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Mnemonic discrimination deficits in multidimensional schizotypy

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Abstract

Current developmental psychopathology models indicate that schizophrenia can be understood as the most extreme expression of a multidimensional continuum of symptoms and impairment referred to as schizotypy. In nondisordered adults, schizotypy predicts risk for developing schizophrenia-spectrum psychopathology. Schizophrenia is associated with disruptions in detecting subtle differences between objects, which is linked to hippocampal dysfunction. These disruptions have been shown in the Mnemonic Similarity Task (MST) when patients are less likely to reject lures that are similar but not identical to studied objects, and instead mistake them for studied items. This pattern of errors may be a behavioral manifestation of impaired pattern separation, a key episodic memory ability associated with hippocampal integrity and overreliance on pattern completion. We examined whether multidimensional schizotypy is associated with such deficits in nondisordered young adults. Participants ($n = 230$) were assessed for positive, negative, and disorganized schizotypy and completed the MST and a perceptual discrimination task. MST performance showed that a combination of elevated negative and disorganized schizotypy was associated with decreased rejections of similar lures because they were mistakenly identified as studied items. These deficits were not observed in traditional recognition measures within the same task, nor in perceptual discrimination, suggesting that mnemonic discrimination deficits assessed by MST were selective and did not reflect generalized deficits. These findings extend the results obtained in schizophrenia patients and support a multidimensional model of schizophrenia-spectrum psychopathology.

KEYWORDS
mnemonic discrimination, pattern separation, schizophrenia, schizotypy

1 | INTRODUCTION

1.1 | Pattern separation and mnemonic discrimination

Routine everyday events are often similar but not identical to past experiences. For example, one may always eat breakfast at the same table, but have different amounts or types of cereal each day. People's tendency to follow routines leads to the creation of similar memory representations that could interfere with one another. However, a key aspect of healthy episodic memory systems is the ability to mitigate interference by differentiating among similar representations. Computational models of hippocampal function assume that this can be accomplished when sensory inputs are encoded uniquely via a process

known as pattern separation (McClelland et al., 1995; Norman & O'Reilly, 2003). Behavioral evidence for pattern separation, referred to as *mnemonic discrimination*, is observed when people distinguish an earlier encoded representation (e.g., a studied pumpkin) from a similar sensory input (e.g., a similar pumpkin). The Mnemonic Similarity Task (MST; Stark et al., 2019) assesses mnemonic discrimination and provides a useful measure of the behavioral impact of hippocampal dysfunction. The task has been widely used in healthy and clinical populations. There are many variants of the MST, with different stimuli and scoring methods, but they typically include a study phase and a test phase, which involves identifying studied, unstudied, and similar test stimuli (lures) that vary in degree of similarity to the studied items.

1.1.1 | Mnemonic discrimination and hippocampal function

Discriminating similar lures in the MST is a sensitive marker of hippocampal integrity, and it has been used to assess hippocampal dysfunction in healthy aging, dementia, and a range of psychopathology (see Stark et al., 2019). Hippocampal dysfunction is associated with greater impairments in the ability to reject similar lures in variants of the MST, although such dysfunction often does not affect discrimination of studied from unstudied items in the same task (i.e., Kirwan et al., 2012). Thus, lure discrimination in the MST is a sensitive marker of hippocampal dysfunction, whereas general recognition ability appears to be impacted less by such dysfunction.

Evidence from brain imaging studies indicates that lure discrimination in the MST is positively associated with the volume of hippocampal structures, including studies with older adults (Dillon et al., 2017; Doxey & Kirwan, 2015; Reagh et al., 2018; Stark & Stark, 2017), children (e.g., Canada et al., 2019), patients with depression (Dery et al., 2013; Shelton & Kirwan, 2013), and multiple sclerosis (Zuppichini & Sandry, 2018). Studies have also confirmed the critical role of dentate gyrus (DG) and cornu ammonis (CA1/CA3) subregions of hippocampus in discrimination of similar lures in the MST (for reviews, see Leal & Yassa, 2018; Stark et al., 2019). Volumetric reductions in DG were shown to be associated with impaired lure discrimination (Canada et al., 2019; Dillon et al., 2017; Doxey & Kirwan, 2015; Reagh et al., 2018; Stark & Stark, 2017). In addition, amnesic patients with damage limited to the DG region or CA1 region showed selective impairments when attempting to discriminate similar lures, without any difficulty in discriminating studied items from dissimilar unstudied items (Baker et al., 2016; Hanert et al., 2019). Thus, lure discrimination in the MST offers a useful behavioral signature of dysfunction in select hippocampal subfields.

1.2 | Schizophrenia, mnemonic discrimination, and hippocampal dysfunction

Schizophrenia is a severe mental illness that involves a broad array of cognitive impairments, neuroanatomical anomalies, and disruptions in

neurological functioning (e.g., American Psychiatric Association, 2013; Heinrichs & Zakzanis, 1998; Tandon et al., 2009). Episodic memory deficits are robust in schizophrenia (e.g., Achim & Lepage, 2005; Dickinson et al., 2008; Gold et al., 1992; Mesholam-Gately et al., 2009; Ragland et al., 2015; Ranganath et al., 2008). Studies using the MST have shown selective lure discrimination deficits in schizophrenia patients, patients with first-episode psychosis, and children and adolescents at genetic risk for schizophrenia (Das et al., 2014; İmamoğlu et al., 2023; Martinelli & Shergill, 2015). However, studies have not comprehensively examined the associations of symptom dimensions of schizophrenia with the MST.

Mnemonic discrimination deficits in schizophrenia may also signal disruptions in hippocampal subfield functioning. For example, hyperactivity in CA1 (Lieberman et al., 2018), GABAergic dysfunction in CA2/CA3 (Benes, 1999), and disruption in the DG (Tamminga et al., 2010) have been hypothesized to be a consequence of schizophrenia. Since these subfields play a critical role in mnemonic discrimination (Leal & Yassa, 2018; Stark et al., 2019), it is not surprising that schizophrenia patients show impaired lure discrimination in the MST.

1.2.1 | Schizotypy and schizophrenia

Although schizophrenia has traditionally been classified as a categorical disorder, current models suggest that it can be conceptualized as the most extreme manifestation of a dynamic continuum of clinical and subclinical symptoms and impairment referred to as *schizotypy* (Kwapil & Barrantes-Vidal, 2015; Lenzenweger, 2010). Schizotypy offers a useful and unifying construct for understanding the development, expression, and treatment of schizophrenia-spectrum psychopathology, as well as variation in normal behavior, as it encompasses subclinical expressions, the psychosis prodrome, Cluster A personality disorders, and schizophrenia and related psychotic disorders. Schizotypy (and by extension schizophrenia) is multidimensional with positive (psychotic-like), negative (deficit), and cognitive-behavioral disorganization dimensions. These dimensions are associated with unique etiologies, symptoms, and trajectories (e.g., Kemp et al., 2021). Thus, schizotypy offers a useful approach for studying schizophrenia-spectrum psychopathology across a broad range of severity and for capturing its heterogeneity.

Consistent with the dimensional model of schizotypy, evidence indicates that there is continuity in terms of the deficits observed across subclinical and clinical expressions of positive, negative, and disorganized schizotypy, such that persons with subclinical schizotypy tend to show attenuated forms of the symptoms and impairment seen in patients with schizophrenia-spectrum disorders (for reviews, see Chun et al., 2013; Ettinger et al., 2015; Nelson et al., 2013). For example, episodic memory deficits are reliably documented in schizophrenia (e.g., Dickinson et al., 2008; Gold et al., 1992; Mesholam-Gately et al., 2009; Ranganath et al., 2008), in genetic risk for schizophrenia (İmamoğlu et al., 2023), and studies by our laboratory and others confirmed similar (albeit milder) deficits in subclinical expressions of schizotypy (for a selective review, see Ettinger et al., 2015). In our studies,

such deficits emerged in free recall (Sahakyan & Kwapil, 2016), cued-recall (Sahakyan & Kwapil, 2018b), recognition (Sahakyan & Kwapil, 2019), source memory (Sahakyan & Kwapil, 2016), intentional forgetting (Sahakyan et al., 2020), measures of retrieval organization reflecting context processing (Sahakyan & Kwapil, 2018a), and relational memory (Sahakyan et al., 2019). In addition, reduced hippocampal volume is one of the most robust brain abnormalities in schizophrenia (Adriano et al., 2012; van Erp et al., 2016). Consistent with continuum models of schizotypy and schizophrenia, hippocampal volumetric reductions in nonclinically ascertained adults were predicted by the negative × disorganized schizotypy interaction, specifically in the anterior portion of DG and CA1/CA3 subfields of the left hippocampus (Sahakyan et al., 2021), suggesting that reductions in these brain regions occur prior to the onset of clinical illness and might play a role in the etiology of schizophrenia and related disorders. Although mnemonic discrimination deficits are documented in schizophrenia (Das et al., 2014; Martinelli & Shergill, 2015), to our knowledge they have not been examined in subclinical positive, negative, and disorganized schizotypy. Thus, we do not know if similar impairments are present in people at risk for schizophrenia-spectrum disorders or if they represent sequelae of such disorders.

1.3 | The present study

The present study examined the association of mnemonic discrimination using the MST with positive, negative, and disorganized schizotypy in a sample of nonclinically ascertained young adults. Based on our previous research on memory deficits in schizotypy, we expected to observe MST deficits primarily in negative schizotypy. Most of our previous research assessed schizotypy using Wisconsin Schizotypy Scales (e.g., Chapman et al., 1978) that did not include the disorganized dimension. Therefore, these studies did not support a priori expectations of associations between lure discrimination and disorganized schizotypy. However, our subsequent research employed the Multidimensional Schizotypy Scale (e.g., Gross, Kwapil, Raulin, et al., 2018; Kwapil et al., 2018), which assesses the disorganized dimension. In volumetric assessment of hippocampus and its subfields, we found that an interaction of negative and disorganized schizotypy was associated with reduced hippocampal volume in DG and CA hippocampal subregions (Sahakyan et al., 2021). Specifically, the interaction of negative and disorganized dimensions predicted smaller hippocampal volume, especially in the DG and CA subregions—regions shown to support mnemonic discrimination. Given that previous research has repeatedly demonstrated associations with hippocampal volume and mnemonic discrimination ability across a range of healthy populations and pathologies, we hypothesized that elevated negative and disorganized schizotypy would be associated with deficits in mnemonic discrimination. We did not expect perceptual discrimination to be associated with schizotypy given the use of a relatively high-functioning nonpatient sample. Nevertheless, we included a task to assess that ability because perceptual discrimination has been shown to mediate mnemonic discrimination deficits in schizophrenia patients (Martinelli & Shergill, 2015).

2 | METHOD

2.1 | Participants

The initial sample included 246 young adults recruited from the University of Illinois at Urbana-Champaign (UIUC). They were tested individually in the laboratory. Sixteen participants (7%) were excluded due to invalid protocols (see below), leaving 149 female and 81 male participants ages 18–25 years ($M = 19.0$, $SD = 1.1$) with usable scores. Following Cohen (1992), the sample provided sufficient power to detect hypothesized small-to-medium effect sizes. The study was approved by the UIUC Institutional Review Board (protocol #16149), all participants provided informed consent, and they received course credit for their participation. The data were collected for the present study, and neither the data nor the sample have been used in other studies.

2.2 | Materials

Participants completed the MST (Stark et al., 2013) and a perceptual discrimination task (PDT; Martinelli & Shergill, 2015), and the Multidimensional Schizotypy Scale-Brief (MSS-B; Gross, Kwapil, Raulin, et al., 2018).

2.2.1 | Mnemonic similarity task

The stimuli for the MST and PDT were images of everyday objects (400 × 400 pixels) taken from a publicly available database (https://github.com/celstark/MST). Figure 1a shows the MST. During the study and test phases, pictures of everyday objects appeared individually in the center of the display against a white background for 2 s each in random order. To ensure encoding during study, participants pressed a key to indicate if objects belonged indoors or outdoors. The study phase was followed immediately by a test phase that included three object types. The objects were identical to studied objects (old), similar but not identical to studied objects (similar), or new to the experiment with different identities than studied objects (new). Participants pressed a key to identify objects as old, similar, or new.

Participants completed two cycles of unique object sets in the study-test procedure. Each cycle included 72 study objects and 108 test objects, comprising three unique sets of 36 objects that were assigned to the old, similar, and new object conditions. The new objects only appeared at test. For all object types, each 36-object set included 12 objects from each of the three most confusable "lure bins" (i.e., bins 1, 2, and 3) from the complete set of stimuli indicated above. Lures in each bin varied in their degree of perceived similarity to studied objects, with bin 1 lures being most similar, bin 2 lures
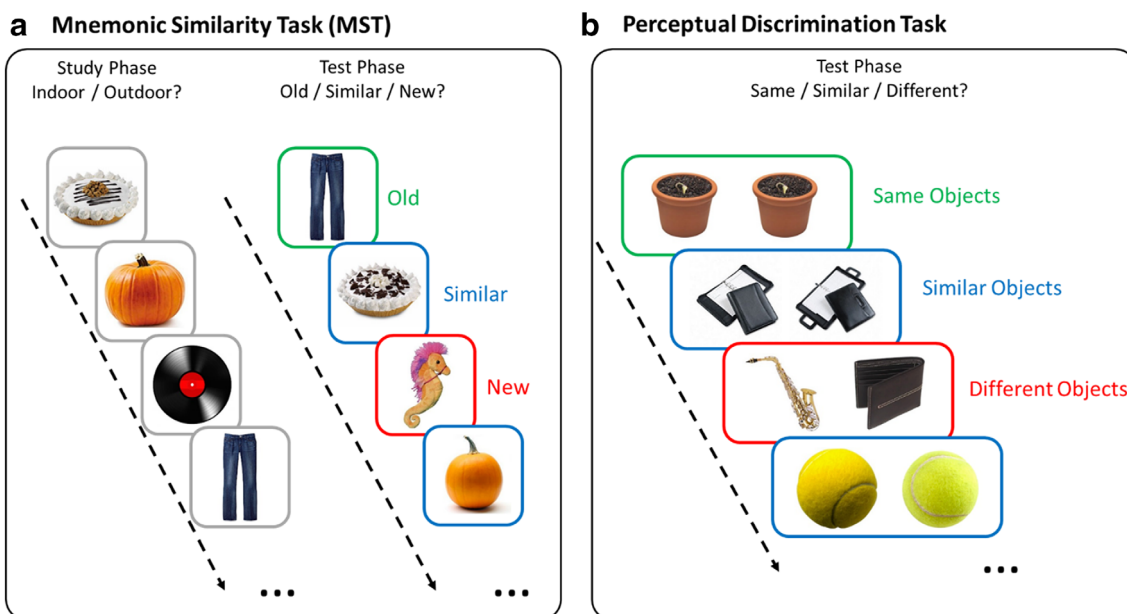
FIGURE 1 Mnemonic Similarity Task (a) and Perceptual Discrimination Task (b).

being moderately similar, and bin 3 lures being least similar of the three bins. Note that the full material set in the traditional MST also includes lures from bins 4 and 5 that are less similar to studied objects than the materials used here. We included the most similar lure bins to create a sensitive task that places high demands on the hippocampal regions most susceptible to dysfunction associated with schizophrenia. In the full material set, objects are sorted into lure bins based on normative probabilities of participants misclassifying similar lures as studied objects, with lower-numbered bins indicating higher normative false alarm rates (Stark et al., 2013). These error rates were equated across sets. For counterbalancing, object sets were rotated through conditions across three versions of the experiment.

2.2.2 | Perceptual discrimination task

The PDT (Figure 1b) included objects that were not used in the MST but had the same normative false alarm rates for similar lures. This safeguarded against task contamination from exposure to objects in the MST, while ensuring comparable perceptual similarity between similar objects in both tasks. Participants were told that their task was to classify the relationship between object pairs. Because the task assessed perceptual discrimination, there was only a test phase. Pairs of everyday objects appeared side-by-side against a white background until participants made a response. Participants pressed a key to indicate if a pair included the same object, similar objects, or different objects. Same objects included the exact same picture (e.g., the same potted plant), similar objects included the two versions of an object that could serve as a studied object and its similar lure (e.g., two similar but not identical day planners), and different objects were entirely different (e.g., a saxophone and a wallet). The presentation order was randomized. There were 90 total object pairs comprising 36 same

pairs, 36 similar pairs, and 18 different pairs. For counterbalancing, we rotated the object sets through test object conditions across three versions of the experiment.

2.2.3 | Multidimensional Schizotypy Scale-Brief

The MSS-B contains 38 true-false items that assess positive, negative, and disorganized schizotypy. Sample items include: *I have sometimes felt that strangers were reading my mind* (positive schizotypy), *Generally, I do not have many thoughts or emotions* (negative schizotypy), and *I find that I am very often confused about what is going on around me* (disorganized schizotypy). The subscales are scored as the number of items answered in the schizotypic direction with scoring range of 0–13 for the positive and negative schizotypy subscales, and 0–12 for disorganized schizotypy, with higher scores indicating greater endorsement of schizotypy than lower scores. Consistent with the full-length Multidimensional Schizotypy Scale (Kwapil et al., 2018), the MSS-B subscales have good internal consistency and test–retest reliability (e.g., Gross, Kwapil, Raulin et al., 2018; Kemp, Gross et al., 2020) and validity (e.g., Gross, Kwapil, Burgin, et al., 2018; Kemp, Bathery, et al., 2020). The MSS-B items were intermixed with a 13-item Infrequency Scale (Chapman & Chapman, 1983) to identify invalid responders. Following Chapman and Chapman, participants who endorsed more than two infrequency items were excluded from the analyses.

2.3 | Procedure

Participants were tested individually in a quiet room. Upon providing consent, they completed in order the MST, PDT, and MSS-B. All stimuli were presented electronically using E-Prime 3.0 software on a

computer screen that included a 17-inch display (1920 × 1080 resolution). The viewing distance was approximately 20 inches.

2.3.1 | Analytic approach

Initially, we examined MST and PDT performance for the overall sample by computing the response probabilities for each object type. Figure 2 summarizes these probabilities in the MST (panel a), and the PDT (panel b). Since we were primarily interested in differences between trials that required mnemonic discrimination, in the MST we only tested for statistical differences in response probabilities for the similar objects. We also evaluated classification of similar objects across three levels of lure similarity (i.e., across lure bins). In the PDT, we only tested for statistical differences in response probabilities for similar objects, since we only included perceptual discrimination of similar objects as a predictor in the hierarchical regression models described below.

The hallmark of pattern separation impairment is reflected in reduced ability to correctly categorize a similar object as "similar," reflecting an increased tendency to miscategorize similar objects as "old." Therefore, to evaluate if schizotypy was associated with mnemonic discrimination deficits, we conducted hierarchical regression analyses predicting the probability of identifying similar objects as such in the MST (the analyses of errors, in which similar objects were miscategorized as "old" is presented in the Supporting Information).

Step 1 included the probability of identifying new objects as "similar" to control for general bias to identify any object as "new." Step 2 included simultaneous entry of MSS-B positive, negative, and disorganized schizotypy subscales; Step 3 included the three two-way schizotypy interactions; and Step 4 included the three-way interaction. In addition, correct responses were examined at three levels of lure bins using separate models for each bin, with the same predictor entry order. Simple slopes analyses were computed to disentangle statistically significant interactions by examining the effect of one predictor at low ($-1\ SD$ below the mean), medium ($0\ SD$ or mean), and high ($+1\ SD$) levels of the other predictor.

In prior work, we demonstrated that schizotypy dimensions were differentially associated with recognition deficits in a traditional old/new recognition task that did not include similar lures at test (Sahakyan et al., 2019). In contrast, the current MST includes three response categories because the test includes similar lures. Furthermore, previously reported impairments in recognition were based on the association of recognition performance with Wisconsin Schizotypy Scales, which did not include disorganized schizotypy, whereas the MSS-B does. Therefore, it is unclear whether the association of schizotypy with recognition deficits would generalize to traditional recognition performance on the MST. The main reason for examining general recognition across schizotypy dimensions was to assess whether general recognition ability explained performance on the MST, since one previous study reported such findings with schizophrenia patients (Martinelli & Shergill, 2015). We therefore conducted hierarchical regression analyses on the "Old called Old" responses, and on "New called Old" responses (the latter is in the Supporting Information) to examine these issues. The order of entry of the predictors was the same as described above, with the exception of step 1, in which we entered new objects classified as "old" to account for the general bias to classify any object as "old."

Finally, we examined discrimination of similar object pairs in the PDT as a function of schizotypy dimensions. Patients with schizophrenia often show generalized performance deficits. Thus, when studying cognitive impairment in patients, it is useful to demonstrate differential deficits to rule out that findings do not simply reflect generalized impairment (Chapman & Chapman, 1973). A previous study showed that perceptual discrimination deficits in schizophrenia patients account for their mnemonic discrimination deficits in MST (Martinelli & Shergill, 2015). It was therefore necessary to evaluate if there were impairments in perceptual discrimination across schizotypy dimensions, and whether perceptual discrimination accounted for deficits in mnemonic discrimination. We did not expect nonclinically ascertained participants to exhibit generalized performance deficits as they have not suffered the catastrophic consequences that accompany psychotic disorders. Nevertheless, to more rigorously examine whether the deficits in mnemonic discrimination are specific to hippocampus-driven pattern separation processes as opposed to reflecting a broader pattern of cognitive impairment, we examined the ability to distinguish between similar and dissimilar items that were presented side-by-side based on perceptual rather than mnemonic processes.

2.4 | Transparency and openness promotion

Data and analytic code for the study will be made available on Open Science Framework at https://osf.io/tzdk3/

3 | RESULTS

3.1 | Multidimensional schizotypy assessment

Descriptive statistics and inter-correlations for the MSS-B subscales are in Table 1. Note that participants scored across the full range of the subscales. Consistent with previous literature, correlations among the subscales were minimal, suggesting that multicollinearity was not a problem in the regression analyses.

3.2 | Overall task performance

3.2.1 | Mnemonic similarity task

We conducted separate paired-samples t-tests for classification responses within the Similar object type (Figure 2, middle of panel A). Participants made significantly more "old" than "similar" responses,
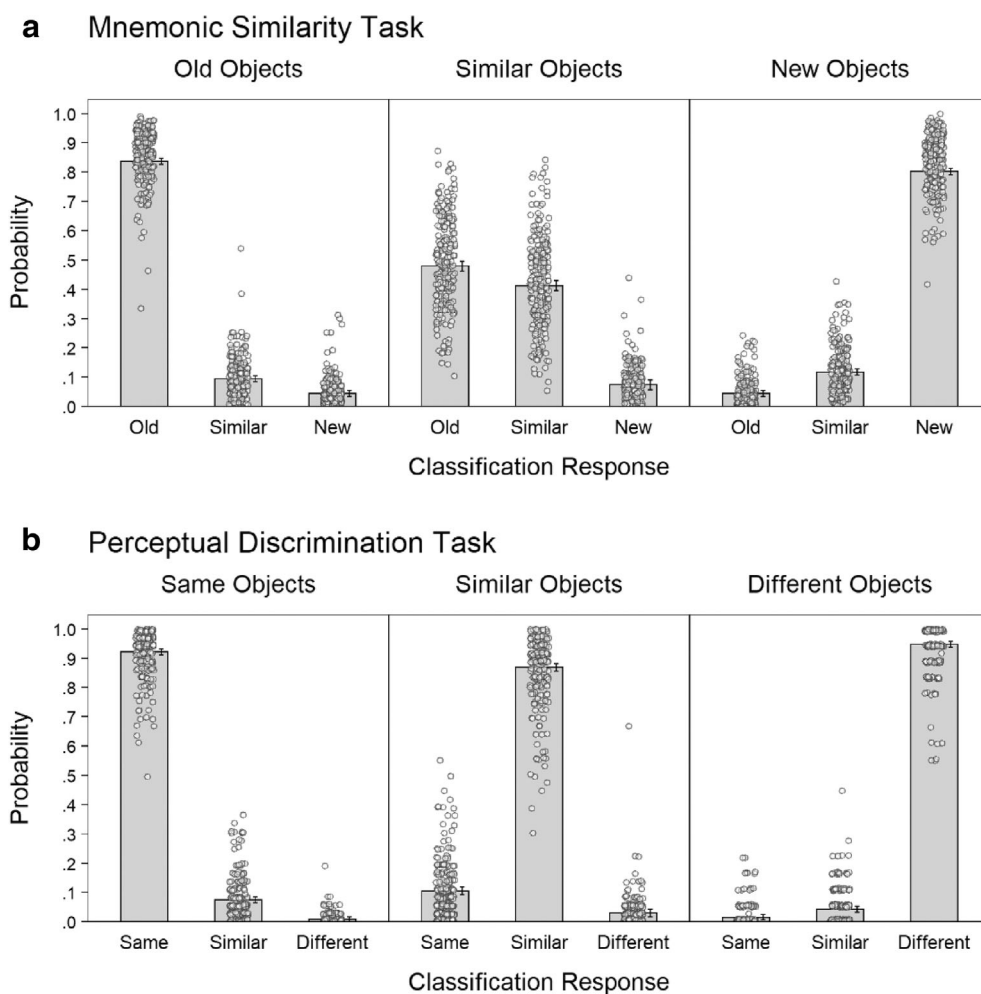
a Mnemonic Similarity Task

b Perceptual Discrimination Task

$t(229) = 3.45$, $p < .001$, $d = 0.23$, and significantly more "similar" than "new" responses, $t(229) = 28.53$, $p < .001$, $d = 1.88$. The finding that participants made more incorrect "old" than correct "similar" responses is the result of the stimuli coming from the most confusable lure bins. We examined the effect of lure bins on Similar object identification by comparing response probabilities across bins (Figure 3). As lures became less confusable with studied objects (going from bins 1–3), correct "similar" responses (middle panel) increased significantly between each lure bin, smallest $t(229) = 10.06$, $p < .001$, $d = 0.66$, whereas incorrect "old" responses (left panel) decreased significantly between each bin, smallest $t(229) = 13.16$, $p < .001$, $d = 0.87$. Rare "New" responses occurred significantly more often in Bin 3 than the other bins, smallest $t(229) = 7.04$, $p < .001$, $d = 0.57$.

3.2.2 | Perceptual discrimination task

We also conducted separate paired-samples t-tests for classification responses within the Similar object type (Figure 2, middle of panel B). Participants made significantly more correct "similar" responses than incorrect responses of either type, smallest $t(229) = 52.71$, $p < .001$,

$d = 3.48$, thus showing highly accurate visual discrimination of similar pairs.

3.3 | MST classification probability as a function of multidimensional schizotypy

3.3.1 | Mnemonic discrimination: Similar items called "similar"

To account for a general bias to categorize any stimulus as "similar," we entered the proportion of new items categorized as "similar" at Step 1. Entering that predictor as a covariate controls for variance associated with response bias and minimizes some of the limitations (e.g., reduced reliability and ambiguity) associated with the traditional difference score approach of subtracting that term from the outcome measure (e.g., Cafri et al., 2010; Cronbach & Furby, 1970; Edwards, 2002). At step 2, we simultaneously entered the MSS-B positive, negative, and disorganized schizotypy subscale scores, so that we could examine the unique contribution of each schizotypy dimension over-and-above the other schizotypy dimensions. At

TABLE 1   Descriptive statistics and inter-correlations of MSS-B subscales.

MSS-B subscales	Descriptive statistics				Correlations	
	Mean	SD	Coefficient alpha	Range	Negative Schizotypy	Disorganized Schizotypy
Positive schizotypy	2.55	2.84	.83	0–12	.06	.33
Negative schizotypy	1.53	2.21	.80	0–13		.26
Disorganized schizotypy	1.94	2.87	.88	0–12		

FIGURE 3   Correct classification of similar objects in Mnemonic Similarity Task across lure bins. Bar heights are mean estimates, points are individual participant probabilities, and error bars are 95% confidence intervals.
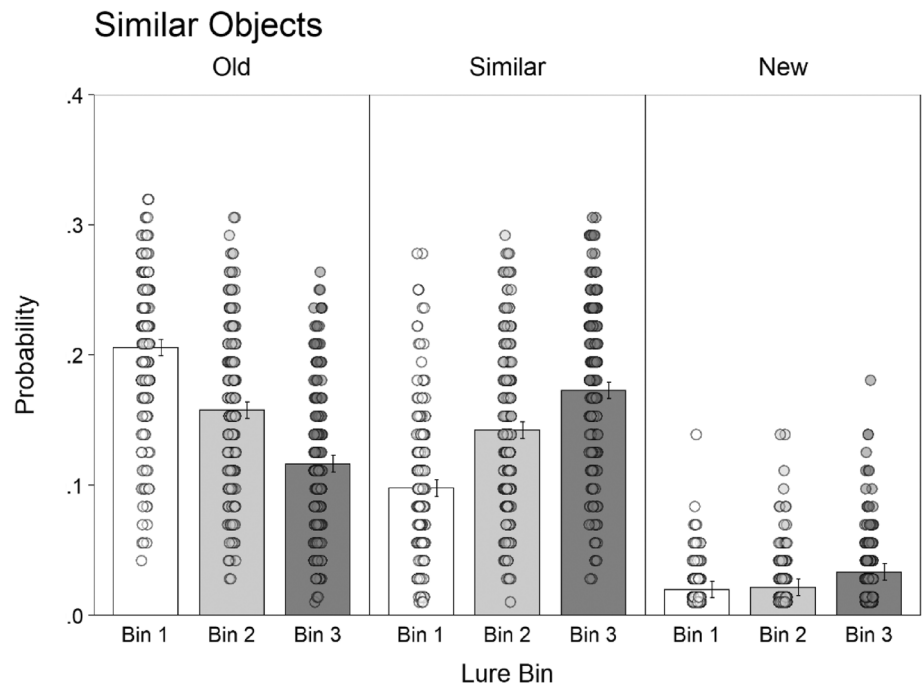
step 3, we entered the three 2-way interaction terms of schizotypy scores to examine if they accounted for variance over-and-above the schizotypy main effects. At step 4, we entered the three-way schizotypy interaction term.[1]

As seen in Table 2, neither the bias term nor the main effects of any schizotypy dimensions predicted the proportion of similar stimuli categorized as "similar." However, the interaction of negative and disorganized schizotypy was significant in step 2 and it is visualized in Figure 4. Simple slopes analysis indicated that at low (-1 SD) levels of disorganized schizotypy, negative schizotypy was significantly positively associated with identifying similar items as "similar" ($p = .038$). However, the reverse was found at high ($+1$ SD) levels of disorganized schizotypy, where negative schizotypy was significantly negatively associated with identifying similar items as "similar" ($p = .035$). At moderate levels of disorganized schizotypy (0 SD), negative schizotypy was unassociated with accuracy ($p = .459$). In sum, the combination of high negative and high disorganized schizotypy was associated with reduced probability of

correctly identification of similar items as such showing that mnemonic discrimination deficits associated with high negative schizotypy were only present for people with high disorganized schizotypy.

3.3.2 | Mnemonic discrimination: Similar items called "similar" across lure bins

We examined mnemonic discrimination as correct identification of similar items as "similar" using separate models for objects in each of the three levels of lure similarity, entering predictor variables in the same sequence as in the previous model. The results are summarized in Table 2 and visualized in Figure 5.

When the lures were least similar to their corresponding studied objects (Figure 5, left panel), a significant interaction of negative and disorganized schizotypy predicted mnemonic discrimination of similar objects. No other predictors were significant. Simple slopes analyses showed that high negative schizotypy participants were significantly less likely to correctly identify similar objects when disorganized schizotypy was also high ($+1$ SD), $p = .033$. However, at medium (0 SD) or low levels (-1 SD) of disorganized schizotypy, there was no association between negative schizotypy and accuracy as the slopes were not significantly different from zero ($p = .966$ at 0 SD and $p = .202$ at

[1]Note that Stark and colleagues (e.g., Stark et al., 2019, 2023) have advocated for the use of the difference score based Lure Discrimination Index (LDI) to assess mnemonic discrimination. The LDI is computed as the probability of responding "similar" to similar lure items minus the probability of responding "similar" to the novel lure items. Stark et al. (2023) reported that the LDI has good psychometric properties, including test–retest reliability. Nevertheless, given the limitation of difference score indices we opted for a regression-based approach in the present study.

TABLE 2 Prediction of similar items categorized as "similar" in MST (Mnemonic Similarity Task) by positive, negative, and disorganized schizotypy.

Outcome	Step 1 New items called similar (bias)		Step 2 Positive schizotypy		Negative schizotypy		Disorganized schizotypy		Step 3 Neg × Dis interaction		Pos × Dis interaction		Pos × NegSz interaction		Step 4 Pos × Neg × Dis interaction	
	β	sr²	β	sr²	β	sr²	β	sr²	β	sr²	β	sr²	β	sr²	β	sr²
Overall (all lure bins)	−.049	.002	−.012	.000	−.015	.000	−.088	.006	−.237**	.039	−.062	.002	.140	.016	.022	.000
Lure Bin 1	.053	.003	.050	.002	.036	.001	−.021	.000	−.125	.011	−.093	.005	.122	.012	.011	.000
Lure Bin 2	−.068	.005	.013	.000	.029	.001	−.104	.009	−.192*	.026	−.039	.001	.107	.009	−.005	.000
Lure Bin 3	−.103	.011	−.022	.000	−.053	.003	−.044	.002	−.190	.025	−.043	.001	.099	.008	.004	.000

Note: Each row represents a separate hierarchical linear regression analysis. For each predictor, the standardized regression coefficient (β), semipartial r-square (sr²) are reported.
*p < .05 **p < .01 ***p < .001.

−1 SD). Likewise, when the lures were of moderate similarity to their corresponding studied objects (Figure 5, middle panel), a significant interaction of negative and disorganized schizotypy predicted mnemonic discrimination, while none of the remaining predictors were significant. Simple slopes analyses revealed the same pattern for negative and disorganized schizotypy, but there was only a significant positive slope at low levels of disorganized schizotypy ($p = .038$) that appeared to offset the negative schizotypy impairment. At moderate and high levels of disorganized schizotypy, there was no relationship between negative schizotypy and mnemonic discrimination ($p = .241$ at 0 SD, and $p = .224$ at −1 SD). Finally, when lures were of high similarity to the studied objects (Figure 5, right panel), none of the predictors were significant. These results indicate that the pattern of associations with schizotypy dimensions and mnemonic discrimination across lure bins was consistent with the overall pattern reported, except when lures were most similar to studied objects.[2]

3.4 | General recognition as a function of multidimensional schizotypy

The associations between schizotypy dimensions and mnemonic discrimination thus far are consistent with our hypotheses. However, examining only mnemonic discrimination as an outcome variable is insufficient to infer such selectivity. To further test this assertion, we used the same regression models as above to test the hypothesis that schizotypy dimensions would *not* show the same associations with traditional recognition performance as they did with mnemonic discrimination. This differential approach was especially important because prior work showed that schizotypy is associated with impaired performance in standard recognition tasks that did not include similar lures (Sahakyan et al., 2019; Sahakyan & Kwapil, 2016). It is therefore possible that the patterns above only reflect general (not selective) memory differences associated with schizotypy dimensions.

There was an additional reason for entering recognition ability in the regression analyses. Namely, identifying similar items as "similar" is a correct response that involves the contribution of several processes, one of which could involve retrieving the studied objects and mentally comparing them to similar lures (i.e., a recall-to-reject strategy; Kirwan & Stark, 2007; Lacy et al., 2011). To account for the role of memory for studied objects in lure discrimination, we examined if controlling for recognition hits ("Old called Old"), which captures individual differences in the ability to remember studied objects, would eliminate the mnemonic discrimination deficits in lure rejections ("Similar called Similar"). If the association of elevated negative and disorganized schizotypy with lure discrimination remains significant after controlling for general recognition ability, then it would suggest

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[2]Given that in MST, most responses to similar items were "Similar" or "Old" (and not "New"), it suggests that the results for "Similar called Old" should mirror the findings described in "Similar called Similar" section. We conducted such analyses (including examining these errors across lure bins) and report them in Table S2.
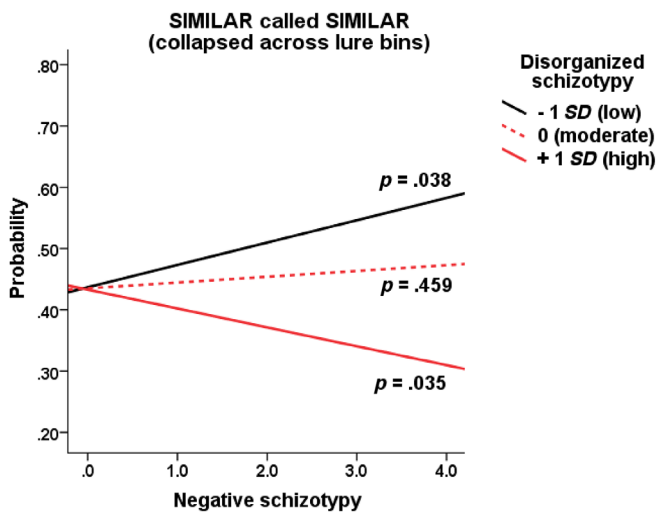
FIGURE 4 Prediction of correct classification of similar objects in Mnemonic Similarity Task by negative and disorganized schizotypy.

that the mnemonic discrimination deficits in schizotypy remain over-and-above deficits in general recognition.

The hierarchical regression model that we used to examine these possibilities was comparable to the previous models, except that general recognition was the outcome variable. We controlled for a general bias to identify any stimulus as "old," by entering the proportion of new items categorized as "old" at step 1. Predictor variables were entered in the remaining steps in the same sequence as in the previous models. Table 3a shows that neither the bias term, nor the main effects of schizotypy dimensions were significant. However, there were significant negative × disorganized (Figure 6, left panel) and positive × negative (Figure 6, right panel) interactions. No other predictors were significant. Simple slopes analyses for both interactions indicated differences among the slopes, although none of the slopes were significant, and if anything, the qualitative pattern of results for the negative × disorganized interaction was the exact opposite of what we observed when mnemonic discrimination was the outcome variable. Taken together, these findings suggest that the associations of schizotypy and mnemonic discrimination did not simply reflect general recognition differences.

3.4.1 | Recognition ability and MST deficits in schizotypy

In this set of analyses, we further evaluated if general recognition deficits in schizotypy reported above contribute to the mnemonic discrimination deficits in MST. We re-ran the hierarchical regression including "Similar items called Similar" responses (mnemonic discrimination) as the outcome variable reported previously, but at step 1, we added "Old called Old" responses (traditional recognition) to partial out the variance associated with general recognition. The results in Table 3b indicate that although general recognition explained some of the variance in mnemonic discrimination, which is not surprising given

that such discrimination can be accomplished using a recall-to-reject strategy, the interaction of negative and disorganized schizotypy remained significant after accounting for the general recognition deficits. These results suggest that recognition deficit by itself does not account for MST deficits in negative and disorganized schizotypy.

3.5 | Perceptual discrimination as a function of multidimensional schizotypy

We examined identification accuracy for similar pairs in PDT correctly classified as "similar" by entering the bias term first (different pairs classified "similar") at step 1, and entering MSS-B positive, negative, and disorganized schizotypy subscale scores at step 2, three 2-way interaction terms at step 3, and three-way interaction term at step 4. The results are summarized in Table 3c. Aside from significant effect of bias, indicating that stronger bias to mistakenly classify different pairs as "similar" was associated with lower probability to correctly classify similar pairs as "similar, neither the main effects of schizotypy dimensions, nor their interactions were significant. These findings suggest that schizotypy was not associated with visual discrimination deficits in the perceptual task.

3.5.1 | Perceptual discrimination and MST deficits in schizotypy

To evaluate the contribution of perceptual ability to mnemonic discrimination more rigorously, we re-ran previously reported analyses on similar items called "similar" in the MST. However, at step 1, we added the accuracy of similar objects classified as "similar" in the PDT to examine if negative by disorganized schizotypy interaction remains significant after accounting for perceptual discrimination of similar objects. The remaining steps in the hierarchical regression analyses were the same as reported previously. Table 3d shows that although perceptual discrimination ability was associated with mnemonic discrimination ability, the negative-by-disorganized schizotypy interaction remained significant after accounting for perceptual discrimination.

4 | DISCUSSION

Effective functioning relies on the ability to differentiate among similar representations because routine events are often similar but not identical to past experiences. Patients with schizophrenia show deficits in the ability to discriminate similar events, so we examined whether mnemonic discrimination deficits are associated with subclinical schizotypy. The results showed that none of the schizotypy dimensions by themselves (i.e., main effects) accounted for MST performance. However, the interaction of negative schizotypy and disorganized schizotypy was associated with impaired ability to distinguish studied objects from similar lure objects. Furthermore, participants
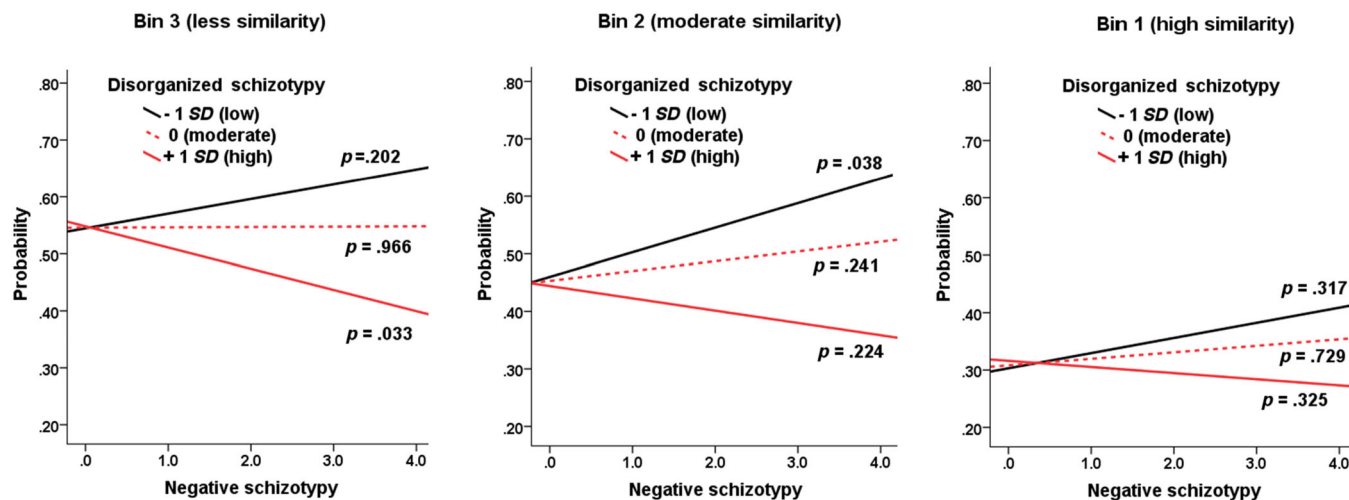
FIGURE 5 Prediction of correct classification of similar objects in Mnemonic Similarity Task by negative and disorganized schizotypy across lure bins.

with elevated negative and disorganized schizotypy had an enhanced propensity to mistake unstudied similar objects for studied objects (i.e., enhanced errors). Thus, elevated negative and disorganized schizotypy is associated with mnemonic discrimination deficits. This is consistent with reports of mnemonic discrimination deficits in schizophrenia, although the literature has not specifically examined such deficits by symptom dimensions in patients.

We did not observe similar deficits with positive schizotypy, or in the interactions of positive schizotypy with the other dimensions. This is in contrast to Vass et al. (2022), but consistent with our previous finding that hippocampal volume and episodic memory deficits were not associated with positive schizotypy. Furthermore, the deficits were selective to the recognition of similar lures in the MST. Even though we found associations between the schizotypy dimensions and general recognition ability (i.e., ability to discriminate studied objects from unstudied dissimilar objects), these general recognition deficits did not account for discrimination deficits of similar lures in the MST. Finally, none of the schizotypy dimensions were associated with visual discrimination ability in the PDT, and individual variation in perceptual discrimination did not account for the mnemonic discrimination deficits in negative and disorganized schizotypy, unlike findings in schizophrenia (Martinelli & Shergill, 2015). Thus, our study appears to demonstrate a selective deficit in mnemonic discrimination relative to general recognition or perceptual discrimination. However, future work should consider including comparison tasks that may demonstrate double dissociations for negative and disorganized schizotypy.

Given that discriminating similar lures in MST is a sensitive marker of hippocampal integrity (Stark et al., 2019), the finding of mnemonic deficits in negative and disorganized schizotypy appears consistent with our recent structural MRI findings regarding hippocampal subfields (Sahakyan et al., 2021). Specifically, we found that that the interaction of negative and disorganized schizotypy was associated with reduced hippocampal volume in a nonclinical sample, especially

in left DG and CA anterior regions that are key hippocampal subregions implicated in MST performance.

Relatedly, hippocampal pattern separation that leads to mnemonic discrimination has been shown to vary based on percept input change (i.e., lure similarity). We showed here that the associations between schizotypy dimensions and mnemonic discrimination were weaker for highest similarity lures. This result is reminiscent of group differences in mnemonic discrimination showing that deficits associated with hippocampal function are small or even absent for the most perceptually similar items (Stark et al., 2013; Yassa et al., 2011). Such findings can be accounted by the view that age differences in mnemonic discrimination reflect shifts in the degree to which CA3 is biased toward pattern separation or completion (Wilson et al., 2006). Accordingly, greater input changes are required for impaired groups to engage CA3 in pattern separation. However, group differences in mnemonic discrimination do not present when stimuli are too perceptually similar because the high percept-to-memory feature overlap continues to bias CA3 toward pattern completion. Extending this view to the current findings, high similarity lures (bin 1) may have been less sensitive to symptom-related deficits in pattern separation because the input changes were too small even for low-symptom to optimally engage pattern separation to discrimination lures. Future studies should aim to characterize this relationship by including a broader range of perceptual similarity among lures to map out behavioral input–output functions to determine if they correspond with predictions from models of hippocampal subfield contributions encoding and retrieval (e.g., Duncan & Schlichting, 2018; Yassa & Stark, 2011).

The finding that mnemonic discrimination deficits are specifically characteristic of elevated negative and disorganized schizotypy follows our previous findings that demonstrate a consistent pattern of memory impairment in negative schizotypy. We observed deficits in free recall (Sahakyan & Kwapil, 2018a), single-item recognition (Sahakyan & Kwapil, 2018b), source memory (Sahakyan & Kwapil, 2016), directed forgetting (Sahakyan et al., 2020), and

TABLE 3 Performance by positive, negative, and disorganized schizotypy and their interactions.

(a)

	Step 1		Step 2						Step 3						Step 4	
	New items called old (bias)		Positive schizotypy		Negative schizotypy		Disorganized schizotypy		Neg × Dis interaction		Pos × Dis interaction		Pos × Neg interaction		Pos × Neg × Dis interaction	
Outcome	β	sr^2	β	sr^2	β	sr^2	β	sr^2	β	sr^2	β	sr^2	β	sr^2	β	sr^2
Old items called Old	−.084	.007	.010	.000	−.016	.000	−.123	.012	.183*	.024	.139	.012	−.151*	.019	.007	.000

(b)

	Step 1		Step 2								Step 3						Step 4	
	Old items called Old (recognition)		New items called Similar (bias)		Positive schizotypy		Negative schizotypy		Disorganized schizotypy		Neg × Dis interaction		Pos × Dis interaction		Pos × Neg interaction		Pos × Neg × Dis interaction	
Outcome	β	sr^2	β	sr^2	β	sr^2	β	sr^2	β	sr^2	β	sr^2	β	sr^2	β	sr^2	β	sr^2
Similar items called Similar	−.174**	.029	−.081	.006	−.012	.000	−.015	.000	−.112	.010	−.212**	.038	−.042	.002	.122	.012	.022	.000

(c)

	Step 1		Step 2						Step 3						Step 4	
	Different called similar (bias)		Positive schizotypy		Negative schizotypy		Disorganized schizotypy		Neg × Dis interaction		Pos × Dis interaction		Pos × Neg interaction		Pos × Neg × Dis interaction	
Outcome	β	sr^2	β	sr^2	β	sr^2	β	sr^2	β	sr^2	β	sr^2	β	sr^2	β	sr^2
PDT Similar Accuracy	−.440***	**.194**	.079	.005	−.095	.008	.000	.000	−.074	.004	−.055	.002	−.115	.011	.109	.005

(d)

	Step 1		Step 2								Step 3						Step 4	
	PDT similar accuracy		New items called Similar (bias)		Positive schizotypy		Negative schizotypy		Disorganized schizotypy		Neg × Dis interaction		Pos × Dis interaction		Pos × Neg interaction		Pos × Neg × Dis interaction	
Outcome	β	sr^2	β	sr^2	β	sr^2	β	sr^2	β	sr^2	β	sr^2	β	sr^2	β	sr^2	β	sr^2
Similar items called Similar	−.154*	.023	−.028	.001	−.023	.000	−.001	.000	−.083	.006	−.224**	.033	−.059	.002	.119	.011	.008	.000

Note: Medium effect sizes (f^2) in bold text, all other effects sizes are small. Each row represents a separate hierarchical linear regression analysis. For each predictor, the standardized regression coefficient (β), semipartial r-square (sr^2) are reported.

Abbreviation: PDT, perceptual discrimination task.

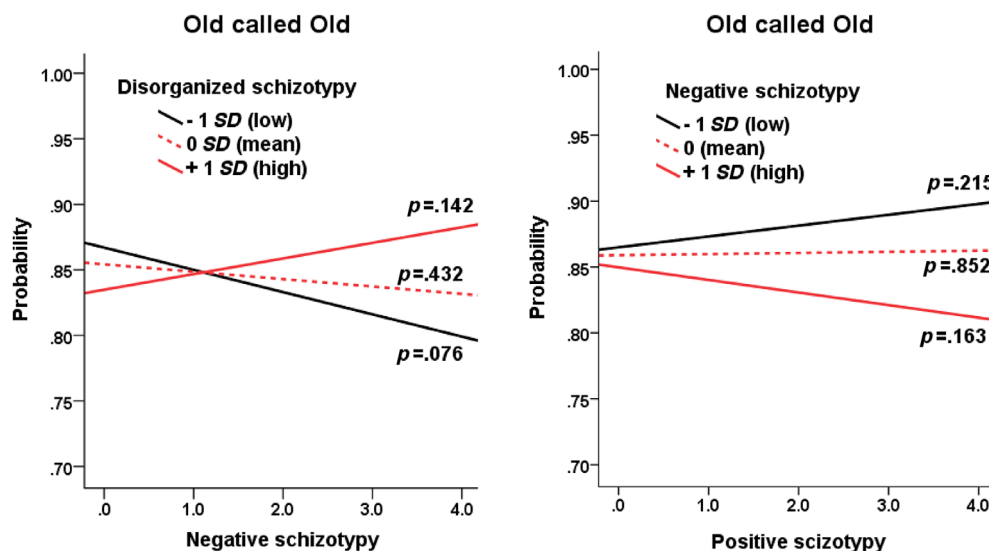$*p < .05$; $**p < .01$; $***p < .001$.

FIGURE 6 Prediction of correct classification of old objects (general recognition ability) in Mnemonic Similarity Task by negative and disorganized schizotypy (left panel), and positive and negative schizotypy (right panel).

relational memory (Sahakyan et al., 2019). The majority of these studies assessed schizotypy with the Wisconsin Schizotypy Scales, which only assessed positive and negative, but not disorganized, schizotypy. Therefore, the current study expands on previous findings by assessing disorganized schizotypy, and finding that it interacts with negative schizotypy to produce the observed deficits. Other studies have also examined various forms of memory in schizotypy (see Ettinger et al., 2015, for a selective review), but the interpretation of those studies is often constrained by methodological limitations such as failure to examine schizotypy dimensions separately, use of problematic measures of schizotypy, and use of clinical screening measures of memory that often are insufficient for detecting subtle deficits. Among the studies that did consider separate dimensions of schizotypy, reduced nonverbal memory was observed in negative schizotypy, but not positive schizotypy (Gooding & Braun, 2004), and a similar association was found in free recall (Kaczorowski et al., 2009).

In our prior work, we found that elevated positive schizotypy was associated with increased false alarms in a single item-recognition task that includes discriminating between the two classes of items—studied and unstudied stimuli (Sahakyan & Kwapil, 2018b). In the current investigation, we included three types of stimuli (studied, unstudied similar, and unstudied dissimilar items), and assessed the disorganized dimension of schizotypy. Neither unstudied similar, nor unstudied dissimilar, items (both of which could be construed as false alarms) were associated with positive schizotypy. It could be that methodological differences between recognition tests played a role or the fact that schizotypy was assessed as three-dimensional in the current study, but two-dimensional in the previous study.

Overall, findings that mnemonic discrimination was impaired in participants with elevated negative and disorganized schizotypy is consistent with views that the negative dimension is a core feature of schizotypy and schizophrenia (e.g., Horan et al., 2007). Negative schizotypy appears to be the most heritable dimension in relatives of schizophrenic patients (e.g., Tarbox & Pogue-Geile, 2011) and

offspring of high negative schizotypy individuals are at heightened risk for developing schizophrenia (Kendler & Walsh, 1995). Thus, it is not surprising that mnemonic discrimination deficits were linked to negative schizotypy. This is noteworthy considering that memory impairment is a prominent form of cognitive impairment in schizophrenia (e.g., Aleman et al., 1999; Heinrichs & Zakzanis, 1998), and it is a stronger predictor of functional outcome than clinical symptoms or other cognitive variables (Green, 1996; Milev et al., 2005). Taken together, the findings of impaired mnemonic discrimination in negative schizophrenia are consistent with memory impairment in schizophrenia and negative symptoms of schizophrenia in particular. The finding that negative schizotypy interacted with disorganized schizotypy to predict impaired mnemonic discrimination is consistent with findings that disorganized symptoms of schizophrenia are associated with cognitive and functional impairment (e.g., Harvey, 2013).

Cognitive impairment is a hallmark of schizophrenia and related disorders (e.g., Heinrichs & Zakzanis, 1998). Although some cognitive impairment appears to develop or worsen as a consequence of the illness, cognitive impairment appears to occur across the entire schizotypy spectrum from subclinical schizotypy to full-blown schizophrenia. Cognitive ability can be markedly disrupted in patients with schizophrenia and contributes to significant impairment in many areas of functioning. However, there are considerable individual differences among patients in the severity of cognitive impairment. Furthermore, just as mild schizotypic experiences (e.g., odd beliefs, perceptual experiences) often presage the development of delusions and hallucinations, milder forms of cognitive impairment may characterize individuals with subclinical expressions of schizotypy. However, we need to consider the association of cognitive impairment with specific symptom dimensions, the cognitive and neural processes underlying these impairments, and the extent to which cognitive performance deficits represent meaningful, etiologically relevant deficits in ability, as opposed to generalized poor performance resulting from consequences of the disorder. Patients often exhibit severe cognitive impairment across multiple domains. However, it is often difficult to disentangle these deficits from the

effects of symptoms, pharmacotherapy, and stigmatizing on cognitive performance. The question remains about what we should expect in terms of cognitive performance in subclinical schizotypy. Given that cognitive impairment is strongly linked to functional impairment, we would expect that people with subclinical schizotypy should exhibit milder, less impairing manifestations, especially given that they are less likely to be receiving neuroleptic medications or experiencing other adverse effects of psychotic illnesses. Searching for subtler effects requires more precision than is needed to assess gross cognitive impairment characteristic of schizophrenia. However, detecting cognitive functioning in subclinical schizotypy may provide clues about etiologically relevant impairment and their underlying processes.

Several limitations of the present study should be noted. The sample was limited to college students at one university. This may limit the generalizability of the findings and calls for replication with independent and diverse samples. However, college students are widely used for studying schizotypy and offer a promising group as they have just entered the age of greatest risk for developing schizophrenia-spectrum disorders. Furthermore, given that they are functioning well enough to enroll in a major university, they are not likely to be experiencing psychotic symptoms or taking neuroleptic medications—allowing us to examine schizotypy unconfounded by many of the consequences of psychotic disorders. The effect sizes in the present study are relatively small (especially in comparison to cognitive impairment in patients with schizophrenia). However, as discussed in Sahakyan and Kwapil (2019), it can be difficult to disentangle the extent to which the large effect sizes reported for cognitive impairment in schizophrenia represent deficits in cognitive ability, as opposed to performance deficits related to the consequences of psychotic disorders (factors that are largely not issues in nondisordered schizotypic samples). Thus, we believe that finding hypothesized schizophrenic-like impairment in nonclinically ascertained schizotypy (albeit small effects), conveys important information about cognition across the schizotypy continuum. The present findings expand our knowledge of cognitive impairment in the schizophrenia spectrum and support the multidimensional model of schizotypy.

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CONFLICT OF INTEREST STATEMENT

None of the authors have any conflicts of interest to report.

DATA AVAILABILITY STATEMENT

Data and analytic code for the study will be made available on Open Science Framework following publication of the manuscript at: https://osf.io/tzdk3/

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.