*Cognitive Neuropsychiatry,* 2015
Vol. 20, No. 4, 296–310, http://dx.doi.org/10.1080/13546805.2015.1031372



# Temporal context and the organisational impairment of memory search in schizophrenia

Sean M. Polyn[a]*, Joshua D. McCluey[a], Neal W. Morton[a], Austin A. Woolard[b], Andrew S. Luksik[b] and Stephan Heckers[b]

[a]*Department of Psychology, Vanderbilt University, PMB 407817, 2301 Vanderbilt Place, Nashville, TN 37204, USA;* [b]*Department of Psychiatry, Vanderbilt University, Nashville, TN, USA*

(*Received 18 September 2014; accepted 14 March 2015*)

*Introduction.* An influential theory of schizophrenic deficits in executive function suggests that patients have difficulty maintaining and utilising an internal contextual representation, whose function is to ensure that stimuli are processed in a task-appropriate manner. In basic research on episodic memory, retrieved-context theories propose that an internal contextual representation is critically involved in memory search, facilitating the retrieval of task-appropriate memories. This contextual machinery is thought to give rise to temporal organisation during free recall: the tendency for successive recall responses to correspond to items from nearby positions on the study list. If patients with schizophrenia have a generalised contextual deficit, then this leads to the prediction that these patients will exhibit reduced temporal organisation in free recall.
*Methods.* Using a combination of classic and recently developed organisational measures, we characterised recall organisation in 75 patients with schizophrenia and 72 nondisordered control participants performing a multi-trial free-recall task.
*Results.* Patients with schizophrenia showed diminished temporal organisation, as well as diminished subjective organisation of their recall sequences relative to control participants. The two groups showed similar amounts of semantic organisation during recall.
*Conclusions.* The observation of reduced temporal organisation in the patient group is consistent with the proposal that the memory deficit in schizophrenia can be characterised as a deficit in contextual processing.

**Keywords:** free recall; episodic memory; organisation; retrieved-context model



Cognitive impairments in schizophrenia exhibit themselves both on measures of general intelligence (e.g., IQ; Woodberry, Giuliano, & Seidman, 2008) and a variety of specialised cognitive tasks (Barch, 2005). Researchers have proposed that a number of these impairments may be understood in terms of a context-related deficit (Hemsley, 2005), in which patients with schizophrenia exhibit an inability to take advantage of linguistic context (Chapman, Chapman, & Miller, 1964), an inability to maintain task context (Cohen, Barch, Carter, & Servan-Schreiber, 1999) and an inability to remember the source context of a piece of information (Danion, Rizzo, & Bruant, 1999). Cohen and Servan-Schreiber (1992) proposed that patients with schizophrenia are specifically impaired in their ability to maintain and manipulate an internal representation of context. They developed a computational model of executive function that relies on a contextual

*Corresponding author. Email: sean.polyn@vanderbilt.edu

representation to guide task-appropriate behaviour and show that damage to this contextual mechanism causes the model to exhibit deficits in attentional and linguistic tasks that mirror the schizophrenic deficit.

This idea that context-related processes are impaired in schizophrenia may help us to understand the nature of other memory-related impairments in schizophrenia. Patients diagnosed with schizophrenia reliably exhibit deficits on episodic memory tasks, when compared to nondisordered control groups (Gold, Randolph, Carpenter, Goldberg, & Weinberger, 1992; Ranganath, Minzenberg, & Ragland, 2008). Among episodic memory tasks, the schizophrenic deficit seems to be more pronounced in tasks involving memory search, such as free recall, as compared to tasks involving recognition judgements (e.g., Aleman, Hijman, deHaan, & Kahn, 1999; Paulsen et al., 1995).

The free-recall task is highly demanding of context-related cognitive processes, requiring a participant to target memories associated with a particular spatio-temporal context, i.e., the interval spent studying a particular list of words. Several influential computational models of human memory suggest that an internal representation of context is critically involved in the process of memory search in free recall (e.g., Davelaar, Goshen-Gottstein, Ashkenazi, Haarmann, & Usher, 2005; Howard & Kahana, 2002; Howard, Shankar, Aue, & Criss, 2015; Polyn, Norman, & Kahana, 2009; Raaijmakers & Shiffrin, 1981). Retrieved-context models propose that an internal contextual representation changes gradually over time and is associated with studied material, providing the memory system with a retrieval cue that can be used to flexibly target memories from a particular study list (Howard & Kahana, 2002; Kahana, Howard, & Polyn, 2008; Lohnas, Polyn, & Kahana, in press). In these models, the dynamics of this contextual representation determine the order in which materials are retrieved from memory.

One of the most prominent organisational phenomena in free recall is the temporal contiguity effect, which exhibits itself as a tendency for neighbouring items in a recall sequence to come from neighbouring list positions (Howard & Kahana, 1999; Kahana, 1996). Temporal organisation seems to be ubiquitous in free recall and has been observed in a large number of studies widely varying in their methodological details (Kahana, 1996; Kahana et al., 2008; Polyn, Erlikhman, & Kahana, 2011; Polyn et al., 2009). Retrieved-context models of memory search propose that temporal organisation in free recall is dependent on a contextual mechanism. Specifically, when a particular studied item is retrieved, the system can retrieve the state of context that prevailed when that item was studied. Because the contextual representation changed gradually during the study period, this retrieved contextual information is a good cue for the neighbours of the just-recalled item.

If patients with schizophrenia have a generalised contextual deficit, then these patients should exhibit reduced temporal organisation in free-recall tasks. Such an observation would be a step towards understanding the nature of the episodic memory impairment in this population. In the current study, patients with schizophrenia and nondisordered control participants performed a free-recall task as part of a cognitive battery. We employ modern organisational metrics that take into account the full distribution of lags exhibited in recall transitions. In addition, we demonstrate that, for these materials, there is little or no evidence for semantic organisation in the recall sequences, allowing us to obtain an estimate of temporal organisation in the absence of semantic organisation.

## Experimental methods

### *Participants*

We examined the memory performance of 75 patients diagnosed with schizophrenia (SZ; 50 males and 25 females) and 72 nondisordered control participants (NC; 33 males and 39 females). These participants were recruited through the Vanderbilt Psychiatric Hospital and from community outpatient clinics, as approved by the Vanderbilt University Institutional Review Board. After giving informed consent, patients were interviewed by a researcher trained in the Structured Clinical Interview for DSM-IV (SCID; First, Spitzer, Gibbon, & Williams, 1997). Premorbid IQ was estimated using the Wechsler Test of Adult Reading (WTAR; Wechsler, 2001). Patient symptoms were assessed with the Positive and Negative Syndrome Scale (PANSS; Kay, Fiszbein, & Opfer, 1987). Patients were excluded from the study if they had a history of significant head injury, significant medical or neurological illness or current substance abuse within three months prior to the study. The patients were given a consensus diagnosis based on the SCID and their medical records and discussion with a senior clinician.

Healthy control participants were recruited from the community through advertisements and gave informed consent to participate in the study. To qualify as a control participant, the subject could not have any history of an Axis I psychiatric disorder, a significant medical or neurological condition, substance abuse or use of psychotropic medications. The controls participated in the same assessments as the patients, except for the PANSS. All participants were compensated for their participation in the study.

The distribution of ages between the two groups was not significantly different (NC mean = 34.5, SD = 12.3; SZ mean = 36.1, SD = 11.7; $t(145) = 0.841$, $p = 0.4$). Patients had lower estimated premorbid IQ (NC mean = 108.1, SD = 12.5; SZ mean = 92.9, SD = 17.8; $t(139) = 5.88$, $p < 0.001$). The IQ scores for two NC and two SZ patients were excluded from this calculation because WTAR was not an accurate representation of their IQ, either due to a reading disability or English not being their first language; two other patients did not have an IQ score recorded. The patients were moderately symptomatic (mean PANSS total scores = 69.5, SD = 17.3); three patients did not have PANSS scores recorded. Most of the patients were medicated at the time of testing with a mean chlorpromazine equivalence of 628.6 mg (SD = 436.0), excluding 11 patients who either were not taking medication at the time of the interview, or for whom we did not have sufficient information to calculate this value.

### *Materials and procedure*

Each participant was tested using the Screen for Cognitive Impairment in Psychiatry (SCIP; Purdon, 2005). The analyses reported in this manuscript examine the free-recall trials that are part of the SCIP. On each of 3 trials, the experimenter read a 10-item list at a rate of roughly 3 seconds per word. Every participant received the same set of words, which were read in the same order on every trial: drum, curtain, bell, coffee, school, parent, moon, garden, hat, farmer. After the final word, the participant was asked to verbally recall the studied items in any order, and the experimenter recorded the order of responses. After the third trial, the participant was told they would be asked to recall the list again later. After performing a letter-recall task (a variant of the Brown–Peterson task; Brown, 1958; Peterson & Peterson, 1959) and a verbal fluency task (generating words beginning with a particular letter), they were asked to recall the set of 10 words (but the list was not repeated by the experimenter).

### *Analysis techniques*

We employed three organisational measures to characterise the free-recall response sequences. The temporal organisation score is used to quantify the contiguity effect, which is defined as the tendency to successively report neighbouring list items during the recall sequence. This technique provides a percentile ranking for each recall transition, corresponding to how close the two recalled items are to one another in the list (in terms of positional lag), relative to the other items that could have been next recalled. If the recalled items were chosen randomly from the list, the expected value of this statistic is 0.5. Stronger temporal organisation produces values closer to 1 (for more detail, see Polyn et al., 2009). Each participant is assigned a temporal organisation score that is the mean of the set of values calculated for the participant's recall transitions. As an example, consider a recall sequence in which the first response is "drum". If the next response is "curtain", this recall transition will be assigned a score of 1, as "curtain" is the most proximal word to "drum" on the original study list. If a less proximal word was recalled instead of "curtain", the score would be lower, according to the rank of the lag between the two words (e.g., if the next response is "parent", the recall transition will be assigned a score of 0.5).

The semantic organisation score examines whether participants tend to organise the words according to their semantic meaning (Polyn et al., 2009). As with the temporal organisation score, this measure operates at the level of recall transition and provides a percentile ranking corresponding to how similar in meaning the two recalled items are, relative to the other items that could have been next recalled. This analysis requires a model of semantic similarity to characterise the relatedness of each possible pair of words. We used the word association spaces (WAS; Steyvers, Shiffrin, & Nelson, 2004) model of semantic similarity, which has been shown to have predictive power regarding the organisation of recall sequences in free recall (Howard, Addis, Jing, & Kahana, 2007). As an example, consider a recall sequence in which the first response of the participant is the word "bell". The remaining words are arranged in terms of their semantic similarity to "bell". Using the WAS model to order the other words in descending similarity, we have: drum, curtain, school, hat, coffee, garden, farmer, parent, moon. If the next response was "drum", this recall transition would be assigned the maximum ranking of 1.0, if instead, the next response had been "coffee", the recall transition would be assigned a ranking of 0.5. As with the temporal organisation score, a mean score of 0.5 indicates no evidence for semantic organisation of the responses.

As mentioned, participants studied the same list of words three times. We focus our analysis of temporal organisation on the first trial, as recall organisation on later trials may reflect a combination of memory for the study list and memory for previous recall sequences. In order to characterise the influence of memory for previous recall sequences on the current trial (for Trials 2, 3 and 4), we employed a third metric characterising subjective organisation. The analysis of subjective organisation takes a pair of recall sequences made by a particular subject on successive trials and quantifies the degree to which they are produced in a similar order across the two trials (regardless of whether the recall order matches the study order). For example, if a participant recalled "moon" followed by "drum" on both Trials 1 and 2, this would increase estimates of subjective organisation. The analysis tallies the number of pairs of items recalled on two successive recall trials in adjacent output positions (for either of the two possible orders of the items), a score referred to as bidirectional inter-trial repetition, or ITR2. This measure, the pair frequency (PF) analysis, is defined as: $PF = O(ITR2) - E(ITR2)$, where these terms

are the observed and expected values of ITR2, with E(ITR2) given as $2c(c-1)/hk$, "where $c$ is the number of common items recalled on both trials $t$ and $t+1$, $h$ is the number of items recalled on trial $t$ and $k$ is the number of items recalled on trial $t+1$" (Sternberg & Tulving, 1977, pp. 542–543). Since subjective organisation does not take the composition of the study list into consideration, it can be thought of as a broad measure that captures both idiosyncratic organisational effects as well as organisational effects due to the structure of the study list. Thus, subjective organisation can be influenced by both temporal and semantic information.

## Results

### *Recall performance*

We carried out a two-factor repeated measures analysis of variance on the proportion of items recalled, with trial (1–4) and disease status (SZ vs. NC) as within-subject and between-subject factors, respectively. This was done in a multivariate framework to account for potential sphericity violations. This analysis revealed a main effect of disease status ($F(1, 144) = 113.0$, $p < 0.0001$), a main effect of trial ($F(3, 142) = 233.2$, $p < 0.0001$) and an interaction between the two ($F(3, 142) = 7.84$, $p < 0.0001$). Table 1 reports the mean proportion of items recalled on each trial for the patient and control groups. Two-sample $t$ tests confirm that the patients recalled significantly fewer items overall ($t(145) = 10.7$, $p < 0.001$), as well as on each trial considered individually (Trial 1: $t(145) = 8.39$, $p < 0.001$; Trial 2: $t(145) = 10.7$, $p<0.001$; Trial 3: $t(144) = 8.74$, $p < 0.001$) and on the delayed recall test ($t(145) = 8.48$, $p < 0.001$). For each group, overall recall performance was correlated with IQ (NC $r = 0.335$, $p < 0.005$; SZ $r = 0.470$, $p < 0.0001$).

Figure 1 shows the serial position curve for each group, on the first trial of the memory task. Although the patients with schizophrenia recalled fewer items, the average serial position curve for this group looks qualitatively similar to the serial position curve for the matched controls, with each group showing a substantial primacy effect and recency effect.

### *Subjective organisation*

The overall shape of the serial position curve is similar between the two groups, suggesting that perhaps the patients with schizophrenia are simply recalling fewer items than the matched control participants. However, measures of recall organisation reveal basic differences in recall dynamics between the two groups. Subjective organisation exhibits itself in a multi-trial free-recall paradigm as a tendency to recall items in a similar

Table 1. Proportion of items recalled for patients with schizophrenia (SZ) and healthy controls (NC) over all trials, separately for the three free-recall trials, and for the delayed recall period.

| Trial | SZ proportion recalled (SEM) | NC proportion recalled (SEM) |
|---|---|---|
| Overall | 0.53 (0.021) | 0.79 (0.012) |
| 1 | 0.44 (0.021) | 0.66 (0.015) |
| 2 | 0.59 (0.021) | 0.86 (0.013) |
| 3 | 0.69 (0.022) | 0.92 (0.012) |
| Delayed | 0.39 (0.032) | 0.73 (0.023) |

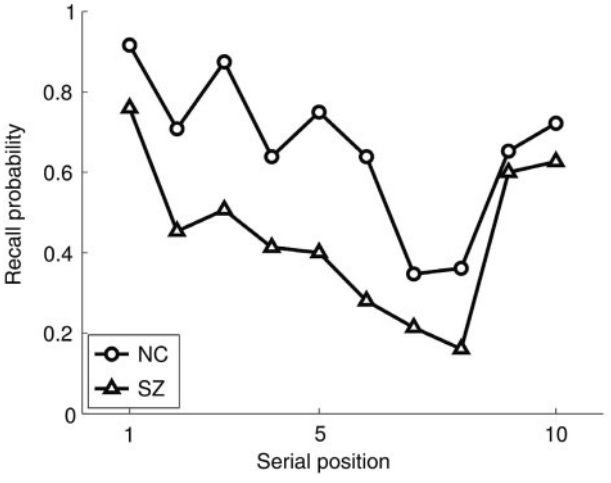


Figure 1. Serial position curves for patients with schizophrenia (SZ) and matched control participants (NC).
Note: Although SZ patients recalled significantly fewer items, the qualitative shape of the serial position curve was similar between the two groups.



order across trials, regardless of whether that order reflects the actual presented order of the study list. Sternberg and Tulving (1977) recommended the PF measure as a metric to assess subjective organisation (see "Analysis techniques"). For each set of recall tests considered, participants were excluded if they recalled fewer than four items on any of the included recall tests (the number of remaining participants is included in Table 2), to improve the reliability of this metric. As shown in Table 2, the patients showed reduced subjective organisation relative to the control group using PF, overall ($t(101) = 2.71$, $p < 0.01$), as well as for each pair of trials (Trials 1–2: $t(117) = 2.95$, $p < 0.005$; Trials 2–3: $t(137) = 3.70$, $p < 0.001$; Trial 3–final test: $t(110) = 2.38$, $p < 0.05$).

Given that our two groups differed in terms of estimated IQ, we examined whether the PF measure of subjective organisation was related to estimated IQ. We found that the two pairs of adjacent immediate recall tests (Trials 1–2 and Trials 2–3) did not have different PF for either group (NC $t(70) = 1.33$, $p = 0.19$; SZ $t(46) = 0.143$, $p = 0.88$). As such we pooled these trial pairs for an analysis examining the interaction of IQ and PF. We found that the relation between IQ and PF score was different for the two groups ($F(1, 111) = 4.64$, $p < 0.05$). A stronger relation was observed between IQ and PF for the

Table 2. Pair frequency measure of subjective organisation for patients with schizophrenia (SZ) and healthy controls (NC).

| Trials | SZ | NC | SZ participants | NC participants |
|---|---|---|---|---|
| All trials | 0.76 (0.12) | 1.45 (0.17) | 33 | 70 |
| Trials 1–2 | 0.73 (0.13) | 1.43 (0.17) | 47 | 72 |
| Trials 2–3 | 0.75 (0.12) | 1.68 (0.22) | 68 | 72 |
| Trials 3–final | 0.45 (0.16) | 1.20 (0.23) | 43 | 70 |

Note: See text for details of statistics.

control participants ($r = 0.253$, $p < 0.05$) than for the patients with schizophrenia ($r = -0.114$, $p = 0.46$).

### *Temporal organisation*

Our analysis of subjective organisation indicates that the healthy participants recalled the studied items in a similar order across trials, whereas the patients with schizophrenia recalled the studied items in a less consistent order across trials. Although PF serves as a good general measure of recall organisation, it does not give insight into whether the observed recall organisation is influenced by the structure of the studied list. For this we turn to measures characterising temporal and semantic organisation.

We calculated a temporal organisation score for each participant's first recall trial and report these in Table 3. Performance on later trials reflects memory for the study periods as well as the interpolated recall periods, so we excluded the later trials from our estimates of temporal organisation. To improve the reliability of the temporal organisation metric, we excluded participants who recalled fewer than four items. The temporal organisation score is significantly diminished for the patient group relative to the control group ($t(119) = 2.47$, $p < 0.05$). One might expect this, simply due to the lower recall performance of the patients: A study of individual differences in free recall in a group of healthy participants showed a direct relationship between recall performance and the magnitude of the contiguity effect (Sederberg, Miller, Howard, & Kahana, 2010).

We used an analysis of covariance (ANCOVA) framework to examine the relationship between recall performance and temporal organisation score and to determine whether the organisational deficit of the patients exceeded what would be expected given their overall diminished recall performance. We found no significant relation between recall performance and temporal organisation score ($F(1, 118) < 1$). A test for parallelism indicates that the relation between recall performance and temporal organisation score does not vary between groups ($F(1, 117) < 1$). There is still a significant effect of disease status on temporal factor with recall performance included as a covariate ($F(1, 118) = 4.85$, $p < 0.05$).

We carried out an ANCOVA to document whether variability in IQ is important to understanding the relationship between disease status and temporal organisation score. Given that recall performance did not reliably affect temporal organisation score in our analyses earlier, we did not include it in this model. There was a significant relation

Table 3. Temporal organisation scores for patients with schizophrenia (SZ) and healthy controls (NC), divided according to proportion of items recalled.

| Proportion recalled | SZ (SEM) | NC (SEM) | SZ participants | NC participants |
|---|---|---|---|---|
| 0.2 | 0.41 (0.15) | – | 7 | – |
| 0.3 | 0.52 (0.07) | – | 14 | – |
| 0.4 | 0.59 (0.02) | 0.70 (0.04) | 8 | 3 |
| 0.5 | 0.68 (0.03) | 0.66 (0.05) | 21 | 14 |
| 0.6 | 0.55 (0.07) | 0.73 (0.03) | 9 | 14 |
| 0.7 | 0.67 (0.05) | 0.70 (0.02) | 9 | 24 |
| 0.8 | 0.61 (0.004) | 0.70 (0.04) | 2 | 11 |
| 0.9 | – | 0.65 (0.05) | – | 6 |
| Overall | 0.59 (0.03) | 0.69 (0.01) | 70 | 72 |

Note: Temporal organisation scores and proportion recalled correspond to performance on Trial 1 of the multi-trial free-recall test.

between IQ and temporal organisation score ($F(1, 114) = 4.76$, $p < 0.05$). A test for parallelism confirmed that the relation between IQ and temporal organisation score did not vary between groups ($F(1, 113) < 1$). We found that there was no reliable effect of disease status on the temporal organisation score when the effect of IQ was factored out ($F(1, 114) = 1.48$, $p = 0.23$). We carried out a second analysis in which we took a subsample of the participants in each group, in order to create two groups of participants that were matched in terms of estimated IQ. Specifically, for each patient, we found a control participant whose IQ was within one point of that patient's IQ (if one existed in the set). The control participants were sampled without replacement during this selection process. By this procedure, we created two groups of 42 participants, who did not differ significantly in terms of IQ ($t(82) = 0.02$, $p = 0.99$). The two groups did not differ in terms of their temporal organisation scores ($t(80) = 1.48$, $p = 0.142$), consistent with the results of the ANCOVA. These results are consistent with the idea that patients show decreased temporal organisation relative to normal control participants and that this memory deficit is related to the IQ deficit seen in patients with schizophrenia. This point receives further attention in the discussion.

### *Semantic organisation*

We used a measure of semantic organisation (see "Analysis techniques") to examine whether the decreased temporal organisation observed in the patient group corresponded to an increased tendency to organise words based on their meanings. This semantic organisation score is similar to the temporal organisation score in that it provides a percentile ranking for each pair of successively reported words, corresponding to how semantically similar those items are relative to the other items that could have been recalled (see "Analysis techniques"; Polyn et al., 2009). As earlier, we focused our analysis on the first trial and excluded data from participants who recalled fewer than four items. We found that semantic organisation was at near-chance levels (0.5) for both groups of participants. The mean semantic organisation score for the NC group was 0.549 (SEM = 0.016), which was reliably different than chance ($t(71) = 3.00$, $p < 0.005$). The mean semantic organisation score for the SZ group was 0.533 (SEM = 0.025), which was not reliably different from chance ($t(48) = 1.33$, $p = 0.19$). We found no evidence for different amounts of semantic organisation across the two groups (two-sample $t$ test of NC vs. SZ semantic organisation scores $t(119) = 0.556$, $p = 0.58$). A follow-up ANCOVA took IQ into account as a covariate but still did not find evidence for a difference in semantic organisational scores as an effect of disease status ($F(1, 114) < 1$).

## Discussion

Prominent theories of cognitive deficits in schizophrenia propose that this population has an impaired ability to make use of contextual information (Cohen & Servan-Schreiber, 1992; Hemsley, 2005). Theories of human memory search propose that a contextual retrieval cue is critically involved in memory search and that the dynamics of this cue give rise to temporal organisation in free recall. In the current study, we sought to determine whether patients with schizophrenia show impaired temporal organisation in free recall. If so, this would be a first step towards linking the recall deficit in schizophrenia to the more general contextual deficit seen in other cognitive tasks.

Patients exhibited decreased subjective organisation relative to matched control participants, which reflects a tendency for patients to be less consistent in the order they

report items across trials. This extends the results of a classic study of recall organisation in schizophrenia reported by Koh, Kayton, and Berry (1973), where decreased subjective organisation was observed in multi-trial free recall, but only on a list of items with strong category structure. In that study, patients and control participants showed statistically similar levels of subjective organisation for uncategorised materials, although this null result may have been due to low statistical power.

In the current study, patients showed weaker temporal organisation than controls, even when accounting for a potential relationship between temporal organisation and recall performance. A positive relationship between these two performance measures was reported by Sederberg et al. (2010), in a meta-analysis of a number of free-recall experiments. Although temporal organisation and recall performance were not correlated in the current experiment, this may have been due to a lack of statistical power. The relationship between these two measures may be subtle; although Sederberg et al. (2010) demonstrated a significant positive correlation at the level of their meta-analysis, some of the studies in the meta-analysis did not show a significant relationship between these measures, when considered on their own. Prior work examining the organisational properties of recall sequences in patients with schizophrenia is unclear on whether they exhibit decreased temporal organisation. Although many studies have demonstrated that semantic organisation is decreased in these patients (e.g., Calev, 1984; Koh et al., 1973; Paulsen et al., 1995), only a few studies have examined temporal organisation.

The few studies that report measures of temporal organisation show mixed results regarding a temporal organisational deficit in schizophrenia. Brébion, Amador, Smith, and Gorman (1997) used a "sequence index" that calculated the proportion of recall transitions of lag +1, to characterise temporal organisation in patients with schizophrenia and nondisordered controls. On lists with category structure, controls showed less temporal organisation than patients, but this was related to an increased tendency of the control participants to exhibit semantic organisation on those lists. On lists of randomly chosen words, there was no difference in temporal organisation between the groups. A study by Koh and Kayton (1974), found partial support for a temporal organisation deficit in schizophrenia. In this study patients showed reduced temporal organisation on a delayed recall test but not on an immediate test. They used a measure known as input–output concordance (Mandler & Dean, 1969) which characterised temporal organisation in terms of the proportion of recall transitions with lag +1 and −1. We suggest that the temporal organisation metrics used in both of these studies are less sensitive than the measures of temporal organisation employed here, which take into account the full distribution of lags across recall transitions, rather than restricting the analysis to lags corresponding to adjacent study items.

We found no reliable difference in semantic organisation between the two groups, which suggests that the decline in temporal organisation in patients does not reflect an increased usage of semantic information in this group. For both groups, the measure of semantic organisation was near chance levels, suggesting that neither group made strong use of the semantic structure of the study list. This is in line with the lack of an obvious category structure in the studied materials.

In each of these analyses we examined the relationship between the dependent measure and IQ. A number of researchers have argued that it is inappropriate to match groups on general intelligence, especially given the general consensus that lower IQ test performance by a patient with schizophrenia can reflect the severity of that patient's pathology (Chapman & Chapman, 1973; Miller & Chapman, 2001). In other words, if the

disease causes damage to a cognitive system that affects both IQ as well as recall organisation, then it would be inappropriate to include IQ as a factor in a statistical analysis, as the assignment of IQ to participant is not random when considering disease status. A recent meta-analytic study supports the idea that there is a premorbid difference in IQ between patients diagnosed with schizophrenia and matched healthy people and suggests that there is also a reliable decline in IQ associated with the transition from the premorbid to the postmorbid schizophrenic state (Woodberry et al., 2008).

We examined how measures of recall organisation related to the estimated IQ of the participant. The decrease in temporal organisation in patients with schizophrenia showed a relationship to estimated IQ of the participant, and a statistical model including IQ as a covariate failed to show a reliable relationship between temporal organisation and disease status. This is consistent with the idea that the underlying cognitive deficit in schizophrenia is related to both selective deficits on memory tests in addition to generalised impairment, as measured with IQ tests. The deficit in subjective organisation showed a more complicated relationship with IQ, in which a positive correlation was observed between IQ and subjective organisation for the healthy participants, but not for the patients with schizophrenia. The interpretation of this result is less clear; one possibility is that healthy participants with higher IQ scores are more likely to engage associative processes supporting subjective organisation, but patients are unable to engage these processes, regardless of estimated IQ.



### Retrieved-context models and the context-deficit hypothesis of schizophrenia

A number of theorists have proposed that the seemingly diverse cognitive impairments associated with schizophrenia can be explained in terms of a deficit in the utilisation, or influence, of contextual information (Cohen, Braver, & O'Reilly, 1996; Cohen & Servan-Schreiber, 1992; Hemsley, 2005). In the framework of Cohen and colleagues, context is centrally involved in cognitive control and can play a role in both working memory (e.g., when task-relevant information about prior stimuli must be maintained) as well as inhibitory control (e.g., when a strong response tendency must be overridden to make an appropriate response). In the domain of language processing, patients with schizophrenia often fail to use contextual constraints to resolve semantic ambiguity, e.g., when the content of a prior sentence constrains the meaning of an ambiguous word in the next sentence (Bazin, Perruchet, Hardy-Bayle, & Feline, 2000; Chapman et al., 1964). Cohen and Servan-Schreiber (1992) suggest that this deficit is not specific to the domain of language or semantics but extends to any situation when prior information must be held in mind to influence future behaviour (Barch & Ceaser, 2012). In line with this proposal, patients with schizophrenia also show an impairment in a continuous performance task where the correct response to a target stimulus is conditional on the identity of the preceding stimulus in the sequence. The idea that patients with schizophrenia are impaired in their ability to maintain task context also explains the pattern of deficits seen in the Stroop task, where patients have difficulty inhibiting the strong tendency to read a presented word, even though the task instructions are to name the colour of the ink it is typed in (Cohen et al., 1999).

In the domain of episodic memory, patients with schizophrenia also show a deficit in terms of the influence or utilisation of contextual information. This can exhibit itself as an inability to remember or take advantage of the source characteristics of an experience (Danion et al., 1999; Talamini, De Haan, Nieman, Linszen, & Meeter, 2010; Vinogradov

et al., 1997). A number of researchers have also found specific impairments in memory for the spatial context (Brébion, David, Pilowsky, & Jones, 2004; Rizzo, Danion, Van der Linden, Grangé, & Rohmer, 1996) and temporal context (Rizzo, Danion, Van der Linden, & Grangé, 1996; Schwartz, Deutsch, Cohen, Warden, & Deutsch, 1991; Waters, Maybery, Badcock, & Michie, 2004) of a study event. In a few cases, the deficit in memory for temporal context was found to be related to participants' overall recall performance on the task, raising the question of the specificity of the contextual deficit (Brébion, David, Jones, Ohlsen, & Pilowsky, 2007; Elvevåg, Egan, & Goldberg, 2000).

In the current study, we demonstrate that patients with schizophrenia show reduced temporal organisation of their recall sequences in a free-recall task. As described in the introduction (and elsewhere, e.g., Kahana, 2012), retrieved-context models propose that temporal organisation arises from the dynamics of an internally maintained representation of context. Here, we propose that the theoretical framework associated with these models may help us understand the common cognitive operations underlying the memory and performance deficits observed in schizophrenia.

Damage to either of two central mechanisms in a retrieved-context model could give rise to a context-specific deficit. The first is an integrative mechanism that causes the contextual representation to change gradually over time. Damage to this mechanism could prevent the memory system from constructing a distinctive contextual representation for a given experience. The second is an associative mechanism that binds the representation of a studied item to the contextual representation. Damage to this mechanism would have a similar effect; although the contextual representation would be intact, items would be poorly bound to it. In either case, the system would have difficulty retrieving the contextual details associated with a particular event. In these models, context is critically involved in the process of memory retrieval. Thus, it is unclear whether one would expect a context-specific deficit to be correlated with overall recall performance (e.g., Elvevåg, Duncan, & McKenna, 2000). It may be possible to elucidate this issue in future modelling work, in which a retrieved-context model is used to explicitly simulate the performance of patients with schizophrenia on a battery of memory tasks.

Although the application of retrieved-context models to the schizophrenic condition is speculative, this framework would naturally explain the relationship between the deficits in source memory exhibited by patients with schizophrenia (e.g., Danion et al., 1999), and the temporal organisational deficit observed in this study. Recent work by Howard et al. (2015) demonstrates how the contextual representation in these models can be used to perform temporal discrimination judgements, providing a potential explanation for the deficit observed in patients with schizophrenia in these tasks (e.g., Rizzo, Danion, Van der Linden, & Grangé, 1996; Schwartz et al., 1991). Furthermore, as noted by Polyn et al. (2009), the integrative mechanism in these models is similar to the mechanism that allows the Cohen and Servan-Schreiber model to maintain task context, raising the possibility that the same cognitive machinery underlies the task performance deficits characterised in that work.

### Contextual processing and the symptoms of schizophrenia

Bleuler, in his seminal work, emphasised the importance of disorganisation in understanding the nature of the schizophrenic condition (Bleuler, 1950). Central to this framework is the idea that disordered associative structures in the cognitive system give rise to

disorganised thinking, delusions and other symptoms characteristic of schizophrenia (Chapman & Chapman, 1973). Retrieved-context models of memory may provide a way to link the symptoms of this disease with the behavioural deficits seen in cognitive testing. As described earlier, some of the cognitive deficits in schizophrenia may arise from the erratic functioning of a contextual mechanism responsible for linking experiences to their proper spatiotemporal context and flexibly targeting memories of past experience.

Under this proposal, it may be possible to link these cognitive disturbances to the symptomatology of the disease in a principled way (Hemsley, 2005). Damage to this contextual system could lead to disorganised thinking, as one would be unable to efficiently retrieve memories appropriate to a given situation. This could make it more difficult for a patient to generate a string of thoughts that follow one another in a logical manner. Delusions might then arise when these already disorganised thoughts are formed into memories and may also be related to retrieval of memories without their associated context. This could lead to problems with reality monitoring (Johnson, Hashtroudi, & Lindsay, 1993), in which a patient misattributes an imagined experience to a real situation.



## Conclusion

Patients with schizophrenia show impaired performance on cognitive tasks involving episodic memory. Here, we examined the schizophrenic memory deficit in terms of recall organisation during a free-recall task, showing that patients show altered temporal and subjective organisation relative to control participants. According to retrieved-context models of memory, these behavioural differences are consistent with damage to a context-based mechanism used to guide memory search.

## Acknowledgements

Thanks to Michael Geoghegan and Zachary Bullard for help processing the data. Many thanks to Andrew Tomarken, Sohee Park, Neil Woodward and Joanna Peery Polyn for helpful comments and discussion.

## Disclosure statement

No potential conflict of interest was reported by the authors.

## Funding

This work was supported by the National Science Foundation [grant number 1157432] to SMP and by a Vanderbilt Discovery grant to SMP.

## References

Aleman, A., Hijman, R., deHaan, E. H. F., & Kahn, R. S. (1999). Memory impairment in schizophrenia: A meta-analysis. *American Journal of Psychiatry*, *156*, 1358–1366.

Barch, D. M. (2005). The cognitive neuroscience of schizophrenia. *Annual Review of Clinical Psychology*, *1*, 321–353. doi:10.1146/annurev.clinpsy.1.102803.143959

Barch, D. M., & Ceaser, A. (2012). Cognition in schizophrenia: Core psychological and neural mechanisms. *Trends in Cognitive Sciences*, *16*, 27–34. doi:10.1016/j.tics.2011.11.015

Bazin, N., Perruchet, P., Hardy-Bayle, M. C., & Feline, A. (2000). Context-dependent information processing in patients with schizophrenia. *Schizophrenia Research*, *45*, 93–101. doi:10.1016/S0920-9964(99)00167-X

Bleuler, E. (1950). *Dementia praecox; or, the group of schizophrenias*. New York, NY: International Universities Press.

Brébion, G., Amador, X., Smith, M., & Gorman, J. (1997). Mechanisms underlying memory impairment in schizophrenia. *Psychological Medicine*, *27*, 383–393. doi:10.1017/S0033291796004448

Brébion, G., David, A. S., Jones, H. M., Ohlsen, R., & Pilowsky, L. S. (2007). Temporal context discrimination in patients with schizophrenia: Associations with auditory hallucinations and negative symptoms. *Neuropsychologia*, *45*, 817–823. doi:10.1016/j.neuropsychologia.2006.08.009

Brébion, G., David, A. S., Pilowsky, L. S., & Jones, H. (2004). Recognition of visual stimuli and memory for spatial context in schizophrenic patients and healthy volunteers. *Journal of Clinical and Experimental Neuropsychology*, *26*, 1093–1102. doi:10.1080/13803390490515513

Brown, J. (1958). Some tests of the decay theory of immediate memory. *Quarterly Journal of Experimental Psychology*, *10*, 12–21. doi:10.1080/17470215808416249

Calev, A. (1984). Recall and recognition in chronic nondemented schizophrenics: Use of matched tasks. *Journal of Abnormal Psychology*, *93*, 172–177. doi:10.1037/0021-843X.93.2.172

Chapman, L. J., & Chapman, J. P. (1973). *Disordered thought in schizophrenia*. Englewood Cliffs, NJ: Prentice Hall.

Chapman, L. J., Chapman, J. P., & Miller, G. A. (1964). A theory of verbal behavior in schizophrenia. In B. A. Maher (Ed.), *Progress in experimental personality research* (Vol. 4, pp. 49–77). New York, NY: Academic Press.

Cohen, J. D., Barch, D. M., Carter, C., & Servan-Schreiber, D. (1999). Context-processing deficits in schizophrenia: Converging evidence from three theoretically motivated cognitive tasks. *Journal of Abnormal Psychology*, *108*, 120–133. doi:10.1037/0021-843X.108.1.120

Cohen, J. D., Braver, T. S., & O'Reilly, R. C. (1996). A computational approach to prefrontal cortex, cognitive control, and schizophrenia: Recent developments and current challenges. *Philosophical Transactions of the Royal Society B: Biological Sciences the Royal Society of London: Series B*, *351*, 1515–1527. doi:10.1098/rstb.1996.0138

Cohen, J. D., & Servan-Schreiber, D. (1992). Context, cortex, and dopamine: A connectionist approach to behavior and biology in schizophrenia. *Psychological Review*, *99*, 45–77. doi:10.1037/0033-295X.99.1.45

Danion, J.-M., Rizzo, L., & Bruant, A. (1999). Functional mechanisms underlying impaired recognition memory and conscious awareness in patients with schizophrenia. *Archives of General Psychiatry*, *56*, 639–644. doi:10.1001/archpsyc.56.7.639

Davelaar, E. J., Goshen-Gottstein, Y., Ashkenazi, A., Haarmann, H. J., & Usher, M. (2005). The demise of short-term memory revisited: Empirical and computational investigations of recency effects. *Psychological Review*, *112*, 3–42. doi:10.1037/0033-295X.112.1.3

Elvevåg, B., Duncan, J., & McKenna, P. (2000). The use of cognitive context in schizophrenia: An investigation. *Psychological Medicine*, *30*, 885–897. doi:10.1017/S003329179900255X

Elvevåg, B., Egan, M. F., & Goldberg, T. E. (2000). Memory for temporal order in patients with schizophrenia. *Schizophrenia Research*, *46*, 187–193. doi:10.1016/S0920-9964(00)00014-1

First, M. B., Spitzer, R. L., Gibbon, M., & Williams, J. B. (1997). *Structured Clinical Interview for DSM-IV axis I disorders—Clinical version (SCID-CV)*. Washington, DC: American Psychiatric Press.

Gold, J., Randolph, C., Carpenter, C., Goldberg, T., & Weinberger, D. (1992). Forms of memory failure in schizophrenia. *Journal of Abnormal Psychology*, *101*, 487–494. doi:10.1037/0021-843X.101.3.487

Hemsley, D. R. (2005). The schizophrenic experience: Taken out of context? *Schizophrenia Bulletin*, *31*, 43–53. doi:10.1093/schbul/sbi003

Howard, M. W., Addis, K. A., Jing, B., & Kahana, M. J. (2007). Handbook of latent semantic analysis. In T. K. Landauer, D. S. McNamara, S. Dennis, & W. Kintsch (Eds.), *LSA: A road towards meaning* (pp. 121–141). Mahwah, NJ: Lawrence Erlbaum.

Howard, M. W., & Kahana, M. J. (1999). Contextual variability and serial position effects in free recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*, 923–941. doi:10.1037/0278-7393.25.4.923

Howard, M. W., & Kahana, M. J. (2002). A distributed representation of temporal context. *Journal of Mathematical Psychology*, *46*, 269–299. doi:10.1006/jmps.2001.1388

Howard, M. W., Shankar, K. H., Aue, W. R., & Criss, A. H. (2015). A distributed representation of internal time. *Psychological Review*, *122*, 24–53. doi:10.1037/a0037840
Johnson, M. K., Hashtroudi, S., & Lindsay, D. S. (1993). Source monitoring. *Psychological Bulletin*, *114*, 3–28. doi:10.1037/0033-2909.114.1.3
Kahana, M. J. (1996). Associative retrieval processes in free recall. *Memory & Cognition*, *24*, 103–109. doi:10.3758/BF03197276
Kahana, M. J. (2012). *Foundations of human memory* (1st ed.). New York, NY: Oxford University Press.
Kahana, M. J., Howard, M. W., & Polyn, S. M. (2008). Associative retrieval processes in episodic memory. In H. L. Roediger III (Ed.), *Cognitive psychology of memory. Vol. 2 of Learning and memory: A comprehensive reference, 4 vols. (J. Byrne, Ed.)* (pp. 467–490). Oxford: Elsevier.
Kay, S. R., Fiszbein, A., & Opfer, L. A. (1987). The Positive and Negative Syndrome Scale (PANSS) for schizophrenia. *Schizophrenia Bulletin*, *13*, 261–276. doi:10.1093/schbul/13.2.261
Koh, S. D., & Kayton, L. (1974). Memorization of "unrelated" word strings by young nonpsychotic schizophrenics. *Journal of Abnormal Psychology*, *83*, 14–22. doi:10.1037/h0036233
Koh, S. D., Kayton, L., & Berry, R. (1973). Mnemonic organization in young nonpsychotic schizophrenics. *Journal of Abnormal Psychology*, *81*, 299–310. doi:10.1037/h0034525
Lohnas, L. J., Polyn, S. M., & Kahana, M. J. (in press). Expanding the scope of memory search: Modeling intralist and interlist effects in free recall. *Psychological Review.*
Mandler, G., & Dean, P. J. (1969). Seriation: Development of serial order in free recall. *Journal of Experimental Psychology*, *81*, 207–215. doi:10.1037/h0027767
Miller, G. A., & Chapman, J. P. (2001). Misunderstanding analysis of covariance. *Journal of Abnormal Psychology*, *110*, 40–48. doi:10.1037/0021-843X.110.1.40
Paulsen, J., Heaton, R., Sadek, J., Perry, W., Delis, D., & Braff, D. (1995). The nature of learning and memory impairments in schizophrenia. *Journal of the International Neuropsychological Society*, *1*, 88–99. doi:10.1017/S135561770000014X
Peterson, L. R., & Peterson, M. J. (1959). Short-term retention of individual verbal items. *Journal of Experimental Psychology*, *58*, 193–198. doi:10.1037/h0049234
Polyn, S. M., Erlikhman, G., & Kahana, M. J. (2011). Semantic cuing and the scale-insensitivity of recency and contiguity. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *27*, 766–775. doi:10.1037/a0022475
Polyn, S. M., Norman, K. A., & Kahana, M. J. (2009). A context maintenance and retrieval model of organizational processes in free recall. *Psychological Review*, *116*, 129–156. doi:10.1037/a0014420
Purdon, S. E. (2005). *The Screen for Cognitive Impairment in Psychiatry (SCIP): Instructions and three alternate forms*. Edmonton, AB: PNL.
Raaijmakers, J. G. W., & Shiffrin, R. M. (1981). Search of associative memory. *Psychological Review*, *88*, 93–134. doi:10.1037/0033-295X.88.2.93
Ranganath, C., Minzenberg, M. J., & Ragland, J. D. (2008). The cognitive neuroscience of memory function and dysfunction in schizophrenia. *Biological Psychiatry*, *64*, 18–25. doi:10.1016/j.biopsych.2008.04.011
Rizzo, L., Danion, J.-M., Van der Linden, M., & Grangé, D. (1996). Patients with schizophrenia remember that an event has occurred, but not when. *The British Journal of Psychiatry*, *168*, 427–431. doi:10.1192/bjp.168.4.427
Rizzo, L., Danion, J.-M., Van der Linden, M., Grangé, D., & Rohmer, J.-G. (1996). Impairment of memory for spatial context in schizophrenia. *Neuropsychology*, *10*, 376–384. doi:10.1037/0894-4105.10.3.376
Schwartz, B. L., Deutsch, L. H., Cohen, C., Warden, D., & Deutsch, S. I. (1991). Memory for temporal order in schizophrenia. *Biological Psychiatry*, *29*, 329–339. doi:10.1016/0006-3223(91)90218-B
Sederberg, P. B., Miller, J. F., Howard, M. W., & Kahana, M. J. (2010). The temporal contiguity effect predicts episodic memory performance. *Memory & Cognition*, *38*, 689–699. doi:10.3758/MC.38.6.689
Sternberg, R. J., & Tulving, E. (1977). The measurement of subjective organization in free recall. *Psychological Bulletin*, *84*, 539–556. doi:10.1037/0033-2909.84.3.539
Steyvers, M., Shiffrin, R. M., & Nelson, D. L. (2004). Word association spaces for predicting semantic similarity effects in episodic memory. In A. F. Healy (Ed.), *Cognitive psychology and*

*its applications: Festschrift in honor of Lyle Bourne, Walter Kintsch, and Thomas Landauer* (pp. 237–249). Washington, DC: American Psychological Association.

Talamini, L., De Haan, L., Nieman, D., Linszen, D., & Meeter, M. (2010). Reduced context effects on retrieval in first-episode schizophrenia. *PLoS ONE*, *5*, e10356. doi:10.1371/journal.pone.0010356.t002

Vinogradov, S., Willis-Shore, J., Poole, J. H., Marten, E., Ober, B. A., & Shenaut, G. K. (1997). Clinical and neurocognitive aspects of source monitoring errors in schizophrenia. *American Journal of Psychiatry*, *154*, 1530–1537. doi:10.1176/ajp.154.11.1530

Waters, F. A., Maybery, M. T., Badcock, J. C., & Michie, P. T. (2004). Context memory and binding in schizophrenia. *Schizophrenia Research*, *68*, 119–125. doi:10.1016/S0920-9964(03)00221-4

Wechsler, D. (2001). *Wechsler Test of Adult Reading: WTAR*. San Antonio, TX: The Psychological Corporation.

Woodberry, K. A., Giuliano, A. J., & Seidman, L. J. (2008). Premorbid IQ in schizophrenia: A meta-analytic review. *American Journal of Psychiatry*, *165*, 579–587. doi:10.1176/appi.ajp.2008.07081242