number of study participants to 231 (demographics and details regarding retention: SI Section S0). The results of this study were extremely similar when excluding these 12 individuals (SI Section S0).

Data Quality

Several steps were taken to ensure high data quality. Following recommendations for research using crowdsourced samples (Chandler & Shapiro, 2016; Johnson & Borden, 2012), only MTurk workers with a history of providing good-quality responses (i.e., an acceptance ratio of ≥ 96%) were allowed to participate. Further, participants were required to correctly answer a question designed to discriminate participants who paid careful attention to study materials from those who did not do so. Participants failing to correctly answer this question were not allowed to complete the study and their data were not considered in any analyses. Finally, the data were screened for repeating GPS coordinates to further ensure that responses were valid and unique. Data collected from MTurk workers with similar quality requirements have been shown to be comparable to data collected in the laboratory (Chandler & Shapiro, 2016; Johnson & Borden, 2012).

Symptom Measures

Green et al. Paranoid Thoughts Scale-B (GPTS-B). The GPTS-B (Green et al., 2008; example item: "People have intended me harm") is a 16-item self-report measure of dispositional persecutory ideation. Participants rate on a five-point scale (1 = "Not at all," 5 = "Totally) how well each item corresponds to their thoughts and feelings about others over the past month. The GPTS-B is sensitive to clinically significant changes in paranoia and has excellent internal consistency in community samples ($\alpha = .92$ in Green et al., 2008; in the present study: $\omega_t = .98$, $\alpha = .98$). The validity of the GPTS-B in nonclinical individuals is supported by research showing that higher GPTS-B scores in these individuals are associated with a greater likelihood of reporting persecutory ideation during a virtual reality experience (Freeman et al., 2010).

Cognitive Tasks

Cognitive Reflection Test (CRT). The CRT (Frederick, 2005; example item: "How many cubic feet of dirt are there in a hole that is three feet deep by three feet wide by three feet long?") measures analytic thinking by presenting participants with several problems that have intuitive-but-incorrect responses that must be overridden to arrive at the correct answer. The version of the CRT employed here consisted of seven items: three reworded items from the original CRT (via Shenhav, Rand, & Greene, 2012) and the four-item non-numeric CRT (Thomson & Oppenheimer, 2016). Previous research has shown that this seven-item version of the CRT has acceptable reliability (Pennycook & Rand, 2017). Scores on the CRT represent the number of correct answers given by participants. Higher scores reflect greater cognitive ability and/or a more analytic cognitive style (greater willingness to engage in analytic reasoning). In the present study, the seven-item CRT had good internal consistency ($\omega_t = .86$, $\alpha = .81$). Although previous studies examining analytic reasoning in the context of paranoia have employed the rational-experiential inventory (e.g., Freeman, Lister, & Evans, 2014), the CRT was used here-in because research indicates that performance on the CRT may reflect the default-interventionist function ascribed to analytic reasoning in extant theories linking delusions to dual-process reasoning deficits (see Speechley & Ngan, 2008; Travers, Rolison, & Feeney, 2016; Ward & Garety, 2017).

The Bias Against Disconfirmatory Evidence (BADE) task. Participants completed three versions of the BADE task (original version: Woodward et al., 2006). The first two versions were emotional variants of the BADE task that have been previously used to study belief inflexibility in the context of depression and social anxiety (Everaert et al., 2018). The emotional BADE task features two sets of stimuli. The first set, which consists of disconfirming-the-negative scenarios, lures participants into endorsing a negative interpretation that must then be revised in the face of information suggesting that a more positive interpretation is warranted. The second set, which consists of disconfirming-the-positive scenarios, encourages positive interpretations that must then be revised in the face of information suggesting a more negative interpretation is warranted. Participants also completed a third version of the BADE task. This third version of the BADE task was designed to have emotionally neutral content (like the original BADE task) and self-referential scenarios (like the emotional BADE task). This novel version of the BADE task was created to allow for exploratory investigations into the nature of the belief revision deficit in paranoid individuals.

Each of these BADE task versions consisted of 12 self-referential scenarios (examples: SI Section S1) that comprised three statements. After viewing each statement, participants rated how well four interpretations (presented in randomized order) described the events of the scenario on a 21-point scale (1 = "poor," 21 = "excellent"). Across scenarios, these interpretations could be grouped into three categories. Each scenario contained two Lure interpretations (arbitrarily divided into two subcategories, Lure-A and Lure-B, for consistency with the original BADE task), one True interpretation, and one Absurd interpretation. Lure interpretations were initially the most plausible explanations for the events in the scenario but became less so by the scenario's end. True interpretations were initially moderately plausible and became the most plausible by the scenario's end. Absurd interpretations remained consistently implausible throughout each scenario. Although some prior studies using the BADE task (e.g., Bronstein & Cannon, 2017) have employed a small number of scenarios breaking this pattern, such scenarios were not included in the present study to reduce participant burden.

Procedure

Participants completed this study over the course of three days. This design feature was intended to limit participant fatigue. On the first day, informed consent was obtained in accordance with the Yale University Institutional Review Board. Participants then completed basic demographic questions, 12 BADE task scenarios (4 disconfirming-the-positive scenarios, 4 disconfirming-the-negative scenarios, and four neutral scenarios, presented in random order), and several additional measures (including the GPTS-B and CRT, in random order). On the second and third day of the study, participants completed 12 additional BADE task scenarios (4 from each task version). Participants were provided with remuneration (4.5 USD) for completing the entire study.

Data Reduction and Analyses

Analysis of data from each version of the BADE task began by averaging participants' ratings for each category of interpretation (Lure-A, Lure-B, True, and Absurd) across all scenarios from that task version. As in past research (Bronstein & Cannon, 2017; Everaert et al., 2018), the resulting 12 average ratings were subjected to Principal Component Analysis (PCA) with direct oblimin rotation (i.e., the extracted components were allowed to be correlated). PCA results for data from each version of the BADE task are reported in SI Sections S2-S3.

In accordance with previous research (Bronstein & Cannon, 2017), PCA suggested that data from the neutral BADE task could be reduced to two components. The first component, "Evidence Integration Impairment," reflects the inability to revise beliefs in response to disambiguating information. The second component, "Positive Response Bias," reflects willingness to provide high plausibility ratings to interpretations. Note that other researchers (e.g., Sanford et al., 2014) call these components “Evidence Integration” and “Conservatism,” respectively. In keeping with our previous research, we call them “Evidence Integration Impairment” (to highlight higher component scores’ reflection of poorer evidence integration ability) and “Positive Response Bias” (to highlight higher component scores’ reflection of a less conservative response style and avoid confusion with political conservatism).

Also in accordance with previous research (Everaert et al., 2018), PCA suggested that data from the emotional BADE task’s disconfirming-the-negative and disconfirming-the-positive scenarios could be reduced to three components. For disconfirming-the-negative scenarios, these components were “Negative Interpretation Bias” (which reflects a bias toward endorsing interpretations for ambiguous events that have a negative emotional valence), “Positive Interpretation Bias (which reflects a bias toward endorsing interpretations for ambiguous events that have a positive emotional valence), and “Negative Interpretation Inflexibility” (which reflects inability to revise negative interpretations in response to disambiguating information which suggests that a more positive interpretation may be warranted). For disconfirming-the-positive scenarios, these components were “Negative Interpretation Bias,” “Positive Interpretation Bias,” and “Positive Interpretation Inflexibility” (which reflects inability to revise positive interpretations in response to disambiguating information which suggests that a more negative interpretation may be warranted). The ability of this procedure to separate interpretation bias and inflexibility in ambiguous emotional contexts is notable given evidence that paranoid individuals may exhibit a negative interpretation bias that is related to reduced cognitive flexibility (i.e., a reduced awareness of or willingness to consider the alternatives in a given situation; Savulich, Freeman, Shergill, & Yiend, 2015).

These PCA-derived components were entered into multiple regression models in order to test both of this study’s hypotheses. The hypothesis that analytic cognitive style would be related to BADE (Hypothesis 1) was tested using three multiple regression models. In each model, one measure of belief inflexibility (Evidence Integration Impairment, Positive Interpretation Inflexibility, or Negative Interpretation Inflexibility) was entered as the criterion variable. Measures of analytic cognitive style (CRT scores) and measures of response/interpretation bias (Negative Interpretation Bias and Positive Interpretation Bias, or Positive Response Bias) were entered as predictors. The hypothesis that the relationship between analytic cognitive style and persecutory ideation would be partially explained by the mutual relationship between these variables and the bias against disconfirmatory evidence (Hypothesis 2) was also tested using three mediation models. In each model (PROCESS Model 4; Preacher & Hayes, 2004), one measure of belief inflexibility (Evidence Integration Impairment, Positive Interpretation Inflexibility, or Negative Interpretation Inflexibility) was entered as a potential mediator. A post-hoc commonality analysis was conducted (in R; see Nimon et al., 2008) using a multiple regression model in which measures of belief revision ability derived from each type of scenario were simultaneously entered as predictors of paranoia. Commonality analysis partitions the variance in the criterion variable explained via a multiple regression model into variance unique to a given predictor variable and variance shared between combinations of predictors (see Nimon & OsWald, 2013).

Collinearity statistics were within acceptable limits for all regression models used to test Hypotheses 1 and 2 (VIFs <1.25, Tolerances >.798). Collinearity was greater for the regression model used in the post-hoc analysis (VIFs <= 14.62, Tolerances >= .06). However, because commonality analysis models multicollinear data explicitly, it can be used to decompose regression effects even when predictor variables are correlated (Ray-Mukherjee et al., 2014). Regression model parameters were estimated using bootstrapping procedures. Data relevant to each model were bootstrapped 5000 times and 95% confidence intervals were generated. Confidence intervals that do not overlap with zero suggest statistically significant effects. All variables entered into these models were standardized. Prior to entering variables into these regression models, outliers were detected using the method of Hubert and Van der Veeken (2008), as implemented in R's RobustBase package, because this method is robust to skewed data. Identified outliers were winsorized (see Fuller, 1991). For further information about outlier filtering, see SI Section S4. To view results with outliers included (which were qualitatively similar to the results obtained after outlier filtering), see SI Section S5. Although previous research indicates that prior exposure to the CRT does not undermine its predictive value (Bialek & Pennycook, 2017), the analyses described above were repeated with prior exposure to the CRT as a covariate (SI Section S6). These analyses yielded results which were extremely similar to those obtained without this covariate.

Results

Descriptive Statistics and Zero-Order Correlations

Descriptive statistics for all variables of interest can be found in SI Section S7. Paranoia scores in the present study were similar to those in a recent study examining the relationship between paranoia and analytic reasoning (Freeman, Lister, & Evans, 2014; in that study: $M = 22.1$, $SD = 10.4$; in the present study: $M = 23.51$, $SD = 13.17$, range = 16-77). This result suggests that the present sample contained sufficient variation in paranoia to examine how individual differences in paranoia might relate to analytic reasoning and other associated outcomes (e.g., belief flexibility). Zero-order correlations between variables are depicted in Table 1.

Hypothesis 1: Engagement in Analytic Reasoning Predicts Bias Against Disconfirmatory Evidence

In the model involving metrics of belief inflexibility and response bias derived from neutral scenarios, Positive Response Bias did not predict Evidence Integration Impairment (belief inflexibility), $\beta(228) = 0.15$, $p = .121$, 95% CI = [-0.01 0.32]. However, engagement in analytic reasoning did predict Evidence Integration Impairment, $\beta(228) = -0.26$, $p = .003$, 95% CI = [-0.40 -0.11]. Approximately 8% of the variance in Evidence Integration Impairment was accounted for by these predictor variables (adjusted $R^2 = .08$).

In the model involving metrics of belief inflexibility and interpretation bias derived from disconfirming-the-positive scenarios, Negative Interpretation Bias did not predict Positive Interpretation Inflexibility, β(227) = 0.01, $p = .887$, 95% CI = [-0.18 0.17]. However, Positive Interpretation Bias predicted Positive Interpretation Inflexibility, β(227) = 0.24, $p = .005$, 95% CI = [0.09 0.40], as did engagement in analytic reasoning, β(227) = -0.28, $p = .001$, 95% CI = [-0.41 -0.13]. Approximately 12% of the variance in Positive Interpretation Inflexibility was accounted for by these predictor variables (adjusted $R^2 = .12$).

In the model involving metrics of belief inflexibility and interpretation bias derived from disconfirming-the-negative scenarios, Negative Interpretation Bias did not predict Negative Interpretation Inflexibility, β(227) = -0.09, $p = .292$, 95% CI = [-0.25 0.05]. However, Positive Interpretation Bias predicted Negative Interpretation Inflexibility, β(227) = 0.41, $p = .001$, 95% CI = [0.19 0.58], as did engagement in analytic reasoning, β(227) = -0.21, $p = .001$, 95% CI = [-0.35 -0.08]. Approximately 21% of the variance in Negative Interpretation Inflexibility was accounted for by these predictor variables (adjusted $R^2 = .21$).

In all three of these multiple regression models, variance in analytic reasoning engagement accounted for variance in belief inflexibility that was not accounted for by measures of response/interpretation bias. This result is consistent with the possibility that a less analytic cognitive style might contribute to belief inflexibility, regardless of the emotional valence of the initial belief or of any corresponding disconfirmatory evidence. Additional statistics for these regression models can be viewed in SI Section S8.

Hypothesis 2: Interpretation Inflexibility partially mediates the relationship between engagement in analytic reasoning and paranoia

The three mediation models reported in this section are described in Table 2 and depicted in Figure 1. In each mediation model, the total effect of engagement in analytic reasoning on persecutory ideation was significant and negative (path c). Engagement in analytic reasoning was also associated with less BADE (path a) in all three models. When both engagement in analytic reasoning and BADE were entered simultaneously into these regression models, BADE predicted increased paranoia (path b). These results suggested that analytic reasoning may exert an indirect effect on paranoia via BADE. Critically, when this indirect effect was taken into account, the remaining (direct) effect of analytic reasoning on paranoia (path c') in each model was less strong than the total effect. In all three models, the significance of this decrease in strength was confirmed by 95% CIs for the completely standardized indirect effect of analytic reasoning on paranoia that did not overlap with zero. The effect size for each mediation was small, suggesting that about 9% of the variance in paranoia was accounted for by overlapping variance in analytic reasoning engagement and BADE.

In all three of these multiple regression models, the previously reported relationship between a less analytic cognitive style and paranoia (Freeman, Lister, & Evans, 2014; Freeman, Evans, & Lister, 2012) was partially mediated by reductions in the ability to revise beliefs in the face of disconfirmatory evidence. These results are consistent with the hypothesis that the relationship between reduced engagement in analytic reasoning and paranoia may be partially explained by the mutual association of these variables with BADE.

Post-hoc analysis

When Evidence Integration Impairment, Negative Interpretation Inflexibility, and Positive Interpretation Inflexibility were examined as predictors of paranoia, commonality analysis revealed that the majority (89%) of the variance in paranoia explained by the specified model was accounted for by variance shared between all three measures of BADE (Table 3). This result suggests that paranoia may be primarily related to a general deficit in belief flexibility that spans emotion-laden and emotion-neutral contexts.

Discussion

The results of this study support the hypothesis that engagement in analytic reasoning is associated with the ability to revise beliefs in response to disconfirmatory evidence. They are also consistent with the hypothesis that the relationship between engagement in analytic reasoning and the bias against disconfirmatory evidence can partially explain the previously-reported relationship between reduced engagement in analytic reasoning and persecutory ideation (Freeman, Lister, & Evans, 2014; Freeman, Evans, & Lister, 2012).

Through these results, the present study builds upon previous theories linking delusions to dual-process reasoning deficits. For example, Dual Stream Modulation Failure (Speechley & Ngan, 2008) suggests that delusion-prone individuals engage in less analytic reasoning in the face of cognitive conflict. It has been suggested that this deficit might lead to an increased bias against disconfirmatory evidence (Speechley, 2012). This suggestion is broadly consistent with previous research indicating that delusional individuals (vs. controls) more often reason according to their preexisting beliefs (regarding the validity of syllogism conclusions) rather than available evidence (the internal logic of syllogisms) when determining the logical validity of syllogisms (Speechley et al., 2013). In syllogism evaluation tasks, responding according to logical validity (rather than preexisting beliefs) is thought to be more likely when analytic reasoning is engaged (Speechley et al., 2010). Delusional individuals' increased use of preexisting beliefs (vs. logical structure) to determine syllogism validity therefore implies that these individuals may be less likely to engage analytic reasoning processes to revise preexisting beliefs according to available evidence. The present study strengthens this interpretation by directly linking the bias against disconfirmatory evidence to reduced engagement in analytic reasoning for the first time.

The present study also builds upon previous theory suggesting that reduced engagement in analytic reasoning processes for the purpose of overriding intuitions might encourage belief inflexibility and thereby maintain paranoia (Ward & Garety, 2017). Preliminary support for this theory can be found in research indicating that the reduction in paranoia resulting from the Maudsley Review Training Program, a therapy that might increase analytic thinking (see Introduction), may be partially explained by the effect of this therapy on belief flexibility (as indexed by reduced recognition that one's delusional belief may be mistaken; Garety et al., 2015). The present study provides stronger support for this theory by demonstrating that the link between performance on the CRT, which may capture the use of analytic reasoning to override intuitive-but-incorrect responses, and paranoia may be partially mediated by a different aspect of belief inflexibility—BADE. Through its support for this theory and for aspects of Dual Stream Modulation Failure, the present study further elucidates potential mechanisms by which reduced engagement in analytic reasoning might encourage and maintain delusions.

Beyond these links with extant theory, the present study extends previous research examining delusion-prone individuals' belief revision deficits in both emotion-laden and emotion-neutral contexts. These prior studies (e.g., Buchy, Woodward, & Liotti, 2007; Riccaboni et al., 2012) observed no differences between the revision of emotion-laden and emotion-neutral beliefs (that were unrelated to delusions) by delusion-prone individuals. Inferences made from these findings regarding the character of belief revision deficits in delusion-prone individuals are qualified by the fact that these previous studies (unlike the present one) did not systematically vary the valence of the to-be-revised belief relative to corresponding disconfirmatory evidence and also did not account for interpretation bias (like the bias toward interpretations with a negative emotional valence present in paranoia, see Savulich et al., 2015) when evaluating belief revision ability. The present study's post-hoc commonality analysis addresses both of these concerns and suggests that the belief revision deficit in delusion-prone individuals is primarily generalized and transcends the boundaries of emotional valence. Notably, this result is broadly consistent with the possibility that decreased engagement in analytic reasoning might cause reductions in belief revision ability. Research employing syllogism evaluation tasks suggests that the reduction in analytic reasoning in delusional individuals, relative to controls, does not differ in magnitude across emotion-laden and emotion-neutral contexts (Speechley, Woodward, & Ngan, 2013). If reduced engagement in analytic reasoning does impair belief revision ability, one might therefore expect the decrease in analytic reasoning observed in this previous research to prompt a general (with respect to emotional valence) deficit in belief revision ability like that which this study suggests may be present in paranoid individuals.

These associations between belief inflexibility and reduced engagement in analytic reasoning provide impetus for discussions of how dual-process reasoning deficits might interact with factors like stress and hypersalient evidence-hypothesis matches to maintain clinically significant persecutory delusions. Hypersalient evidence-hypothesis matches (the increased weighting of matches between available evidence and working hypotheses) have been previously linked to BADE in delusion-prone individuals (Balzan et al., 2013; Sanford et al., 2014). In these individuals, hypersalient evidence-hypothesis matches may increase confidence in intuitive responses (i.e., those generated through experiential reasoning). Research on the metacognitive determinants of analytic reasoning engagement (Thompson, 2009; Thompson et al., 2011) suggests that this confidence increase may prompt delusion-prone people to more frequently accept intuitive responses and forgo analytic thinking. Accordingly, the present study implies that hypersalient evidence-hypothesis matches might increase BADE by discouraging engagement in analytic reasoning. In individuals with psychosis, acute stress may exacerbate this effect by prompting excessive dopamine release and thereby influencing low-level certainty judgments (Broyd et al., 2017). Broadly consistent with this notion, acute stress may reduce engagement in analytic reasoning (see Otto et al., 2013). Acute stress may also encourage BADE by depleting the cognitive resources (cognitive control, working memory) on which analytic reasoning may depend (see Arnsten, 2015; Qin et al., 2009). Future research should examine these putative effects of stress and hypersalient evidence-hypothesis matches on analytic reasoning and belief inflexibility to better contextualize the present study's results within the larger literature on the factors influencing delusion-relevant cognitive biases.

The implications of the present study should be considered in the context of its limitations. One such limitation is that although the psychosis continuum model (see Van Os et al., 2000) suggests that this study's conclusions may be applicable to people with clinically significant persecutory delusions, the preferential drop-out of more paranoid participants in this study (SI Section S0) limits its applicability to these individuals. Future research should therefore attempt to replicate this study in individuals with clinically significant persecutory delusions. A second limitation of this study is that although variance in the metric of belief inflexibility used here-in likely overwhelmingly reflects variance in BADE (see Bronstein & Cannon, 2018), it may also capture variance in the bias against confirmatory evidence (BACE; see Mclean, Mattiske, & Balzan, 2017). In future research, it may therefore be worthwhile to examine potential associations between BACE, analytic thinking, and paranoia. The cross-sectional design of the present study also carries limitations. This design precludes making causal inferences regarding the relationship between analytic reasoning, belief inflexibility, and paranoia. Additionally, this design makes it difficult to conclusively rule out alternative mediation models (e.g., ones in which BADE leads to less analytic thinking). This design also increases the possibility that this study's mediation analyses may be biased in their estimation of the parameters describing any causal pathways between these variables that unfold over time (see Maxwell & Cole, 2007). However, mediation analyses conducted in conditions that may not be ideal for inferring causality (e.g., those employing cross-sectional data) can still be informative in the context of existing research and theory (Hayes & Rockwood, 2017). It is therefore notable that the mediation analyses in the present study are strongly consistent with previous theory (e.g., Ward & Garety, 2017) and are broadly consistent with the results of an existing mediation analysis based on a longitudinal dataset (Garety et al., 2015).

Despite these limitations, the present study meaningfully extends existing knowledge of how deficits in dual-process reasoning might influence paranoia. The present study provides robust evidence across three types of scenarios showing that reduced engagement in analytic reasoning might increase individuals' bias against disconfirmatory evidence, and is consistent with the notion that this effect might lead reduced engagement in analytic reasoning to maintain persecutory ideation. These implications of the present study suggest that future research should continue to leverage dual-process reasoning frameworks in attempts to elucidate pathways leading to the formation and maintenance of delusions.

A potentially interesting goal for such future research would be to examine how analytic reasoning influences the interplay between paranoia and symptoms of social anxiety or depression (SI Section S9). The present study suggests two potential research lines that may help accomplish this goal. The first of these research lines is based upon the present study's observation that reduced engagement in analytic reasoning is correlated with impaired revision of emotionally negative beliefs following exposure to emotionally positive disconfirmatory evidence. This specific belief revision deficit has been previously linked to both anxiety and depression (Everaert et al., 2018), which is intriguing given that depression may maintain paranoia (Vorontsova, Garety, & Freeman, 2013), while social anxiety may encourage threat-laden interpretations of anomalous experiences that could inspire paranoia in the first place (Freeman, 2002). Future research might therefore examine whether reduced engagement in analytic reasoning may promote belief revision deficits that increase the severity of depression and social anxiety symptoms and thereby encourage paranoia. Given the potential influence of depression and social anxiety on paranoia and belief revision deficits, it is notable that symptoms of depression and social anxiety cannot account for the results reported in this manuscript (see SI Section S11).

A second potential line of future research might attempt to explain why the relationship between social anxiety and paranoia is stronger in individuals who engage in less analytic reasoning (see SI Section S12). Given that a central feature of analytic reasoning is its ability to override intuitive interpretations in favor of less-intuitive alternatives (Stanovich & Toplak, 2012), one possible explanation for this moderation effect is that analytic reasoning may reduce the chances that individuals accept intuitive threat-laden interpretations of anomalous experiences that may be promoted by social anxiety and that may encourage paranoia if endorsed.

These and other investigations leveraging dual-process reasoning frameworks are expected to improve our understanding of the cognitive mechanisms that inspire and maintain delusions. In light of research demonstrating that need-for-care among individuals with persistent psychotic experiences is associated with reduced engagement in analytic reasoning (Ward et al., 2017), these investigations are also expected to have significant implications for the treatment of individuals with delusional beliefs.

References

Arnsten, A. F. (2015). Stress weakens prefrontal networks: molecular insults to higher cognition. *Nature Neuroscience*, *18*(10), 1376-1385.

Balzan, R., Delfabbro, P., Galletly, C., & Woodward, T. (2013). Confirmation biases across the psychosis continuum: The contribution of hypersalient evidence-hypothesis matches. *British Journal of Clinical Psychology*, *52*(1), 53-69.

Bialek, M., & Pennycook, G. (2017). The Cognitive Reflection Test is robust to multiple exposures. *Behavior Research Methods*, 1-7.

Bronstein, M. V., & Cannon, T. D. (2017). Bias against disconfirmatory evidence in a large nonclinical sample: Associations with schizotypy and delusional beliefs. *Journal of Experimental Psychopathology*, *8*(3), jep-057516.

Bronstein, M. V., & Cannon, T. D. (2018). Measuring bias against disconfirmatory evidence: An evaluation of BADE task scoring methods and the case for a novel method. *Psychiatry Research*, *261*, 535-540.

Broyd, A., Balzan, R. P., Woodward, T. S., & Allen, P. (2017). Dopamine, cognitive biases and assessment of certainty: A neurocognitive model of delusions. *Clinical Psychology Review*, *54*, 96-106.

Buchy, L., Woodward, T. S., & Liotti, M. (2007). A cognitive bias against disconfirmatory evidence (BADE) is associated with schizotypy. *Schizophrenia Research*, *90*(1-3), 334-337.

Chandler, J., & Shapiro, D. (2016). Conducting clinical research using crowdsourced convenience samples. *Annual Review of Clinical Psychology, 12*.

Evans, J. S. B. (2003). In two minds: dual-process accounts of reasoning. *Trends in Cognitive Sciences*, *7*(10), 454-459.

Freeman, D., Garety, P. A., Fowler, D., Kuipers, E., Bebbington, P. E., & Dunn, G. (2004). Why do people with delusions fail to choose more realistic explanations for their experiences? An empirical investigation. *Journal of Consulting and Clinical Psychology, 72(4)*, 671.

Freeman, D., Garety, P. A., Kuipers, E., Fowler, D., & Bebbington, P. E. (2002). A cognitive model of persecutory delusions. *British Journal of Clinical Psychology*, *41(4)*, 331-347.

Freeman, D., Evans, N., & Lister, R. (2012). Gut feelings, deliberative thought, and paranoid ideation: a study of experiential and rational reasoning. *Psychiatry Research, 197(1)*, 119-122.

Freeman, D., Lister, R., & Evans, N. (2014). The use of intuitive and analytic reasoning styles by patients with persecutory delusions. *Journal of Behavior Therapy and Experimental Psychiatry*, *45*(4), 454-458.

Freeman, D., Pugh, K., Vorontsova, N., Antley, A., & Slater, M. (2010). Testing the continuum of delusional beliefs: an experimental study using virtual reality. *Journal of Abnormal Psychology*, *119(1)*, 83.

Fuller, W. A. (1991). Simple estimators for the mean of skewed populations. *Statistica Sinica*, 1(1), 137-158.

Garety, P., Freeman, D., Jolley, S., Dunn, G., Bebbington, P.E., Fowler, D.G., Kuipers, E., & Dudley, R., (2005). Reasoning, emotions, and delusional conviction in psychosis. J. *Abnorm. Psychol., 114 (3)*, 373–384.

Garety, P., Waller, H., Emsley, R., Jolley, S., Kuipers, E., Bebbington, P., Dunn, G., Fowler, D., Hardy, A., Freeman, D. (2015). Cognitive mechanisms of change in delusions: an experimental investigation targeting reasoning to effect change in paranoia. *Schizophr. Bull. 41(2)*, 400–410.

Green, C. E. L., Freeman, D., Kuipers, E., Bebbington, P., Fowler, D., Dunn, G., & Garety, P. A. (2008). Measuring ideas of persecution and social reference: the Green et al. Paranoid Thought Scales (GPTS). *Psychological Medicine, 38(1)*, 101-111.

Hayes, A. F., & Rockwood, N. J. (2017). Regression-based statistical mediation and moderation analysis in clinical research: Observations, recommendations, and implementation. *Behavior Research and Therapy*, *98*, 39-57.

Hubert, M., & Van der Veeken, S. (2008). Outlier detection for skewed data. *Journal of Chemometrics, 22(3-4)*, 235-246.

Johnson, D. R., & Borden, L. A. (2012). Participants at your fingertips: Using Amazon's Mechanical Turk to increase student–faculty collaborative research. *Teaching of Psychology, 39(4)*, 245-251.

Maxwell, S. E., & Cole, D. A. (2007). Bias in cross-sectional analyses of longitudinal mediation. *Psychological Methods, 12(1)*, 23.

McLean, B. F., Mattiske, J. K., & Balzan, R. P. (2017). Association of the jumping to conclusions and evidence integration biases with delusions in psychosis: a detailed meta-analysis. *Schizophrenia Bulletin*, *43(2)*, 344-354.

Nimon, K., Lewis, M., Kane, R., & Haynes, R. M. (2008). An R package to compute commonality coefficients in the multiple regression case: An introduction to the package and a practical example. *Behavior Research Methods*, *40*(2), 457-466.

Nimon, K. F., & Oswald, F. L. (2013). Understanding the results of multiple linear regression: Beyond standardized regression coefficients. *Organizational Research Methods, 16(4)*, 650-674.

Otto, A. R., Raio, C. M., Chiang, A., Phelps, E. A., & Daw, N. D. (2013). Working-memory capacity protects model-based learning from stress. *Proceedings of the National Academy of Sciences*, *110*(52), 20941-20946.

Pennycook, G. (2017). A perspective on the theoretical foundation of dual-process models In W.I.M. De Neys. *Dual-process Theory 2.0*. Routledge.

Pennycook, G., & Rand, D. G. (2017). Who falls for fake news? The roles of analytic thinking, motivated reasoning, political ideology, and bullshit receptivity.

Preacher, K. J., & Hayes, A. F. (2004). SPSS and SAS procedures for estimating indirect effects in simple mediation models. *Behavior Research Methods, Instruments, & Computers, 36(4)*, 717-731.

Qin, S., Hermans, E. J., van Marle, H. J., Luo, J., & Fernández, G. (2009). Acute psychological stress reduces working memory-related activity in the dorsolateral prefrontal cortex. *Biological Psychiatry*, *66*(1), 25-32.

Ray-Mukherjee, J., Nimon, K., Mukherjee, S., Morris, D. W., Slotow, R., & Hamer, M. (2014). Using commonality analysis in multiple regressions: a tool to decompose regression effects in the face of multicollinearity. *Methods in Ecology and Evolution*, *5*(4), 320-328.

Riccaboni, R., Fresi, F., Bosia, M., Buonocore, M., Leiba, N., Smeraldi, E., & Cavallaro, R. (2012). Patterns of evidence integration in schizophrenia and delusion. *Psychiatry Research*, *200*(2-3), 108-114.

Ross, R. M., Pennycook, G., McKay, R., Gervais, W. M., Langdon, R., & Coltheart, M. (2016). Analytic cognitive style, not delusional ideation, predicts data gathering in a large beads task study. *Cognitive Neuropsychiatry*, *21*(4), 300-314.

Sanford, N., Veckenstedt, R., Moritz, S., Balzan, R. P., & Woodward, T. S. (2014). Impaired integration of disambiguating evidence in delusional schizophrenia patients. *Psychological Medicine, 44(13),* 2729-2738.

Savulich, G., Freeman, D., Shergill, S., & Yiend, J. (2015). Interpretation biases in paranoia. *Behavior Therapy*, *46(1)*, 110-124.

Shenhav, A., Rand, D. G., & Greene, J. D. (2012). Divine intuition: Cognitive style influences belief in God. *Journal of Experimental Psychology: General*, 141(3), 423.

Speechley, W. J. (2012). *Dual-stream modulation failure, cognitive biases and delusions in schizophrenia* (Doctoral dissertation, University of British Columbia).

Speechley, W. J., Murray, C. B., McKay, R. M., Munz, M. T., & Ngan, E. T. C. (2010). A failure of conflict to modulate dual-stream processing may underlie the formation and maintenance of delusions. *European Psychiatry*, *25*(2), 80-86.

Speechley, W. J., Woodward, T. S., & Ngan, E. T. (2013). Failure of conflict to modulate central executive network activity associated with delusions in schizophrenia. *Frontiers in Psychiatry*, *4*.

Stanovich, K. E., & Toplak, M. E. (2012). Defining features versus incidental correlates of Type 1 and Type 2 processing. *Mind & Society*, *11*(1), 3-13.

Thomson, K. S., & Oppenheimer, D. M. (2016). Investigating an alternate form of the cognitive reflection test. Judgment and Decision Making, 11(1), 99.

Thompson, V. A., Turner, J. A. P., & Pennycook, G. (2011). Intuition, reason, and metacognition. *Cognitive Psychology*, *63*(3), 107-140.

Thompson, V. A. (2009). Dual process theories: A metacognitive perspective. *In two minds: dual processes and beyond. Oxford University Press, Oxford*.

Travers, E., Rolison, J. J., & Feeney, A. (2016). The time course of conflict on the Cognitive Reflection Test. *Cognition*, *150*, 109-118.

Van Os, J., Hanssen, M., Bijl, R. V., & Ravelli, A. (2000). Strauss (1969) revisited: a psychosis continuum in the general population? *Schizophrenia Research*, *45*(1), 11-20.

Vorontsova, N., Garety, P., & Freeman, D. (2013). Cognitive factors maintaining persecutory delusions in psychosis: The contribution of depression. *Journal of Abnormal Psychology, 122(4)*, 1121.

Ward, T., & Garety, P. A. (2017). Fast and slow thinking in distressing delusions: A review of the literature and implications for targeted therapy. *Schizophrenia Research.*

Ward, T., Peters, E., Jackson, M., Day, F., & Garety, P. A. (2017). Data-gathering, belief flexibility, and reasoning across the psychosis continuum. *Schizophrenia Bulletin, 44(1)*, 126-136.

Woodward, T. S., Moritz, S., Cuttler, C., & Whitman, J. C. (2006). The contribution of a cognitive bias against disconfirmatory evidence (BADE) to delusions in schizophrenia. *Journal of Clinical and Experimental Neuropsychology*, *28(4)*, 605-617.

Zhu, C., Sun, X., & So, S. H. W. (2018). Associations between belief inflexibility and dimensions of delusions: A meta-analytic review of two approaches to assessing belief flexibility. *British Journal of Clinical Psychology*, *57*(1), 59-81.

Table 1.

Zero-order correlations between variables of interest

	2	2	4	5
1. CRT	-.28***	-.11+	-.11	-.14*
2. GPTS-B		.24***	.23***	.24***
3. Neutral II			.75***	.63***
4. Positive II				.74***
5. Negative II				

Note. CRT = Cognitive Reflection Test. GPTS-B = Green et al. Paranoid Thoughts Scale-B. II = Interpretation Inflexibility. Non-parametric (Spearman's rho) correlations were reported because multiple variables were non-normal in their distribution. ***p< .001, **p<.010, *p<.05, +p<.10.

Table 2.

The relationship between analytic thinking and paranoia is mediated by belief inflexibility

Model	R^2 (Mediation)	Outcome	Predictor	*B*	|*t*|	95% CI
1	.09	EII	CRT	-0.25	4.00	[-0.37 -0.13]
		GPTS-B	EII	0.46	8.00	[0.35 0.57]
			CRT	-0.25	4.49	[-0.36 -0.14]
		GPTS-B	CRT	-0.38	5.98	[-0.49 -0.25]
2	.09	PII	CRT	-0.27	4.40	[-0.40 -0.15]
		GPTS-B	PII	0.47	8.04	[0.35 0.57]
			CRT	-0.24	4.25	[-0.35 -0.13]
		GPTS-B	CRT	-0.38	5.98	[-0.49 -0.25]
3	.09	NII	CRT	-0.28	4.41	[-0.40 -0.15]
		GPTS-B	NII	0.47	8.11	[0.35 0.57]
			CRT	-0.24	4.24	[-0.35 -0.13]
		GPTS-B	CRT	-0.38	5.98	[-0.49 -0.25]

Note. The completely standardized indirect effect of analytic thinking on paranoia through belief inflexibility in each model is as follows: -0.11[-0.21 -0.06] (Model 1), -0.13 [-0.23 -0.07] (Model 2), -0.13 [-0.23 -0.07] (Model 3). Horizontal lines in the table separate different regression and mediation models.

Table 3.

Results of commonality analysis when all metrics of belief inflexibility are used to predict paranoia.

	Coefficient (β)	Percent of Total R^2
EII	0.01	0.03
NII	0.00	0.00
PII	0.00	0.00
EII + NII	0.00	0.00
EII + PII	0.01	0.03
NII + PII	0.01	0.03
EII + NII + PII	0.25	0.89

Note. Percentages sum to less than 100 because of rounding error. EII = Evidence Integration Impairment. NII = Negative Interpretation Inflexibility. PII = Positive Interpretation Inflexibility.

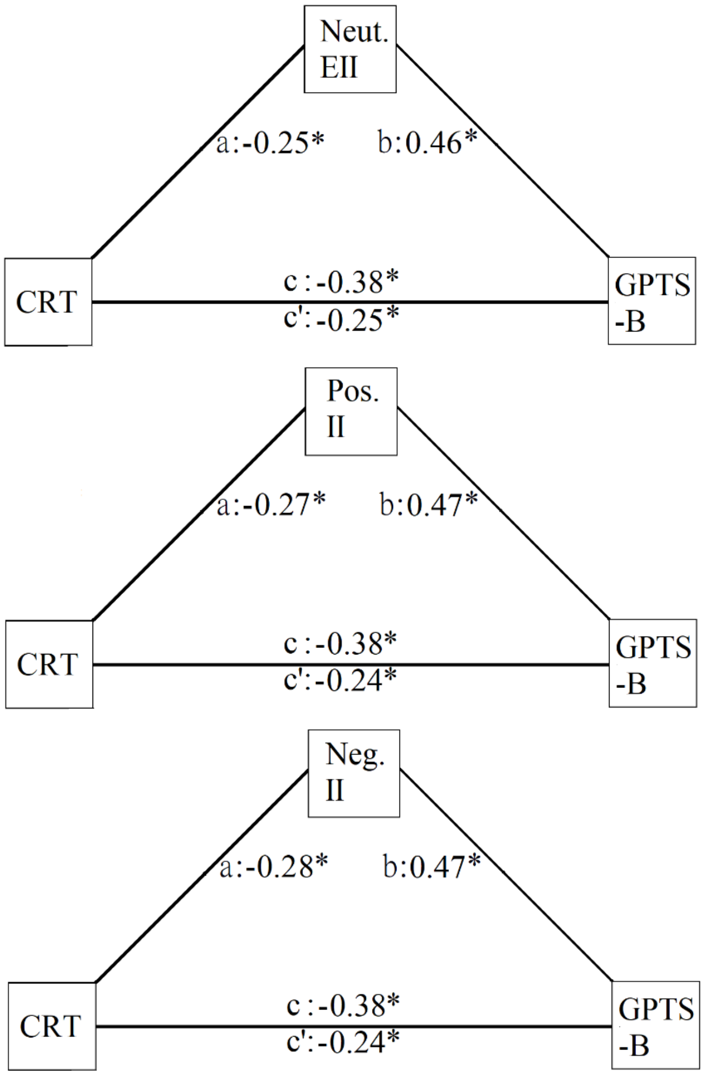

Figure 1. The relationship between analytic cognitive style and paranoia is partially mediated by belief inflexibility. CRT = Cognitive Reflection Test. GPTS-B = Green et al. Paranoid Thoughts Scale-B. Pos. = Positive. Neut. = Neutral. Neg. = Negative. II = Interpretation Inflexibility. EII = Evidence Integration Impairment. *p < .05.