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Moving Beyond Summary Scores: Decomposing Free Recall Performance to Understand Episodic Memory Deficits in Schizotypy

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Negative symptom schizophrenia and negative schizotypy are associated with deficits in episodic memory, which may reflect deficits in context processing. However, studies that rely on summary performance measures such as mean accuracy or latency are limited in the extent that they can examine processes underlying memory impairment. The present study decomposed free recall performance by examining serial position functions, first response probability, temporal contiguity effect, cumulative recall functions, and interresponse times in high-positive schizotypy, high-negative schizotypy, and control groups. The negative schizotypy group exhibited not only impaired overall free recall performance but also a pattern of deficits consistent with impaired context processing on the underlying measures. Specifically, the negative schizotypy group was less likely than the other groups to initiate recall with the first item in the list, suggesting impaired encoding or reinstatement of context, and also showed reduced temporal contiguity compared with the other groups, suggesting diminished temporal organization. The cumulative recall function indicated that the negative schizotypy group experienced disruptions in both the sampling and recovery stages of retrieval. Finally, the negative schizotypy group experienced greater slowing between the responses during retrieval, consistent with the finding of reduced temporal contiguity and indicating that it likely terminated memory search before the remaining groups. The positive schizotypy and control groups did not differ on any of the measures. The finding that context-processing deficits occur in both subclinical negative schizotypy and negative symptom schizophrenia suggests that they may represent core areas of impairment in the schizophrenia spectrum.

Keywords: schizotypy, episodic memory, free recall, context processing

Schizophrenia is a catastrophic mental disorder that is characterized by psychotic symptoms, severely disrupted functioning, and cognitive impairment. However, the traditional model of conceptualizing schizophrenia as a categorical disorder has largely been replaced by the view that schizophrenia is the most extreme expression of a continuum of clinical and subclinical symptoms and impairment referred to as *schizotypy* (e.g., Kwapil & Barrantes-Vidal, 2015; Lenzenweger, 2010). Theoretical models (e.g., Meehl, 1990) and taxometric classification methods (e.g., Lenzenweger & Korfine, 1992) suggest that as much as 10% of the population falls within the schizotypy continuum. This continuum includes psychotic disorders such as schizophrenia, nonpsychotic disorders such as schizotypal personality disorder, and subclinical conditions such as the prodrome and nondisordered schizotypy. This model suggests that similar patterns of symptoms and impairment should be seen across this continuum, albeit with less severe expressions in nondisordered schizotypy. Although most schizotypes will not develop full-blown schizophrenia, nondisordered schizotypes often experience mild or transient symptoms and impairment similar to those reported in schizophrenia. Thus, schizotypy offers a useful and unifying framework for understanding the etiology, development, and expression of schizophrenic psychopathology and impairment.

Schizotypy and schizophrenia are heterogeneous in terms of etiology, symptoms, and course. This heterogeneity can be characterized by a multidimensional structure, with the two most commonly identified dimensions being *positive* and *negative* schizotypy. Positive or psychotic-like schizotypy is characterized by odd beliefs that range from magical thinking to psychotic delusions, and unusual perceptual experiences that range from unusual sensory experiences to illusions to hallucinations. Negative or deficit schizotypy, on the other hand, is characterized by diminished cognition, emotions, and behaviors that include flattened affect, anhedonia, alogia, avolition, and social disinterest (Kwapil & Barrantes-Vidal, 2015).

Questionnaire measures have proven useful for assessing positive and negative schizotypy in clinical and nonclinical samples (e.g., J. P. Chapman, Chapman, & Kwapil, 1995; Kwapil & Chun, 2015). Young adults identified by high scores on questionnaire measures of positive and negative schizotypy exhibit differential

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The data in the present study were used in Sahakyan and Kwapil (2016) to examine overall free recall performance. Portions of the present findings were presented at the 2017 meeting of the Society for Research in Psychopathology and the 2016 meeting of the International Psychonomic Society. The data and stimulus materials are available upon request from the Lili Sahakyan.

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patterns of schizophrenia-spectrum symptoms and impairment (e.g., Barrantes-Vidal et al., 2013; Kwapil, Barrantes-Vidal, & Silvia, 2008). For example, positive schiozotypy is associated with elevated interview-based reports of psychotic-like, schizotypal, and paranoid symptoms, whereas negative schizotypy is associated with elevated interview-based rates of schizoid and negative symptoms. In addition, positive schizotypy predicted the development of psychotic disorders, whereas negative schizotypy predicted schizophrenia-spectrum disorders in a 10-year longitudinal assessment (Kwapil, Gross, Silvia, & Barrantes-Vidal, 2013). Given the distinct patterns of impairment associated with the positive and negative schizotypy dimensions, failure to differentiate these dimensions can obscure meaningful associations.

Cognitive Impairment in the Schizophrenia Spectrum

Cognitive impairment is a hallmark of schizophrenia and related disorders (e.g., Green & Nuechterlein, 1999; Harvey, 2013; Heinrichs & Zakzanis, 1998). Furthermore, at least some of the cognitive impairments in schizophrenia have been linked to a context-processing deficit. *Context* refers to aspects of the external environment (e.g., physical, spatial-temporal surroundings) and internal environment (e.g., thoughts experienced in response to the items, mood, emotions, and psychoactive state) that become incorporated in traces formed during learning, and the associations with context are critical for memory retrieval. For example, patients with schizophrenia have deficits in remembering the source of information (e.g., Danion, Rizzo, & Bruant, 1999), maintaining task context (e.g., Cohen, Barch, Carter, & Servan-Schreiber, 1999), or processing linguistic context (e.g., L. J. Chapman, Chapman, & Miller, 1964). Researchers suggest that cognitive deficits in schizophrenia can be globally understood in terms of impairment in the ability to maintain and manipulate internal representations of context (e.g., Barch et al., 2001; Barch, Carter, MacDonald, Braver, & Cohen, 2003; Braver, Barch, & Cohen, 1999; Braver & Cohen, 1999; Cohen & Servan-Schreiber, 1992; Hemsley, 2005). Computational models of performance in cognitive tasks, which typically elicit performance deficits in schizophrenia, suggest that disrupting the context mechanism of the model leads to a range of cognitive deficits seen in schizophrenia. (e.g., Braver & Cohen, 1999; Cohen & Servan-Schreiber, 1992).

Episodic memory deficits have been reliably documented in schizophrenia (e.g., Dickinson, Ragland, Gold, & Gur, 2008; Gold, Randolph, Carpenter, Goldberg, & Weinberger, 1992; Mesholam-Gately, Giuliano, Goff, Faraone, & Seidman, 2009; Ranganath, Minzenberg, & Ragland, 2008), with larger deficits in free recall than recognition (e.g., Aleman, Hijman, de Haan, & Kahn, 1999; Paulsen et al., 1995). According to several influential models of memory, free recall relies heavily on context processing (e.g., Davelaar, Goshen-Gottstein, Ashkenazi, Haarmann, & Usher, 2005; Howard & Kahana, 2002; Lehman & Malmberg, 2013; Polyn, Norman, & Kahana, 2009; Raaijmakers & Shiffrin, 1981; Sederberg, Howard, & Kahana, 2008). Specifically, during learning, the studied material becomes automatically associated with its episodic context, which gradually changes over time. At the time of recall, the internal representation of context serves as a retrieval cue that is used to flexibly search memories and guide the order in which items come to mind.

The notion that schizophrenia (and more broadly schizotypy) is associated with impairment in context processing implies that there should be not only a deficit in overall accuracy for free recall (e.g., Sahakyan & Kwapil, 2016) but also impairment in the specific processes that contribute to free recall performance. Given how much free recall depends on the use context to initiate retrieval (e.g., Raaijmakers & Shiffrin, 1981), as well as in response transitions during retrieval (e.g., Howard & Kahana, 2002), we would expect to see impairments in the processes related to the use of context during free recall in schizotypy. Polyn et al. (2015) compared patients with schizophrenia with healthy controls and found that patients exhibited poorer overall free recall performance, as well as reduced temporal organization, consistent with the notion of a deficit in context processing. This strategy of examining the retrieval dynamics of free recall offers a promising method for elucidating the processes underlying cognitive impairment in schizotypy and schizophrenia. Such an approach has been successfully used to study context processing in other populations, such as older adults (e.g., Healey & Kahana, 2016; Wahlheim & Huff, 2015), and individual differences in working memory capacity (e.g., Sahakyan, Abushanab, Smith, & Gray, 2014; Spillers & Unsworth, 2011; Unsworth, 2007; Unsworth, Spillers, & Brewer, 2012).

Sahakyan and Kwapil (2016) examined episodic memory in a high-positive schizotypy group, a high-negative schizotypy group, and a comparison group that did not score high on either schizotypy dimension. The negative schizotypy group demonstrated deficits in free recall (as well as deficits in recognition and source memory), consistent with impairments seen in negative symptom schizophrenia. In contrast, the positive schizotypy group did not exhibit these deficits, and their performance was similar to the control participants. These findings highlight the importance of considering positive and negative schizotypy separately. In fact, when both schizotypy groups were combined into a single group, the memory findings were not significantly different from the control group. Although Sahakyan and Kwapil documented the phenomenon of impaired overall memory performance, they did not examine the mechanisms underlying the free recall deficit.

Decomposing Free Recall Processes

The goal of the present investigation was to provide further examination of Sahakyan and Kwapil's (2016) findings by following the approach employed by Polyn et al. (2015) of examining the dynamics of the recall process, with specific emphasis on the role of context. Furthermore, we extended Polyn et al.'s study by expanding the number of measures assessing free recall dynamics and by examining whether impairment in these processes is differentially associated with positive and negative schizotypy. We relied on a combination of classic and recently developed organizational metrics to extract multiple measures from free recall to learn about context processing.

This approach affords several advantages. First, decomposing overall recall accuracy into separate dependent measures provides a more nuanced examination of the processes underlying memory impairment, which cannot be gleaned from summary measures of accuracy. Second, several different measures extracted from the same participants not only sharpen and focus the theoretical interpretations compared with administering different measures to different groups but also bolster the findings of recall differences between the groups, which we had reported earlier—namely, we found recall impairment in the negative schizotypy group compared with the positive schizotypy and control group. If such differences hold up across several dependent measures that describe the retrieval process, they would provide validation of the overall recall differences between the groups. However, if they diverge, it would clarify the processes underlying memory impairment in schizotypy.

In the present study, we decomposed free recall performance by examining (a) serial position functions, (b) first response probability, (c) temporal contiguity, (d) cumulative recall functions, and (e) interresponse times. This is the first study, to our knowledge, to examine these processes in schizotypy. An initial step in characterizing how participants recall a list of items is to calculate the probability of recalling an item as a function of its serial position in the list—known as a *serial position function*. These functions have a characteristic form, with an enhanced recall of the first few items of the list (the primacy effect) and the last few items of the list (the recency effect) in comparison with poorer recall of the middle list items. Polyn et al. (2015) reported that patients with schizophrenia and healthy control subjects had similar shape of the serial position functions, albeit at depressed levels of performance for the patients. However, because their clinical sample was not differentiated in terms of positive or negative symptoms, and because our previous work with nonclinical participants suggests that the recall deficits are more likely in the negative schizotypy group, it remains an open question if serial position functions differ across positive and negative schizotypy and control groups. Theoretically, it is possible for two groups to have similar overall recall but differ in the serial position function.

We also decomposed the recall process into the response-initiation and postinitiation phases, and analyzed each stage separately. The first response probability describes the response-initiation phase, and is measured as the serial position of the first item recalled. The first response can be informative regarding the context that participants use to search their memory as the first retrieved item should have the greatest overlap with the context used to search memory (e.g., the beginning of the list, the end of the list, etc.). According to memory models, the first item presented in a list is more strongly associated with its experimental context relative to the ensuing list items (cf. Farrell, 2012; Lehman & Malmberg, 2013). Therefore, likelihood of initiating retrieval with the first item of the list is indicative of how much context was encoded, and it may also reflect the success of reinstating the context at testing. If schizotypy dimensions have deficits in context encoding and/or context reinstatement, they would be less likely to initiate retrieval with the first presented item of the list.

We also examined postinitiation dynamics, which indicate how participants transition between responses. Given that the order of recall is indicative of which items come to mind, response transitions reveal the organization of memory for the list items. The *temporal contiguity effect* is one of the fundamental organizational principles in free recall (particularly with unrelated items) and refers to a tendency to recall items nearby in the list to the just-recalled item during retrieval. The conditional response probability, as a function of lag (lag-CRP function), estimates the probability of making a recall transition from a word that was just retrieved to the other words on the list as a function of their temporal distance in the list. For example, if a participant recalls an item from Serial Position 7, their next recalled item is more likely to come from the nearby serial positions (i.e., position 6 or 8) than remote positions (i.e., position 10 or 2). Thus, lag-CRP function falls off gradually with distance, or lag. In addition, lag-CRP is characterized by asymmetry such that forward transitions are more common (e.g., a transition from Item 7 to Item 8) than backward transitions (e.g., a transition from Item 7 to Item 6). The temporal contiguity effect is a robust phenomenon that is explained by a context mechanism. According to retrieved-context models of memory (e.g., Howard & Kahana, 2002; Polyn et al., 2009; Sederberg et al., 2008), recall of any item reinstates the experimental context associated with that item, which is then used as a retrieval cue for other items. The retrieval of context leads to the temporal contiguity effect because items with similar context are more likely to be items from the nearby serial positions, and hence are more likely to be recalled in response to the context cue. Because patients with schizophrenia have deficits in temporal contiguity (e.g., Polyn et al., 2015), it is reasonable to predict that the schizotypy groups are likely to show the same deficit. If such findings are obtained, they would contribute to our understanding of the episodic memory impairment in schizotypy and, by extension, schizophrenia. If certain dimensions of schizotypy show reduced temporal contiguity, it could indicate that they are less able to formulate and/or utilize context to guide retrieval of other items. They might be unable to reinstate the context of the retrieved item (i.e., have difficulty jumping back in time), or the retrieved context may be an ineffective cue for other items because items were not well associated with their episodic context during encoding. Thus, deficits in encoding and associating the items with their context could be responsible for why they do not benefit from context cues at the time of retrieval, producing diminished temporal contiguity.

Latency Measures in Free Recall

Thus far we have focused on the probability of recall and the order in which the items are retrieved, which have been well explained by the context-drift/reinstatement models of memory (e.g., Howard & Kahana, 2002; Polyn et al., 2009; Sederberg et al., 2008). However, examination of recall latency is also informative for understanding how participants search for target items in free recall tasks (e.g., Bousfield, Sedgewick, & Cohen, 1954; Kahana, 1996; Miller, Weidemann, & Kahana, 2012; Wixted & Rohrer, 1993, 1994). Context plays an important role in how people search and isolate the relevant items in memory. The relationship between recall duration and the cumulative number of items recalled is described by the exponential function

$$F(t) = L(1 - e^{-\lambda t})$$

where F(t) denotes the cumulative number of items recalled by time t, L represents an estimate of asymptotic recall (i.e., the total number of items that would be recalled given unlimited time), and λ reflects the rate of approach to that asymptote. Thus, if given enough time to recall, L is roughly equal to the total number of items recalled. However, these items can be recalled slowly or quickly, and this information is captured by λ.

Search models of memory distinguish between the two distinct memory retrieval stages, known as the *sampling* and *recovery* stages (e.g., Malmberg & Shiffrin, 2005; Raaijmakers & Shiffrin, 1981; Rohrer & Wixted, 1994; Wixted & Rohrer, 1993). Examination of cumulative recall function enables assessing whether the deficits in memory arise from the sampling stage, the recovery stage, or some combination of both. The sampling stage is most impacted by context processing because free recall is initiated in the absence of externally provided cues, and participants must rely on contextual cues to search their memory. This self-generated contextual information is used to isolate a relevant search set within episodic long-term memory, denoting the sampling stage of retrieval. The latter is reflected in the λ parameter, with the magnitude of λ representing the size of the search set and estimating the total number of the items that were included in a person's search set. A larger value of λ reflects a smaller, more restricted search set, whereas a smaller value of λ reflects more expanded search set (e.g., Wixted & Rohrer, 1993, 1994). Importantly, once an item has been sampled (i.e., included in the search set), it must be recovered in order to be recalled (e.g., Raaijmakers & Shiffrin, 1981; Rohrer, 1996), and successful sampling does not guarantee successful recovery of an item. Only items whose absolute strength exceeds a certain fixed threshold are actually recalled.

We analyzed cumulative recall functions in order to obtain parameter estimates for λ and *L*. This information would help further characterize whether free recall deficits in schizotypy reflect difficulty with the sampling and/or whether they reflect deficits in the recovery process. A sampling deficit would be reflected in differences in λ parameters. For example, in negative schizotypy, the search set could be smaller such that when participants attempt to recall, they focus on and sample only a portion of the target list. Sampling deficits would be reflected in larger λ parameters. There are reasons to believe that we might also obtain deficits in the recovery stage in schizotypy. If items are not processed elaborately and deeply enough, it would reduce their absolute strength, reducing their recovery threshold. In other words, the same number of items may be included in the search set across the schizotypy and control conditions, but some participants might have fewer high-fidelity items in the search set. If this were the case, then we should expect to find differences in *L* but not in λ parameters.

Finally, we also examined interresponse times, which reflect the time between recall of each item. As recall proceeds, people become progressively slower in recalling items, and at some point they stop even if the recall period has not yet ended. The slowing of interresponse times throughout the recall period is predictive of when participants terminate the recall process (Miller et al., 2012; Murdock & Okada, 1970; see also Dougherty & Harbison, 2007). To the best of our knowledge, this is the first investigation of interresponse times in free recall in schizotypy, and it has the potential to inform whether certain dimensions of schizotypy are more likely to terminate retrieval sooner than others, which could explain differences in overall recall.

In summary, the present study examined the dynamics underlying free recall in positive and negative schizotypy, including serial position functions, first response probability, temporal contiguity, cumulative recall functions, and interresponse times. Sahakyan and Kwapil (2016) demonstrated that negative schizotypy is associated with impaired free recall. The present investigation attempted to shed light on the specific processes underlying performance in both schizotypy dimensions. We specifically expected to find deficits in the negative schizotypy group, given our previous findings and given that positive symptoms were *not* associated with context deficits in schizotypal personality disorder (McClure, Barch, Flory, Harvey, & Siever, 2008) or clinical high-risk groups (Niendam et al., 2014). To our knowledge, this is the first study to make such a fine-grained examination of free recall performance and dynamics in schizotypy.

Method

Participants

As described in Sahakyan and Kwapil (2016), the sample was comprised of 75 undergraduates from introductory psychology courses who were invited to participate based on scores on the Wisconsin Schizotypy Scales-Brief version (Winterstein et al., 2011). The positive and negative schizotypy groups included 25 participants each who scored at least 1.5 standard deviations above the mean on the respective schizotypy dimensions based on norms established from 6,137 young adults (Gross, Silvia, Barrantes-Vidal, & Kwapil, 2015). The comparison group contained 25 participants who scored within 0.5 standard deviation of the mean on both the positive and negative schizotypy scores. The study was approved by the Institutional Review Board of the University of North Carolina at Greensboro.

Materials and Procedures

Participants completed brief versions of the Wisconsin Schizotypy Scales, including the Perceptual Aberration (L. J. Chapman, Chapman, & Raulin, 1978), Magical Ideation (Eckblad & Chapman, 1983), Physical Anhedonia (L. J. Chapman, Chapman, & Daut, 1976), and Revised Social Anhedonia (Eckblad, Chapman, Chapman, & Mishlove, 1982) scales. The factor scores for the positive and negative schizotypy dimensions that underlie these scales were computed following formulae in Gross et al. (2015). Note that the scales are widely used, have solid psychometric properties, and the positive and negative schizotypy factors are associated with differential patterns of symptoms and impairment (Gross, Silvia, Barrantes-Vidal, & Kwapil, 2012, 2015). The positive schizotypy group had a mean z score of 2.65 ($SD = 0.67$) on positive schizotypy and 0.07 ($SD = 0.48$) on negative schizotypy; the negative schizotypy group had a mean z score of -0.15 ($SD = 0.54$) on positive schizotypy and 2.53 ($SD = 0.67$) on negative schizotypy; and the control group had a mean z score of -0.12 ($SD = 0.39$) on positive schizotypy and -0.11 ($SD = 0.29$) on negative schizotypy.

As part of a battery of measures, participants completed a free recall test that involved studying 12 unrelated nouns of medium frequency (based on Kučera & Francis, 1967) presented at a rate of 5 s, completing math problems on the computer screen for 30 s, followed by a 60-s recall period, during which participants typed words into the computer in any order they wished. The study-test procedure was repeated five times, with new words presented during each cycle. As noted in Sahakyan and Kwapil (2016), proportion correct recall and intrusion errors (both prior-list and extralist) did not vary across the test cycles, and therefore performance was averaged across the five lists.

Serial position functions were plotted by calculating the probability of recalling an item as a function of its position in the presented list. First response probability was calculated as the number of times the first recalled word comes from a given serial position divided by the number of times the first recalled word could have come from that serial position. It is essentially the serial position for the first recalled item and captures the response-initiation phase of retrieval. The temporal contiguity effect, which refers to the tendency to successively recall neighboring list items during recall, is shown in a lag-CRP function. They are characterized by a systematic decrease as absolute lag increases, and by asymmetry favoring forward transitions over backward transitions. To evaluate how various conditions influence the contiguity effect, we plotted the lag-CRP functions for the three groups to assess the qualitative shape of the lag-CRP function. To formally analyze temporal contiguity, we quantified the effect with a single number, which was introduced by Polyn et al. (2009), known as the temporal factor score. It compresses the complex pattern of the lag-CRP function into a single value, and involves percentile ranking the positional lag of each recall transition with respect to the lags of all transitions that were possible at that time. If the recalled items were chosen randomly from the list, the expected value of this statistic is 0.5, whereas stronger temporal organization yields values closer to 1. To assess temporal contiguity effects across the three groups, we computed temporal factor scores for each participant on each list and took the average of the temporal factor scores across the five lists. To improve the reliability of temporal factor scores, we excluded participants who recalled fewer than four items on a given list, following Polyn et al. (2015).

For the analysis of cumulative recall, we determined the cumulative number of items recalled every 5 s during the 60-s recall period for each of the three groups. Then parameter estimates for λ and L were computed for each group by fitting the exponential function to the cumulative recall data at the group level.

Results

Accuracy, Intrusion Errors, and Distractor Problems

As mentioned in Sahakyan and Kwapil (2016), there were significant differences in the proportion of items recalled across the lists, $F(2, 72) = 3.76$, $MSE = .019$, $p < .05$, such that the negative schizotypy group recalled fewer items compared with the positive and control groups, which did not differ from each other. During retrieval, participants occasionally made intrusions, which were further classified as prior-list errors and extralist errors. Although errors were infrequent and there were no statistical differences between the groups, there was a numerical trend for greater number of errors in the negative schizotypy group both in extralist and in prior-list errors. These results are summarized in Figure 1. Given that avolition is associated with negative schizotypy, and the results could be explained by motivational differences, we also examined the number of math problems solved after each list. As mentioned in Sahakyan and Kwapil, there were no differences in the number of problems attempted and solved, suggesting that factors other than motivation were likely contributing to performance differences between the groups.

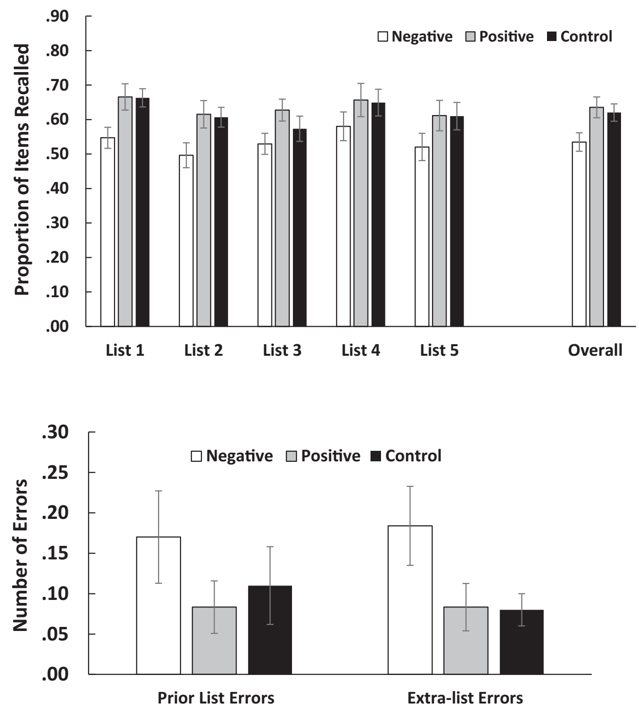

Figure 1. Proportion of items recalled across the lists (top panel) and number of intrusions made across the lists (bottom panel) in three groups. Error bars reflect standard error of the mean.

Serial Position Function

Figure 2 shows serial position function of the recall of the lists for the three groups. The results are based on the average of five lists and serial positions are grouped by two items per bin, resulting in six bins. The Group $\times$ Serial Position Bin ANOVA revealed a significant man effect of group, $F(2, 72) = 4.34$, $MSE = .114$, $p < .05$, and a significant main effect of serial position bin, $F(5, 360) = 43.39$, $MSE = .029$, $p < .001$, but no interaction, $F<1$. The main effect of group confirmed that the negative schizotypy group recalled fewer items, on average, but the impairment was found throughout the entire the serial position function. In addition, the positive schizotypy and the control groups are very similar to each other across the entire serial position curve, bolstering our earlier findings of similar accuracy across the two conditions. The main effect of serial position bin indicated that items from the first two bins were remembered significantly better than the remaining items, confirming the primacy effect. There was no recency effect, and this is expected given that the recall test was not immediate.

First Response Probability

Figure 3 shows the first response probability averaged across the lists for the three groups. As is typical in delayed free recall, participants tend to initiate retrieval with the first item that was presented on the list rather than any remaining items. ANOVA of recall from the first serial position of the list by group was significant, $F(2, 72) = 3.35$, $MSE = .064$, $p < .05$. The negative schizotypy group had diminished likelihood of initiating retrieval

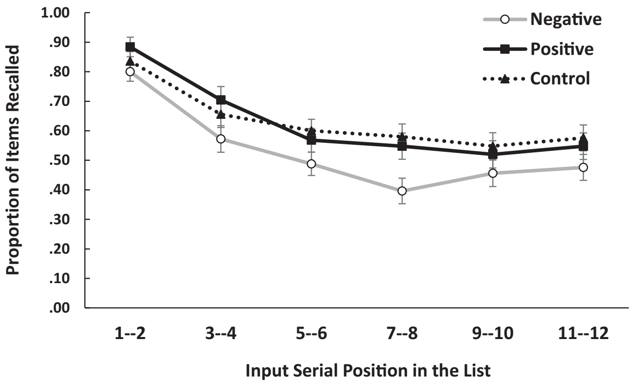

Figure 2. Serial position function across three groups. Error bars reflect standard error of the mean.

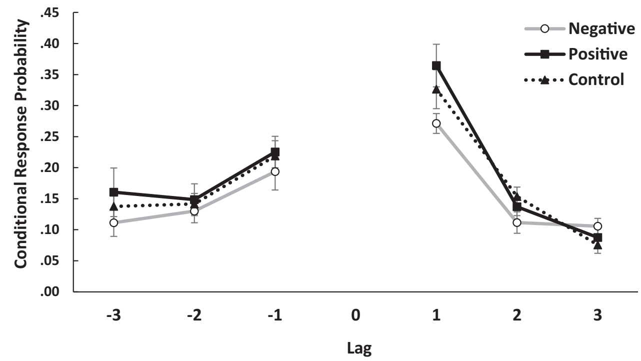

Figure 4. Conditional response probability as a function of lag in three groups. Error bars reflect standard error of the mean.

with the first item of the list compared with the positive schizotypy group, $t(48) = 2.18$, $p < .05$, Cohen's $d = 0.63$, or the control group, $t(48) = 2.44$, $p < .05$, $d = 0.70$, and the latter two groups did not differ from each other, $t(48) = 0.11$, $p = .92$, $d = 0.03$.

Temporal Contiguity

Figure 4 summarizes lag-CRP functions, which reveal the characteristic shape—namely, when transitioning between responses, forward transitions are more common than backward transitions, and transitions to the nearby items in the list are more common than transitions to distant items in the list, demonstrating the temporal contiguity effect. Qualitatively, the shape of the lag-CRP functions were similar across the groups, although the negative schizotypy group showed depressed functions overall both in the forward and backward transitions. Table 1 summarizes the temporal factor scores, which quantify the temporal contiguity effect. All three groups demonstrated temporal organization as evidenced by significantly above chance temporal factor scores in the positive schizotypy group, $t(24) = 7.38$, $p < .001$, $d = 3.01$, the negative schizotypy group, $t(24) = 5.66$, $p < .001$, $d = 2.31$, and the control group, $t(24) = 7.39$, $p < .001$, $d = 3.02$. Thus, participants relied on the temporal context in all three groups while making transitions during recall, confirming the robustness of the contiguity effect. However, there were significant differences between the groups, $F(2, 72) = 3.53$, $MSE = .013$, $p < .05$. Specifically, the negative schizotypy group showed reduced temporal contiguity compared with the positive schizotypy group, $t(48) = 2.44$, $p < .05$, $d = 0.70$, and the control group, $t(48) = 2.35$, $p < .05$, $d = 0.68$, with the latter two groups not differing from each other, $t(48) = 0.12$, $p = .91$, $d = 0.03$.

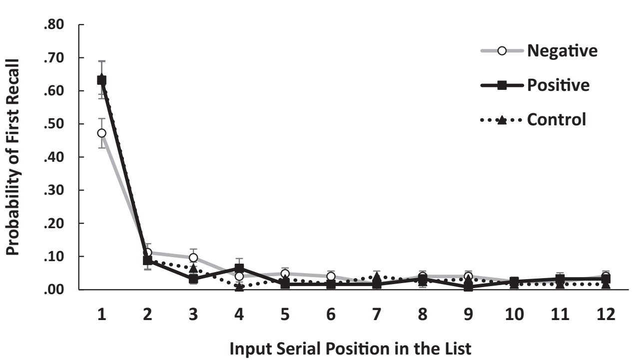

Figure 3. First response probability across three groups. The probability that the very first response comes from a given serial position. Error bars reflect standard error of the mean.

Cumulative Recall Functions

First, we examined how long participants waited before they initiated retrieval after the onset of the test. There were no differences between the groups in terms of when the first word was emitted, $F(2, 72) = 1.88$, $p = .16$. On average, participants retrieved the first word approximately 3.5 s after the onset of the recall signal (3,715 ms in the negative schizotypy group, 3,654ms in the positive schizotypy group, and 3,301ms in the control group), consistent with the notion of a slight pause preceding retrieval output. Although the three groups started retrieval approximately at the same time, they progressed through retrieval at different rates.

Figure 5 shows cumulative recall curves for each of the three groups. The symbols represent the data and the lines represent the best-fitting cumulative exponential functions. The parameter estimates derived from these functions along with their 95% confidence intervals are shown in Table 2, with parameter estimates indicating that the negative schizotypy group had a significantly higher value of λ and a significantly lower value of L compared with the positive or control groups, which did not differ from each other. This suggests the negative schizotypy group was searching through a more restricted search set, which could explain why they hit asymptotic levels faster (i.e., higher λ). Also, compared with

Table 1
Temporal Factor Scores Across Three Groups

Group	TF	95% CI
Negative schizotypy	.61	[.57, .64]
Positive schizotypy	.68	[.63, .73]
Control	.68	[.63, .73]

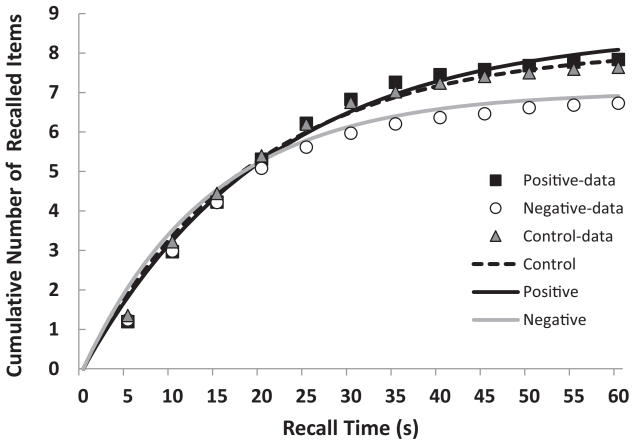

Figure 5. Cumulative recall curves as a function of recall time across three groups. Symbols represent the observed data and the solid lines represent the best fitting exponential.

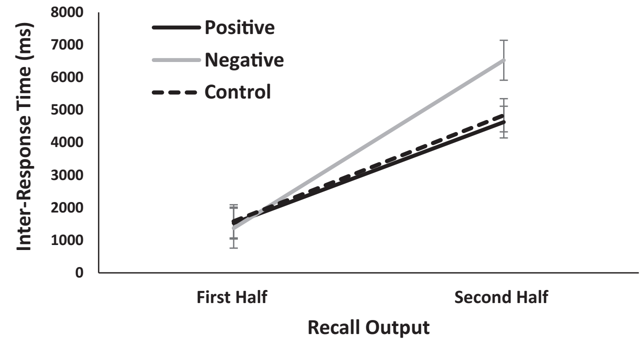

Figure 6. Interresponse time across the first and the second half of recall output in three groups. Error bars reflect standard error of the mean difference between the first half and the second half.

the remaining two groups, the negative schizotypy group recovered fewer items overall (i.e., lower value of L).

Interresponse Times

To more fully describe the recall dynamics, we examined response initiation times as well as interresponse times.

As indicated previously, interresponse times tend to slow down during the retrieval process. To capture this slowing, we divided the retrieval output of each participant into two equal halves, and obtained the average interresponse time across the first half and the second half of their retrieval output. The interresponse times were analyzed with mixed ANOVA, using Retrieval Output (first half vs. second half) as the within-subjects factor and Group as a between-subjects variable. The results are shown in Figure 6. Although interresponse times slowed down across retrieval process as evidenced by the main effect of retrieval output, $F(1, 72) = 152.08$, $p < .001$, there was a significant interaction with the group, $F(2, 72) = 4.47$, $p < .05$. There were no differences between the groups in the first half of retrieval output ($F < 1$), but significant differences in the second half, $F(2, 72) = 3.66$, $p < .05$. The negative schizotypy group had significantly slower interresponse times than the control group, $t(48) = 2.32$, $p < .05$, $d = 0.67$, and the positive schizotypy group, $t(48) = 2.23$, $p < .05$, $d = 0.64$, in their second half of retrieval output. The control and the positive schizotypy group did not differ from each other, $t(48) = 0.02$, $p = .99$ $d = 0.01$.

Table 2
Parameter Estimates of Cumulative Recall Across Three Groups

Group	λ	95% CI	*L*	95% CI
Negative schizotypy	.07	[.061, .078]	7.02	[6.68, 7.36]
Positive schizotypy	.05	[.039, .056]	8.58	[7.97, 9.19]
Control	.05	[.046, .061]	8.14	[7.74, 8.55]

Note. The λ parameter represents rate of approach to the asymptote, and L represents the total number of items recalled given unlimited time. 95% confidence intervals for the parameter estimates are presented in brackets.

Discussion

Cognitive impairment is a hallmark of schizophrenia and related disorders. Furthermore, cognitive deficits are robust predictors of functional impairment in patients with schizophrenia (e.g., Bowie & Harvey, 2006). However, the study of cognitive deficits and processes relevant to the etiology and development of schizophrenia is hampered by the fact that patients with schizophrenia often exhibit generalized performance deficits, and the fact that cognitive performance is often compromised by the symptoms (e.g., paranoia, hallucinations) and consequences (e.g., neuroleptic medications) of the disorder. Schizotypy offers a promising vehicle for examining cognitive impairment in the schizophrenia spectrum, as it is relatively unaffected by the confounding consequences of psychotic disorders. However, studies frequently rely on "canned" clinical neuropsychological batteries that may not be sensitive enough to detect subtle cognitive impairment seen in nondisordered schizotypes. Furthermore, reliance on summary measures of performance (i.e., mean overall accuracy or latency) limits our understanding of the processes underlying cognitive impairment. The use of summary measures tells us which groups performs worse but gives little information about the processes underlying *why* they perform worse. Finally, given the multidimensional structure of schizotypy and schizophrenia, it is essential to examine performance separately in the schizotypy dimensions.

Sahakyan and Kwapil (2016) reported that their negative schizotypy group performed worse than positive schizotypy and control groups on multiple measures of episodic memory (including free recall), whereas the positive schizotypy and control groups did not differ. These overall findings are consistent with the negative symptom schizophrenia literature (e.g., Aleman et al., 1999) and the limited schizotypy literature (e.g., Gooding & Braun, 2004). Our initial findings are consistent with the idea that negative schizotypy is associated with impaired context processing. However, decomposition of free recall performance allows us to examine the specific mechanisms underlying impaired performance in the negative schizotypy group, as well as whether the positive schizotypy group exhibited any underlying areas of impairment, despite not differing from the control participants in terms of overall performance. The finding that the negative schizotypy group was deficient on all of the context-related measures extracted from free recall is notable given that it is not a patient sample and suggests that context impairment impacts multiple processes in negative schizotypy.

To our knowledge, the present study is the first investigation to examine underlying processes in free recall in schizotypy. As noted, this work builds on and extends the work by Polyn et al. (2015) decomposing free recall performance in schizophrenia. Specifically, we expanded on Polyn et al.'s work by examining serial position functions, first response probability, temporal contiguity, and cumulative recall functions.

The serial position findings showed that the negative schizotypy group recalled fewer items on average, but the impairment was present throughout the entire serial position of the list as opposed to being localized to certain portions of the list. These results are consistent with Polyn et al. (2015), who reported similar shape of the serial position function between schizophrenia patients and controls, although the function was overall depressed for patients. Our results extend their findings and demonstrate the same pattern in nonpatients, but specifically in the negative schizotypy group.

Regarding the response initiation stage, the negative schizotypy group was less likely to commence retrieval with the first item of the list compared with the control and the positive schizotypy groups, which did not differ from each other. According to the models of memory search, the ability to initiate recall at the beginning of the list requires two things—reinstating the beginning of the list context on the assumption that context changes over the course of study, and that context is most strongly associated with the first item on the list (e.g., Farrell, 2012; Lehman & Malmberg, 2013). The results in the negative schizotypy group imply that those participants did not encode context at the start of the learning episode as strongly as the remaining two groups, or were less successful at reinstating beginning of the list episodic context.

The temporal contiguity effect was observed in all three groups, confirming the robustness of the contiguity effect (e.g., Healey & Kahana, 2014). These results suggest that all three groups relied on the temporal context while making transitions during recall. Nevertheless, the negative schizotypy group showed reduced temporal contiguity compared with the remaining two groups, which did not differ from each other. Diminished contiguity in the negative schizotypy group suggests that they are less able to formulate and/or utilize context to guide retrieval of other items. They might be unable to reinstate the context of the retrieved item (i.e., have difficulty jumping back in time), or the retrieved context may not be an effective cue to guide the retrieval of other items because items were not well associated with their episodic context during encoding. Thus, deficits in encoding and associating the items with their context could also be responsible for why the negative schizotypy group did not benefit from context cues at the time of retrieval, producing diminished temporal contiguity. The results are consistent with the findings of Polyn et al. (2015), who reported deficits in temporal contiguity in patients with schizophrenia using a similar metric. Our findings extend their results and suggest that this deficit is more likely to emerge in the negative than positive dimension of schizotypy.

Although there were no differences between the three groups in terms of how long they waited before initiating retrieval, there were differences between the groups in terms of how quickly the responses were made. Specifically, the cumulative recall functions showed that the negative schizotypy group approached the asymptote quicker (evidenced by larger value of λ parameter), and they also recovered fewer items (evidenced by smaller L parameter) compared with the remaining two groups, which did not differ from each other. A larger λ parameter indicates that the negative schizotypy group experienced deficits at the sampling stage, suggesting that it was searching through a smaller, more restricted search set compared with the remaining groups. They also recovered fewer items on the average (smaller L parameter). The differences in the L parameter could simply reflect differences in the search set size without any changes in the recovery probability. Thus, the current results could be explained by assuming that the negative schizotypy group was searching through a smaller set of items than the other groups, with no change in recovery ability. However, we have reasons to suspect that the negative schizotypy group also likely has deficits in the recovery stage of retrieval (in addition to the sampling deficit). When the same group of people were given a yes–no recognition test (described in Sahakyan & Kwapil, 2016), the negative schizotypy group showed impaired recognition accuracy compared with the other groups. Because the recognition test is an item-specific test that is sensitive to the strength of encoding, impaired recognition in the negative schizotypy group is consistent with deficits in encoding processes. As indicated earlier, the recovery probability in free recall is attributed to the absolute strength of the item. Thus, fewer numbers of recoverable items in the negative schizotypy group (i.e., low L parameter) could indicate that they had fewer high-fidelity items to recover, indicating deficits in recovery processes as well.

Finally, as retrieval progresses, it tends to slow down and eventually terminates. Our results indicated that the negative schizotypy group was more likely than the other groups to slow down between the responses throughout the retrieval process, especially in the second half of retrieval output. There could be several explanations for these findings. The slowing of interresponse times is an indicator of when participants are likely to terminate memory search (e.g., Miller et al., 2012), and our findings suggest that negative schizotypy participants might be more likely to terminate memory search sooner compared with the remaining groups. Miller et al. demonstrated that retrieval is more likely to terminate following recall errors than following correct responses, and errors typically occur late in recall sequence (e.g., Kimball, Smith, & Kahana, 2007). Given that the negative schizotypy group made more recall errors (i.e., extralist and prior list intrusions), this would also contribute to greater slowing of interresponse times and eventual recall termination. Finally, interresponse times are closely related to temporal contiguity effect. Namely, interresponse times tend to be short when neighboring list items are recalled successively, and they increase with the lag between the items' position in the study list (e.g., Kahana, 1996). Thus, the more likely the recall transition, the faster that transition. Given that the negative schizotypy group was associated with reduced temporal contiguity, it suggests that they were more likely to make remote transitions during the recall process, explaining why they showed reduced contiguity. This would also explain the slowing of interresponse times observed in that group.

Overall, the findings that the negative schizotypy group was searching through a more restricted search set, and had fewer high-fidelity items to recover, provides a more nuanced view and helps us understand the nature of their impairment in free recall. Importantly, the negative schizotypy group showed deficits in the utilization of context, as shown by reduced temporal contiguity and deficits in initiating retrieval with the beginning of the list. Collectively, these findings indicate that the negative schizotypy group may have deficits in binding and associating the items with their episodic context during encoding, and/or they may have difficulty with utilization of context during retrieval. The current findings cannot distinguish between these mechanisms, and they provide a motivation for future research.

Both positive and negative schizotypy are associated with schizophrenia-spectrum symptoms (e.g., Barrantes-Vidal et al., 2013) and risk for developing schizophrenia-spectrum disorders (e.g., Kwapil et al., 2013). Nevertheless, the two dimensions are also associated with differential patterns of symptoms and impairment. As noted in Sahakyan and Kwapil (2016), in contrast with the negative schizotypy group, the positive schizotypy group performed comparably with the control group on overall free recall and recognition task performance. Furthermore, the positive schizotypy and control groups performed similarly on the measures examined in the present report. However, this is not meant to imply that positive schizotypy is not associated with any cognitive impairment. Strikingly, Sahakyan and Kwapil found that the positive schizotypy group differed from the negative schizotypy and control group by demonstrating an unexpected set-size effect on a cued-recall task. This finding is consistent with heightened spreading activation and reduced executive control suggested to underlie psychotic symptoms characteristic of the positive symptom dimension. Thus, it appears that the two dimensions are associated with different patterns of cognitive impairment both in subclinical schizotypy and schizophrenia.

The present findings support the model that context-processing deficits occur in negative schizotypy but not positive schizotypy. This is consistent with studies that reported impaired context processing in schizophrenia patients with negative symptoms (Barch, Carter, MacDonald, Braver, & Cohen, 2003; Gold et al., 2012; Javitt, Rabinowicz, Silipo, & Dias, 2007; Niendam et al., 2014; Owoso et al., 2013; Richard, Carter, Cohen, & Cho, 2013) but not in patients with positive symptoms (Barch et al., 2003; Cohen et al., 1999; Gold et al., 2012; Javitt et al., 2007; MacDonald & Carter, 2003; Niendam et al., 2014; Owoso et al., 2013). The finding that context-related cognitive impairments are found in nondisordered young adults with negative schizotypy traits suggests that these deficits are not simply markers or consequences of the presence of clinical psychosis but precede the development of schizophrenia-spectrum disorders. These findings are consistent with reports that unaffected first-degree relatives of schizophrenia patients exhibit context-processing deficits (e.g., Delawalla, Csernansky, & Barch, 2008; Lopez-Garcia, Young Espinoza, Molero Santos, Marin, & Ortuño Sanchez-Pedreño, 2013; MacDonald et al., 2005; MacDonald, Pogue-Geile, Johnson, & Carter, 2003; Poppe, Carter, Minzenberg, & MacDonald, 2015; Richard et al., 2013). The finding that context-processing deficits occur in both subclinical negative schizotypy and negative symptom schizophrenia, as well as in first-degree relatives, suggests that they may represent core areas of impairment that are relevant to the etiology and development of this dimension of schizophrenia-spectrum psychopathology. Furthermore, the present findings fit in well with the current emphasis on dimensional models of psychopathology (Cuthbert, 2014; Krueger & Bezdjian, 2009).

Chun, Minor, and Cohen (2013) reported that a combined schizotypy group (not differentiated by symptom dimensions) was associated with elevated ratings of subjective cognitive complaints compared with control participants, but was generally unassociated with impaired neuropsychological performance based on standard neuropsychological batteries used in the study of schizophrenia. They suggested that the field was not measuring "the right stuff" in regard to studying cognitive impairment in nonclinical schizotypy. We suggest that tasks assessing episodic memory—specifically, measures that examine specific context-related processes—offer a promising avenue for identifying and understanding cognitive impairment in the schizophrenia spectrum. However, we offer the strict caveat that studies must consider the schizotypy dimensions separately.

The present study built upon the findings of Sahakyan and Kwapil (2016) to show that episodic memory deficits in negative schizotypy appeared to involve specific deficits in the utilization of context. However, this raises the additional questions of whether the deficits in context processing stem from poor encoding of context, poor utilization of context as a cue at retrieval stage, or some combination of both. Furthermore, the present study was limited to only examining positive and negative schizotypy. Future studies should also include disorganized schizotypy participants given their strong link with cognitive dysfunction.

We believe that the present findings support five take-away messages. First, schizophrenic psychopathology is best conceptualized as a continuum of clinical and subclinical symptoms and impairment. Second, the schizotypy continuum is multidimensional, with positive and negative symptom dimensions (and likely a disorganized dimension). Third, psychometric inventories provide a useful method for identifying schizotypy in nondisordered individuals. Fourth, assessment of cognitive deficits in nondisordered schizotypes requires moving beyond prepackaged clinical neuropsychological batteries that are designed for patient populations. Finally, understanding the nature of cognitive deficits in the schizotypy spectrum requires moving beyond the use of simple summary scores, and instead decomposing performance into meaningful components.

Context of the Research

The present study represents an integration of Lili Sahakyan's program of research examining the role of context in encoding and retrieval of long-term memory, and Thomas R. Kwapil's program of research examining the development and expression of schizotypy as a multidimensional construct. The present investigation focused on several core issues of these programs of research: (a) Can we understand the processes underlying memory by decomposing summary measures of memory performance?; (b) Can we identify cognitive impairments reported in schizophrenia in nondisordered schizotypic young adults?; and (c) Are positive and negative schizotypy associated with differential patterns of cognitive impairment? Future studies will seek to build on these findings by further exploring the nature of context processing in understanding cognitive impairments in schizotypy.

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