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Short communication

Intrusive-like memory errors associate with positive schizotypy[☆]

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ABSTRACT

Schizophrenia is characterized by memory impairments, yet the relationships between its distinct symptom clusters (i.e., positive, negative, disorganized) and specific aspects of memory dysfunction remain poorly characterized. In the present study, we compiled a large analog sample ($N = 795$) to test whether positive symptoms, versus negative and disorganized symptoms, were uniquely and differentially related to false alarm versus miss errors during recognition memory. Mixed-effects beta regression analyses revealed that both positive schizotypy and paranoia were more strongly associated with false alarms than misses. Disorganized schizotypy showed a similar pattern, though to a lesser extent; negative schizotypy showed a significant relationship with neither false alarm nor miss errors. We suggest that those higher in positive schizotypy are especially prone to misattribute signal to noise stimuli during recognition memory – characteristic of an "intrusive-like" profile of memory impairment, wherein context-irrelevant stimuli trigger spurious retrieval events – and speculate on the neural processes that might give rise to this asymmetry.

1. Introduction

While memory deficits are a core feature of schizophrenia writ large (Libby et al., 2013), relationships between distinct symptom clusters (i.e., positive, negative, disorganized) and memory dysfunction remain poorly characterized. Indeed, some studies suggest that memory impairment is most closely related to negative symptoms (Aleman et al., 1999), others to disorganized symptoms (Ventura et al., 2010), and still others to positive symptoms (Brébion et al., 1999). Yet prior work frequently relies on *general* memory performance – a practice which may obscure differential relationships between the symptoms of psychosis and *specific error types*, including "false alarms" (i.e., detecting signal in noise stimuli) and "misses" (i.e., failing to detect signal in signal stimuli). As different error types may reflect distinct underlying cognitive and neural processes, characterizing these relationships in greater detail would help to refine our mechanistic models of memory impairment across different dimensions of psychotic illness.

To address this more fine-grained question, adequately powered studies are needed – yet classical case-control studies often lack the sample sizes needed to assess interaction effects (Leon and Heo, 2009). To address this shortcoming, we combined several data sets collected on online marketplaces in the service of unrelated projects to achieve adequate power to test for interactions between psychotic-like symptoms and specific recognition memory errors. Namely, drawing from recent research (Blain et al., 2020; Koller and Cannon, 2021; Sahakyan and Kwapil, 2019), we sought to determine whether positive symptoms (comprising delusion-like beliefs and hallucination-like experiences), as opposed to negative and disorganized symptoms, were differentially related to false alarm versus miss errors. This analytic strategy allowed us to distinguish between several profiles of memory impairment, which we can label as "intrusive-like" (false alarms > misses), "forgetful-like" (misses > false alarms), or more indicative of "general impairment" (misses = false alarms).

2. Methods

2.1. Participants

An omnibus sample of 795 participants was compiled from a series of studies conducted on online marketplaces (n = 709 from Amazon's

☆ We have no conflict of interest to disclose. This study's protocol (2000026576) was deemed exempt by the Yale University IRB. Certain data in this manuscript have been previously published in the context of unrelated analyses; all analyses reported herein have not been reported elsewhere. Data and code that support the findings reported in this article are available here: osf.io/aj49x.

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MTurk via CloudResearch.com; n = 86 from Prolific.co). According to a power analysis conducted in simr (Green et al., 2016), this sample size achieved roughly 86 % power, 95 % CI [78 %, 92 %], to detect a small interaction effect (i.e., $\eta_p^2 = 0.01$). To be included in the final sample, participants had to have completed an encoding and recognition memory phase in their original study but *not* have been included in published analyses testing symptom-by-error-type interactions. Participants were also excluded from analysis if they performed poorly (< 50 % accuracy) on various attention checks or took too long to complete the study (> double the projected length). In the final sample, average age was 38.35 (*SD* = 11.88). 617 (77.61 %) participants reported having received a baccalaureate or post-baccalaureate degree. 352 participants (44.23 %) identified as women. 636 (80.00 %) participants identified as White, 83 (10.44 %) as Black, 42 (5.28 %) as Asian, 11 (1.38 %) as Native American, 1 (0.13 %) as Pacific Islander, and 16 (2.01 %) as Other.

2.2. Measures

The Multidimensional Schizotypy Scale (MSS; Kwapil et al., 2018) was used to measure three clusters of schizotypy: negative (e.g., "I tend to have few interests"), disorganized (e.g., "My thoughts often feel so jumbled that I have difficulty doing anything"), and positive (e.g., "I believe that ghosts or spirits can influence my life"). Paranoia was measured using the Revised Green Paranoid Thoughts Scale, part B (Freeman et al., 2019) which includes items such as "I was convinced there was a conspiracy against me". 43.77 % of the sample scored above the threshold for moderate paranoia (11; mean = 11.40, *SD* = 11.58).

2.3. Procedure

During encoding, participants observed a continuous stream of stimuli one after the other while using their keyboard to complete trial-wise attention checks (e.g., "Is this item natural or man-made?"). The number of encoding trials varied by study, ranging from 64 to 144, with each trial being presented for between 1.5 s and 2.5 s depending on the study. During recognition, participants used their mouse to judge stimuli as either "Old" or "New". The number of recognition trials varied by study, ranging from 32 to 128; in all studies, targets (i.e., stimuli that appeared during encoding) and lures (i.e., stimuli that did not appear during encoding) appeared in equal proportion. Depending on the study, participants saw either visual (i.e., images of everyday objects; n = 756) or verbal stimuli (i.e., 4-letter words; n = 39). Finally, participants responded to questionnaires and demographic questions. Additional details on the procedures of preregistered studies can be found here: osf.io/328g5; osf.io/wbj2p. On average, the procedures took around half an hour to complete in their entirety (mean = 33.75 min; *SD* = 10.35 min). Average performance on the memory tasks (*d'*) was significantly above chance (*d'* = 0), with 89.43 % of participants surpassing this threshold (mean = 1.68, *SD* = 1.16; $t(794) = 40.64$, $p < .001$); this level of performance is comparable to other memory tasks carried out in online environments (e.g., Koller and Cannon, 2021, 2023).

2.4. Analyses

Analyses were conducted in R. Error proportions (ranging from 0 to 1) were calculated by dividing the sum of false alarm errors (responses of "Old" to lures) by the total number of lures; the sum of miss errors (responses of "New" to targets) by the total number of targets. We conducted four mixed-effects beta regressions using the glmmTMB package (Brooks et al., 2017) to model error proportions as a function of the interaction between each symptom score (positive, disorganized, negative, paranoia) and error type (false alarm versus miss). In each model, we included every other aspect of schizotypy as a covariate. Additional covariates were added based on AIC/BIC model selection, including site (Prolific versus MTurk), stimulus type (visual versus verbal), and attention during encoding. As the data were positively skewed (skew = 1.21), outliers were defined using the robustbase package (Todorov and Filzmoser, 2010); no outliers were detecting using this method. To accommodate remaining values of 1 and 0, we then squeezed the error proportion variable using methods described in Smithson and Verkuilen (2006). We used the "check_collinearity" function of the performance package (Lüdecke et al., 2021) to test whether the data met the assumption of collinearity; this analysis indicated low degrees of correlations between model predictors (all VIFs < 4).

3. Results

The beta regression for positive symptoms revealed both a significant main effect, $z(1576) = 6.55$, $p < .001$, OR = 1.06, 95 % CI [1.04, 1.08], and a positive-symptom-by-error-type interaction, $z(1576) = -3.87$, $p < .001$, OR = 0.97, 95 % CI [0.95, 0.98]. This indicated that while those higher in positive symptoms made more errors in general, this relationship was stronger for false alarms than misses (see Fig. 1, top left). Disorganized symptoms also exhibited a significant interaction, $z(1578) = -2.60$, $p < .01$, OR = 0.98, 95 % CI [0.96, 0.99], but no significant main effect ($p = .41$; see Fig. 1, top right). By contrast, negative symptoms showed neither a main effect ($p = .53$) nor an interaction ($p = .52$; see Fig. 1, bottom left). This indicated that those higher in negative symptoms did *not* make more memory errors in general, nor did they exhibit a differential relationship with false alarms versus misses. Finally, paranoia exhibited both a main effect, $z(1576) = 6.18$, $p < .001$, OR = 1.02, 95 % CI [1.02, 1.03], and an interaction, $z(1576) = -6.20$, $p < .001$, OR = 0.97, 95 % CI [0.97, 0.98], in the same direction as positive symptoms (false alarms>misses; see Fig. 1, bottom right).

4. Discussion

In an omnibus sample of online workers, positive symptoms (comprising delusion-like thought and hallucination-like experiences) were more strongly positively associated with false alarm errors than miss errors during recognition memory. This pattern was evident across multiple symptom measures, including a more general positive schizotypy scale and a paranoia-specific scale, and persisted despite covarying for other schizotypy symptom clusters. While disorganized schizotypy showed a similar interactive pattern, this effect was characterized by a slight *negative* association with miss errors rather than a strong positive association with false alarms. Negative schizotypy, by contrast, showed associations with *neither* false alarm nor miss errors after covarying for other aspects of schizotypy. This pattern supports the notion that people experiencing positive symptoms of schizotypy, including paranoia, are especially likely to misattribute signal to noise stimuli during recognition memory (Blain et al., 2020; Koller and Cannon, 2021; Sahakyan and Kwapil, 2019) – characteristic of an "intrusive-like" profile of memory impairment, wherein context-irrelevant stimuli trigger spurious retrieval events.

Drawing from this pattern of findings, we can speculate on possible neural processes that underlie this asymmetry. Namely, such a bias may be instantiated by imbalances in the processes that support retrieval versus encoding, which depend on the morphology of distinct regions within the hippocampus. During encoding, sparse coding within the dentate gyrus (i.e., in which few neurons can be active within a given window of time) facilitates "pattern separation", allowing potentially overlapping inputs to be orthogonalized into distinct representations (Bein et al., 2020; Neunuebel and Knierim, 2014). During retrieval, the intensive recurrent connectivity of region CA3 facilitates "pattern completion", whereby sensory data is matched to an existing representation, allowing the reinstatement of complete memories based on partial reminders (Nakazawa et al., 2002). Notably, these functions are thought to rely on a delicate balance of excitatory (E) and inhibitory (I) interneurons that influence signal-to-noise ratio within hippocampal networks (Sambandan et al., 2010). The dentate gyrus needs adequate

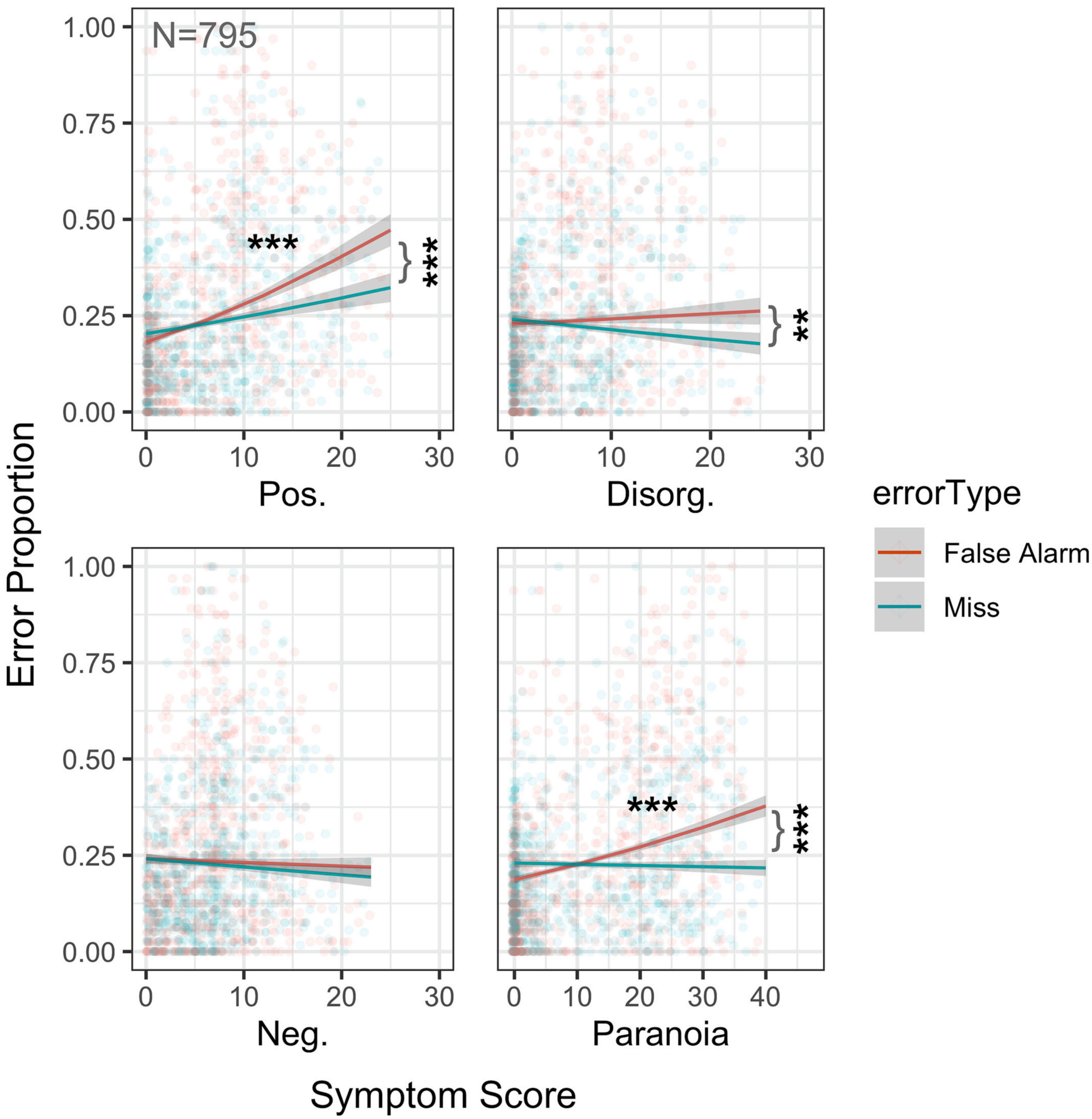

Fig. 1. Error proportion as a function of symptom score and error type (false alarm vs. miss)
Note. Shaded area represents *SE*.

inhibition to suppress co-activity and thus achieve sparse coding; CA3 needs adequate *excitation* to complete auto-associative recall, but adequate *inhibition* to prevent a positive feedback cycle once activation is triggered. As such, a false alarm bias could be related to an E/I imbalance within the hippocampus, whereby *under-inhibition within dentate gyrus* reduces distinctiveness of stored representations during encoding while *over-excitation within CA3* leads to spreading activation during retrieval (Heckers and Konradi, 2015; Tamminga et al., 2010). Such imbalances would increase the likelihood of spurious retrieval events to sensory data that only weakly corresponds to prior experience.

In summary, this study demonstrated that positive schizotypy (including paranoia) in a large analog sample was associated with a bias towards false alarm errors relative to miss errors during recognition memory, while negative schizotypy was not associated with either error type. We considered neural processes that might underlie this asymmetry, including an excitatory/inhibitory imbalance within the regions of the hippocampus that support encoding and retrieval.

CRediT authorship contribution statement

WNK: Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, Visualization, Writing - Original Draft, Writing –

Reviewing and Editing; **TDC:** Conceptualization, Methodology, Writing – Reviewing and Editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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