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Association of schizotypy with semantic processing differences: An event-related brain potential study

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Abstract

Disorganized speech in both schizophrenia and schizotypy has been hypothesized to result from abnormalities in how concepts activate one another in semantic memory. To study whether schizotypy is associated with differences in how categories activate their exemplars, we examined the N400 component of the event-related brain potential (ERP) elicited during a category-verification task. ERPs were recorded in young adults from the general population while they viewed category definitions each followed by a target that was either a high-typicality exemplar, low-typicality exemplar, or non-exemplar; participants' task was to indicate whether or not the target belonged to the category. Schizotypy was assessed via the Schizotypal Personality Questionnaire (SPQ). Overall, N400 amplitude was largest for non-exemplars, smallest for high-typicality exemplars, and intermediate for low-typicality exemplars. SPQ score was associated with decreased N400 amplitude to non-exemplars, and increased amplitude to both types of exemplars. SPQ score was negatively correlated with the N400 amplitude difference between non-exemplars and both low- and high-typicality exemplars, but was not correlated with the amplitude difference between low- and high-typicality exemplars. N400 amplitude differences between non-exemplars and both types of exemplars were correlated with the SPQ Interpersonal factor, but not the Disorganized factor. The results are consistent with an association of schizotypy with decreased use of context to activate related items and inhibit unrelated items.

Keywords: Schizotypy; Disorganized speech; Thought disorder; Semantic processing; Event-related potentials; N400

1. Introduction

Disorganized speech in schizophrenia has been hypothesized to result from abnormalities in how words, and the concepts they represent, activate one another in the brain (McCarley et al., 1999; Nestor et al., 1998; Spitzer, 1997). These hypotheses assume a model of semantic memory in which concepts are

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represented as nodes in a network, and associations between concepts as links among these nodes (Anderson and Pirolli, 1984; Collins and Loftus, 1975; Neely, 1977). When a concept node is activated, as by its corresponding word stimulus, this activation is thought to spread through the network to associated nodes. The degree to which a concept activates another and facilitates its processing is presumably related to the strength of the links between them in the semantic network.

One class of proposed mechanisms for how abnormal activation in semantic memory may cause disorganized speech in schizophrenia involves either increased or more broadly spreading activation of related items. For instance, Spitzer (1997) postulated that indirect associates—those mediated by at least one other concept, like *CAT* and *CHEESE* (mediated by *MOUSE*)—activate one another more strongly in schizophrenia, and that this accounts for sequences of unrelated or weakly associated concepts in schizophrenic speech.

Some semantic priming data support this hypothesis. Semantic priming refers to the tendency for individuals to respond more quickly to a target item when it is preceded by a related than an unrelated prime item. Greater priming is thought to reflect greater activation of the target by the prime. Consistent with increased spread of activation to indirect associates, an abnormally large priming effect for indirectly related words has been found in thought-disordered schizophrenia patients, though only when the prime-target interval, i.e. stimulus-onset asynchrony (SOA), is relatively short (≤300 ms) (Moritz et al., 2001, 2003; Spitzer et al., 1993).

A distinctly different hypothesis attributes disorganized speech in schizophrenia to an impaired ability to use context to activate related items, and to inhibit unrelated items (Cohen and Servan-Schreiber, 1992). This mechanism is not necessarily mutually exclusive with increased spreading activation, as both may occur, albeit with different time courses. In fact, whereas behavioral priming evidence for increased spreading activation has come from studies employing short SOAs, most evidence for impaired context use, whether the context is a word or sentence, has come from experiments with relatively long SOAs. For example, schizophrenia patients exhibited no priming at a long SOA of 950 ms for closely related words that primed at shorter SOAs (Barch et al., 1996). In another study, both schizophrenia patients and controls were slower to recognize a sentence-final word when it was semantically incongruent with the preceding context than when it was congruent; however, thought-disordered patients were delayed less than were controls or non-thought-disordered patients, consistent with impaired use of context (Kuperberg et al., 1998).

Semantic priming effects also have been investigated using the N400 component of scalp-recorded event-related brain potentials (ERPs). The N400 is a negativity peaking approximately 400 ms after presentation of any potentially meaningful stimulus, such as a word or picture. N400 amplitude is sensitive to factors which facilitate an item's processing, such as frequency of usage, repetition, semantic relatedness and congruity; of relevance here is that it varies inversely with the semantic relatedness between the target and its prime (Holcomb and Neville, 1990, 1991; Kutas, 1985; Kutas and Hillyard, 1980; Stelmack and Miles, 1990). In other words, N400 amplitude to a target is reduced (i.e. less negative) when it is more related to the prime. N400 amplitude has thus been used as a measure of the degree to which concepts activate one another in semantic memory, with reduced amplitude corresponding to greater activation.

Results of N400 studies in schizophrenia have been mixed. Prime-target word pairs (SOA = 450 (Kostova et al., 2003) and 600 ms (Strandburg et al., 1997)) yielded larger than normal (more negative) N400 amplitude to related targets in schizophrenia patients, suggesting decreased activation, consistent with the impaired context use hypothesis. In another word-pair experiment, Condray et al. (2003) reported a reduced N400 priming effect (i.e. the difference in N400 amplitude between related and unrelated targets) in patients vs. controls, at SOAs of both 350 and 950 ms, although the N400 amplitude for either related or unrelated targets did not significantly differ between patients and controls. On the other hand, Spitzer (1997) reported that N400 amplitude for indirectly related words (SOA = 200 ms) was reduced (less negative) in patients compared to controls, consistent with relatively greater activation of weaker associates. In a picture-word matching task (SOA = 250 ms) (Mathalon et al., 2002), target words referring to an item from the same category as the picture elicited a smaller N400 in patients than in controls, consistent with increased activation of related items. Studies with sentence-final word paradigms (Kostova et al., 2003; Ohta et al., 1999) showed a larger N400 amplitude to congruent words in patients than controls, consistent with impairment in the use of context to activate congruent items.

Overall, then, the results of these N400 studies, like those of behavioral priming studies, suggest that, at relatively short SOAs, there may be increased or broader activation of potentially related concepts, as reflected in smaller N400 amplitudes for targets related to their primes. However, at longer SOAs, including in a sentence context, schizophrenia patients may be impaired in using context to activate related or expected items, as reflected in larger N400s to these items.

A different approach to understanding semantic activation abnormalities in schizophrenia, which avoids potential confounds of medication and chronic illness, is to study semantic processing in the non-clinical population as a function of schizotypal personality traits. All persons are thought to vary on a continuum in the degree to which they exhibit these traits (Verdoux and van Os, 2002). Individuals high in schizotypy have been found to share a genetic diathesis with schizophrenia patients, along with diverse neurophysiological and neuropsychological abnormalities (Tsuang et al., 2000). Further characterization of these abnormalities as a function of schizotypy thus may contribute to our understanding of the pathophysiology of schizophrenia.

Persons with high schizotypy have been reported to exhibit semantic priming abnormalities similar to those seen in schizophrenia. These include, at relatively short SOAs, increased behavioral priming for weakly related words (Kerns and Berenbaum, 2000; Pizzagalli et al., 2001), and an abnormally large reduction in the N400 to related words (Niznikiewicz et al., 2002), consistent with increased or broader spreading activation. Evidence that higher schizotypy is associated with increased N400 amplitudes to congruent sentence endings (Niznikiewicz et al., 1997), or a decreased difference between the N400 amplitudes to congruent and incongruent endings (Kimble et al., 2000), is consistent with impaired use of context to activate related items over a longer time course. Further research will help more clearly delineate how differences in stimuli, task, and clinical population interact to affect the way in which concepts in the semantic network activate one another in the schizophrenia spectrum.

One relationship in the semantic network that has been extensively studied in normal populations is the relation between categories and their exemplars. Behavioral norming studies have documented the typicality of different exemplars for a wide range of categories (Battig and Montague, 1969; Hunt and Hodge, 1971; McEvoy and Nelson, 1982; Shapiro and Palermo, 1970). For example, *apple* is a high-typicality exemplar of the category *fruit*, whereas *cherry* is a low-typicality exemplar, meaning that individuals rate *apple* as being a more typical fruit than *cherry*, and, when asked to name some fruits, are more likely to say *apple* than *cherry*. Higher typicality is thought to reflect greater semantic relatedness between the category and exemplar (Hampton, 1979; McCloskey and Glucksberg, 1978). After a category name, N400 amplitude is reduced in response to exemplars relative to non-exemplars (Federmeier and Kutas, unpublished results; Heinze et al., 1998; Iragui et al., 1996); in addition, high-typicality exemplars elicit smaller N400 amplitudes than low-typicality exemplars (Federmeier and Kutas, unpublished results; Heinze et al., 1998; Stuss et al., 1988).

In the present study, we aimed to use the N400 to examine whether the way categories activate their exemplars in the semantic network varies with schizotypy. We presented individuals from a normal population with category names followed by target nouns, which were either high-typicality exemplars, low-typicality exemplars, or non-exemplars. Participants, subsequently rated on schizotypy, were asked to indicate whether or not the target was an exemplar of the category. We expected that across all participants, consistent with previous findings (Federmeier and Kutas, unpublished results; Heinze et al., 1998; Iragui et al., 1996; Stuss et al., 1988), the N400 would be largest to non-exemplars, smallest to high-typicality exemplars, and intermediate to low-typicality exemplars.

In addition, if higher schizotypy is generally accompanied by a broader spread of activation to weaker associates, then categories would activate their less typical exemplars relatively more strongly, as reflected in smaller (i.e. less negative) N400s. Therefore, the difference in N400 amplitude between low- and high-typicality exemplars (which we will refer to as the *N400 typicality effect*) would be reduced, and the N400 effect between unrelated non-exemplars and low-typicality items (the *N400 low-typicality category effect*) would be increased. The difference between unrelated non-exemplars and high-typicality items exemplars (the *N400 high-typicality category effect*) would not change.

Alternatively, if persons with higher schizotypy generally make less, or less efficient, use of context, then both high- and low-typicality exemplars, as related words, would be less activated, i.e. elicit larger N400s, in these individuals than in persons with lower schizotypy. We would also expect non-exemplars to be relatively less inhibited, or more activated, eliciting smaller N400s. Overall, this would lead to a smaller N400 high-typicality category effect and a smaller N400 low-typicality category effect, but no change in the N400 typicality effect (see Table 1 for summary of predicted outcomes for these hypotheses).

Clearly, reaction time (RT) data could also be useful in testing some aspects of the hypotheses in question, with broader spread of activation leading to a reduced RT priming effect for high-typicality vs. low-typicality exemplars, and decreased context use reflected in a reduced RT priming effect for both types of exemplars over non-exemplars. In this initial study, however, we chose to use a delayed category-verification response, rendering the behavioral data informative with respect to categorization accuracy but not speed. In the context of examining N400 priming effects, the delayed-response design confers certain advantages: in particular, while the presence of a task helps ensure and verify that participants are attending to the stimuli, freedom from having to make an overt response during reading minimizes movement-related preparatory and executive potentials that could overlap the N400 component and interfere with its interpretation. This is especially important as a baseline for future studies with schizophrenia patients, in whom the motor system may be impacted by various medication regimens.

2. Methods

2.1. Participants

Twenty-four healthy participants [17 female, 18–35 years of age, mean age 21.0, SD=3.5] were recruited from the campus of the University of California, San Diego. Most were undergraduates. Exclusion criteria included: left-handedness, as assessed by the Edinburgh Inventory (Oldfield, 1971); and any self-reported history of: exposure to a language other than English at home as a child; reading difficulties; visual impairment; current or past neurological or psychiatric disorder; and current use of neurological or psychotropic medications. Fourteen reported having a left-handed immediate family member. Participants gave written informed consent and were compensated with course credit or cash. The study procedure was approved by the Human Research Protections Program of the University of California, San Diego.

2.2. Rating scales

Participants completed the Schizotypal Personality Questionnaire (SPQ), a 72-item validated self-rating instrument for schizotypy, with 9 subscales corre-

Table 1
Expected effect of higher schizotypy on N400 amplitudes and N400 effects, according to different hypotheses

Hypothesis	N400 amplitudes			N400 effects		
	High-typicality exemplar	Low-typicality exemplar	Non-exemplar	Typicality effect	High-typicality category effect	Low-typicality category effect
Greater spread of activation to weak associates	No change	Decreased (i.e. less negative)	No change	Decreased	No change	Increased
Decreased context use	Increased (i.e. more negative)	Increased	No change or decreased	No change	Decreased	Decreased

sponding to each of the 9 schizotypal traits (Raine, 1991). These subscales have been found to load onto 3 factors: Disorganized (comprising the Odd Behavior and Odd Speech subscales), Cognitive-perceptual (Ideas of Reference, Odd Beliefs, Unusual Perceptual Experiences and Suspiciousness), and Interpersonal (Social Anxiety, No Close Friends, Constricted Affect and Suspiciousness) (Raine et al., 1994). Participants also completed the Peabody Picture Vocabulary Test (PPVT) (Dunn and Dunn, 1997) as a measure of receptive vocabulary.

2.3. Stimuli

Stimuli were based on existing category production norms (Battig and Montague, 1969; Hunt and Hodge, 1971; McEvoy and Nelson, 1982; Shapiro and Palermo, 1970). For each of 120 categories, the associated target words included (a) a high-typicality exemplar, (b) two low-typicality exemplars (these differed in the degree to which they shared semantic features with the high-typicality exemplar, a distinction made for a separate pilot analysis not directly relevant to this study), and (c) an unrelated non-exemplar. Targets were matched overall for length and word frequency (Francis and Kucera, 1982) across these conditions (overall mean length = 6.1 letters; overall mean log frequency = 0.90). The high-typicality exemplar chosen was the exemplar most frequently produced by individuals in the category norms, except where its very high frequency would prevent the conditions from being matched for word frequency. In such cases an exemplar of as high a rank as possible was used. Low-typicality exemplars were chosen from among those ranked 9th or lower by frequency of generation. Examples are shown in Table 2.

Using these stimuli, 3 different lists were generated. In each list, each of the 120 categories appeared once, and 40 categories were paired with each of the 3 target types. Each of the possible target types for each category occurred in one of the 3 lists. Because each category had two possible low-typicality targets (see above), each list had 2 versions, such that each of the 40 categories paired with a low-typicality target in that list were paired with a different target in each version, and such that each version contained 20 of each of the 2 kinds of low-typicality target. Within each list, length and frequency were matched across the 3 target types. Each list also included 40 additional filler categories followed by an unrelated target. Filler stimuli were not analyzed but were included so that each list included an equal number of exemplar and non-exemplar targets (80 each).

2.4. Task

Participants were tested in a single session in a sound-attenuated, electrically-shielded chamber. They were seated 100 cm in front of a video monitor on which the stimuli were visually presented, with each letter in a word subtending on average approximately 0.36° of visual angle horizontally, and up to 0.55° vertically. Words were displayed in yellow letters on a black background.

Each participant was presented with one of the 3 lists, with the categories presented in a fixed randomized order. Over the course of the study, an equal number of participants saw each of the 3 lists (and an equal number of participants saw each of the 2 versions of each list). Each list was divided into four blocks of 40 trials each, separated by short rest breaks. Each trial consisted of the following sequence: (a) category (e.g. *a type of fruit*) for 2150 ms, (b) blank

Table 2
Sample categories and corresponding target stimuli

Category	High-typicality exemplars	Low-typicality exemplars	Non-exemplars
A type of fruit	Apple	Prune *or* cherry	Clamp
A weapon	Gun	Revolver *or* stick	Musician
A wind instrument	Flute	Clarinet *or* bagpipes	Calendar
A farm animal	Cow	Goat *or* duck	Antenna
A fish	Trout	Cod *or* eel	Parachute
Something worn on the feet	Shoes	Slippers *or* skis	Freight

screen for an interval varied pseudorandomly between 250 and 650 ms (to avoid the superimposition of anticipatory ERP effects which occur when the timing of onset of the target is invariant), (c) target (e.g. *cherry*) for 1000 ms, (d) blank screen for 2000 ms, (e) the prompt *Yes or No?* until participants responded with a button-press (see below), (f) blank screen for 3000 ms until onset of the next trial. All stimuli were presented centered on the screen horizontally and vertically. A central fixation point remained visible throughout, positioned 0.5° below the bottom—most edge of where the words were presented.

Upon presentation of the prompt, participants were required to press one of two buttons, on joysticks held in the right and left hands, respectively. One button (labeled "Yes") signaled that the word was a true exemplar of the preceding category, while the other button (labeled "No") signaled that it was a non-exemplar. The assignment of buttons was reversed for half the participants.

2.5. Electrophysiological data collection and analysis

The electroencephalogram was recorded from 26 tin electrodes embedded in an electro-cap, and referenced to the left mastoid. Electrodes were equally spaced across the scalp, with positions and labels as shown in Fig. 1. Blinks and eye movements were monitored via electrodes placed on the outer canthus (left electrode serving as reference) and infraorbital ridge of each eye (referenced to the left mastoid). Electrode impedances were kept below 5 kΩ. The EEG was processed through Grass amplifiers set at a bandpass of 0.01–100 Hz, continuously digitized at 250 Hz, and stored on hard disk for later analysis.

The EEG was re-referenced off-line to the algebraic mean of the left and right mastoids. ERPs were computed for epochs extending from 100 ms before stimulus onset to 920 ms after stimulus onset. Individual trials containing artifacts due to eye

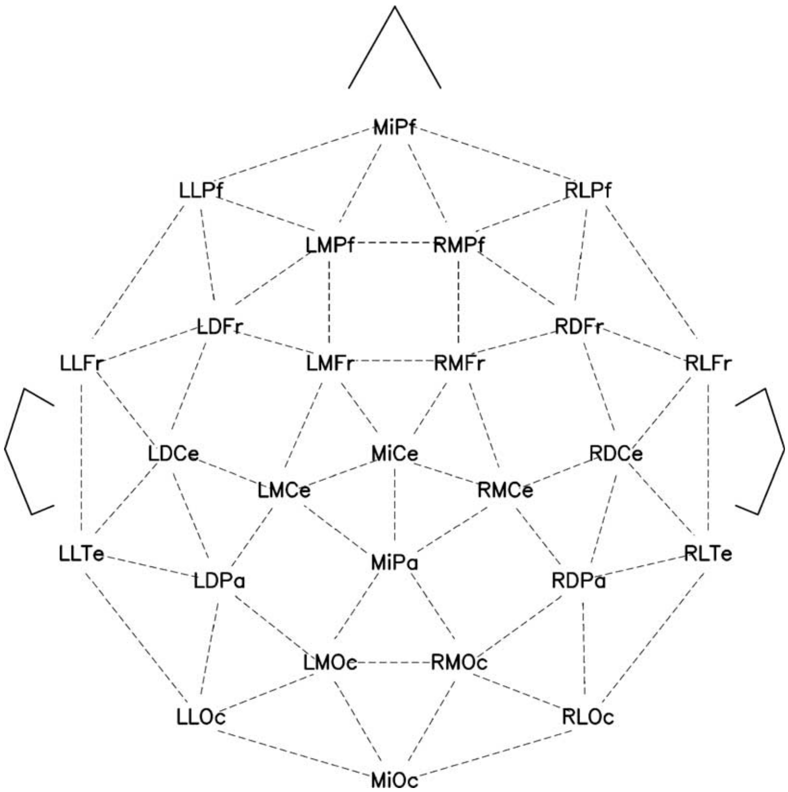

Fig. 1. Schematic diagram of the electrode array.

movement, excessive muscle activity or amplifier blocking were rejected off-line before time-domain averaging; approximately 6% of trials were lost due to such artifacts. If data from a participant contained excessive blinks, they were corrected using a spatial filter algorithm (Dale, 1994); this was applied to only one participant's data.

For each trial, N400 latency was measured as the interval between stimulus onset and the largest negative peak between 250 and 550 ms post-stimulus. N400 amplitude was measured as the mean voltage from 300–500 ms post-stimulus. For each participant, N400 effects were defined as the mean voltage from 300 to 500 ms post-stimulus for the difference waves between ERPs for each pair of target type: non-exemplar minus high-typicality exemplar (high-typicality category effect), non-exemplar minus low-typicality exemplar (low-typicality category effect), and low-typicality exemplar minus high-typicality exemplar (typicality effect).

2.6. Statistical analysis

Table 3 shows statistics for rating scale scores for the study sample. Mean SPQ score did not differ between men and women, according to a t-test with Welch correction for unequal variance [$t=0.41$, $p=0.69$]. The study sample was split by median SPQ score into low- and high-schizotypy groups. Mean SPQ score was 6.0 [SD=3.2] for the low-schizotypy group and 22.2 [SD=6.4] for the high-schizotypy group. These two groups did not differ in vocabulary as measured by the PPVT, according to a t-test with Welch correction for unequal variance [$t=1.85$, $p=0.08$]. Mean age was 22.2 [SD=4.6, range=18–35] for the low-schizotypy group and 19.8 [SD=1.2, range=18–22] for the high-schizotypy group; a Mann-Whitney U test (used because the age distribution for the low-schizotypy group was non-normal) showed that this difference approached significance ($Z=1.90$, $p=0.06$). Eight of 12 participants in the low-schizotypy group and 9 of 12 in the high-schizotypy group were female; these proportions did not differ significantly ($\chi^2=0.20$, $df=1$, $p=0.65$).

Percentage of correct responses was analyzed with repeated-measures analysis of variance (ANOVA), with Schizotypy (low vs. high) as between-subject variable, and Target (high-typicality vs. low-typicality vs. non-exemplar) as within-subject variable. All p-values in this and subsequent ANOVAs with within-subject factors are reported after Greenhouse–Geisser Epsilon correction. In this and subsequent ANOVAs, pairwise comparisons of factor-level means were made using the Tukey procedure for simultaneous pairwise comparisons, with a family confidence co-efficient of 0.95.

Only data from trials with correct responses were included in subsequent ERP analyses.

N400 latency was analyzed in an ANOVA with Schizotypy (low vs. high) as between-subject variable, and Target (high-typicality vs. low-typicality vs. non-exemplar) and Electrode (26 levels, corresponding to all recording sites) as within-subject variables.

N400 amplitude was analyzed in an ANOVA with Schizotypy (low vs. high) as between-subject variable, and Target (high-typicality vs. low-typicality vs. non-exemplar) and Electrode (26 levels, corresponding to all recording sites) as within-subject variables.

To examine the relationship between N400 effects and schizotypy, Pearson product moment correlation co-efficients r were calculated between the high-typicality category effect, low-typicality category effect, and typicality effect, at MiPa, and SPQ total and factor scores.

Table 3
Means, standard deviations and ranges of rating scale scores for the study sample ($n=24$)

Scale	Mean	Median	SD	Range	Maximum possible score
SPQ (total)	14.1	12.5	9.7	1–38	74
SPQ Cognitive-perceptual factor	5.8	5.0	5.0	0–19	33
SPQ Interpersonal factor	5.6	4.5	4.9	0–17	33
SPQ Disorganized factor	4.0	3.5	3.2	0–10	16
PPVT	187.2	190	5.9	170–195	204

3. Results

3.1. Behavioral data

The percentage of correct responses for the low- and high-schizotypy groups for the different conditions are shown in Table 4. Overall, the high rate of correct responses indicates that participants were attending to the stimuli.

Table 4
Percentage of correct categorization responses, by schizotypy group and target condition

Target	Low-schizotypy ($n=12$)			High-schizotypy ($n=12$)		
	Mean	SD	Range	Mean	SD	Range
High-typicality	95.6	2.2	93–100	94.2	4.8	95–100
Low-typicality	84.4	4.9	75–90	84.7	5.9	75–93
Non-exemplar	95.6	4.5	85–100	97.7	2.3	95–100

There was a significant effect of Target [$F(2,44)=78.32$, $p<0.0001$], with percentage of correct responses differing significantly between high- and low-typicality exemplars, and between low-typicality exemplars and non-exemplars, but not between high-typicality exemplars and non-exemplars. There was no effect of Schizotypy [$F(1,22)=0.07$, $p=0.80$], nor a Schizotypy × Target interaction [$F(2,44)=1.45$, $p=0.25$].

3.2. Grand average ERPs

Grand average ERPs ($n=12$) at all electrodes are shown separately for the low and high-schizotypy groups in Fig. 2.

3.3. N400 latency

Overall, N400 latency was greater for non-exemplars (mean = 418 ms) than for either low-typicality exemplars (mean = 396 ms) or high-typicality exemplars (mean = 389 ms) [$F(2,44)=4.54$, $p=0.02$]. N400 latency did not differ between schizotypy groups [$F(1,22)=0.02$, $p=0.88$], and there was no Schizotypy × Target interaction [$F(2,44)=1.26$, $p=0.30$].

3.4. N400 amplitude

N400 amplitude was largest (most negative) for non-exemplars (mean = −0.82 μV), intermediate for low-typicality exemplars (2.23 μV), and smallest for high-typicality exemplars (4.24 μV) [main effect of Target: $F(2,44)=53.97$, $p<0.0001$]. Although the difference in N400 amplitude between target types was broadly distributed over the scalp, it was largest over medial parietal sites on the right hemisphere, a distribution consistent with that seen in previous N400 studies of word reading (Federmeier and Kutas, 1999; Kutas and Van Petten, 1994) [Target × Electrode interaction: $F(50, 1100)=9.86$, $p<0.0001$].

There was no main effect of Schizotypy [$F(1,22)=0.07$, $p=0.80$] on N400 amplitude. There was however a Schizotypy × Target interaction [$F(2,44)=3.86$, $p=0.03$]. Means for different levels of Schizotypy × Target are illustrated in Fig. 3. All factor-level means were significantly different from one another. For both schizotypy groups, N400 amplitude was largest for non-exemplars, intermediate for low-typicality exemplars, and smallest for high-typicality exemplars. In addition, for each of the two

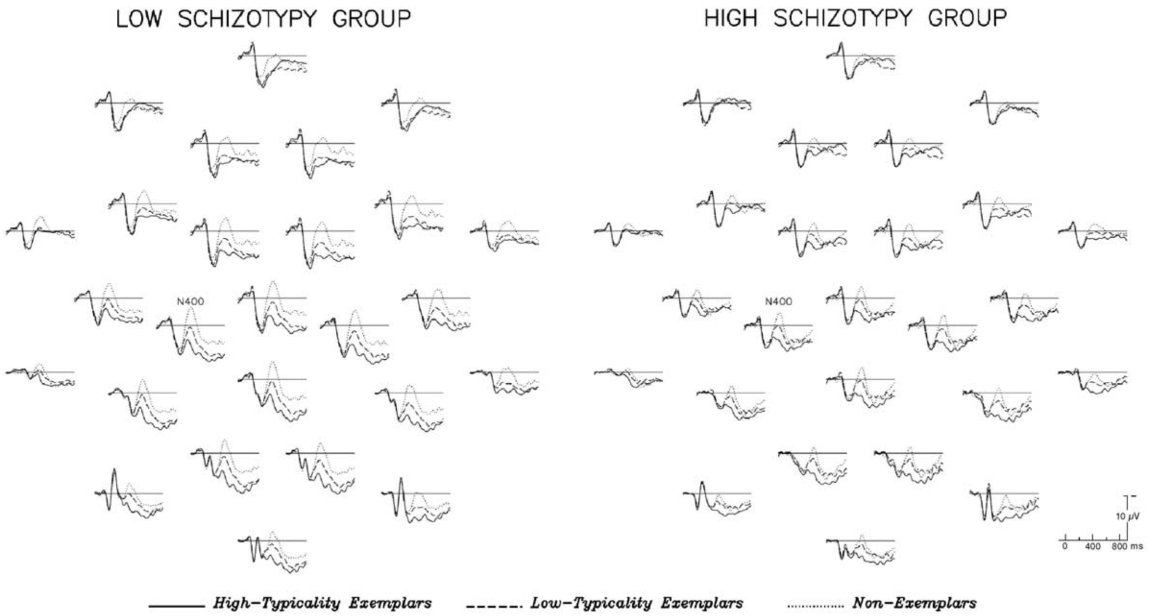

Fig. 2. Grand average ERPs for the three target types, at all electrode sites, for the low- and high-schizotypy groups ($n=12$ per group).

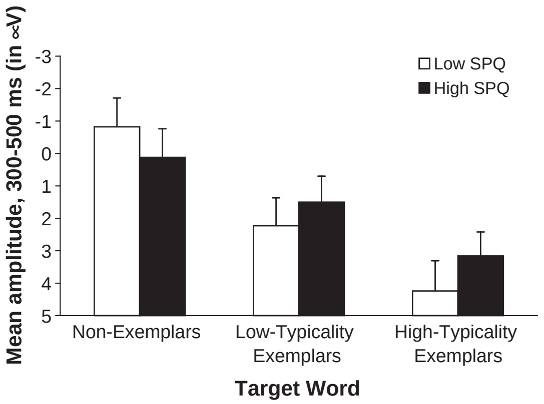

Fig. 3. Mean N400 amplitude between 300–500 ms, averaged across all electrodes.

exemplar types, N400 amplitude was more negative for the high-schizotypy group than the low-schizotypy group, while for non-exemplars, amplitude was less negative (i.e. smaller N400) for the high-schizotypy group than the low-schizotypy group. There was no Schizotypy × Target × Electrode interaction [$F(50,1100)=0.66$, $p=0.97$], indicating that schizotypy did not affect the distribution of N400 effects.

3.5. Correlation of N400 effects with schizotypy

The high-typicality category effect, low-typicality category effect, and typicality effect for low- and high-schizotypy groups at MiPa (Pz in the International 10-20 system) are shown in Fig. 4. Scatterplots of the amplitudes of these effects vs. total SPQ score, for all participants, are shown in Fig. 5. Correlation co-efficients between these effects and SPQ total and factor scores, across all participants, are shown in Table 5. Since the N400 has a negative amplitude, positive correlation co-efficients indicate that the N400 effect was smaller with higher SPQ scores.

Because the high- and low-typicality category effects were found to be significantly correlated with the SPQ Interpersonal factor but not with the Cognitive or Disorganized factors, for each of the two category effects we examined post hoc whether its correlation with the Interpersonal factor was significantly different from its correlation with each of the other two SPQ factors (Neter et al., 1996). The correlation between the high-typicality category effect and the SPQ Interpersonal score did not differ significantly from the correlation between the high-typicality category effect and either the SPQ Cognitive score ($z^*=1.15$, $p=0.36$) or the SPQ Disorganized score ($z^*=1.25$, $p=0.30$). Likewise, the correlation between the

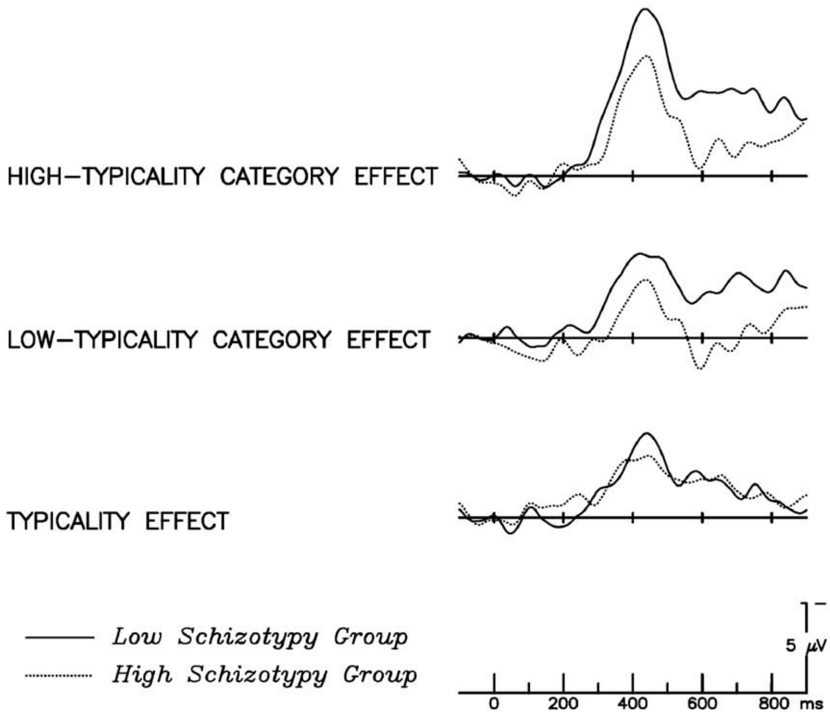

Fig. 4. ERP difference waves, shown for MiPa.

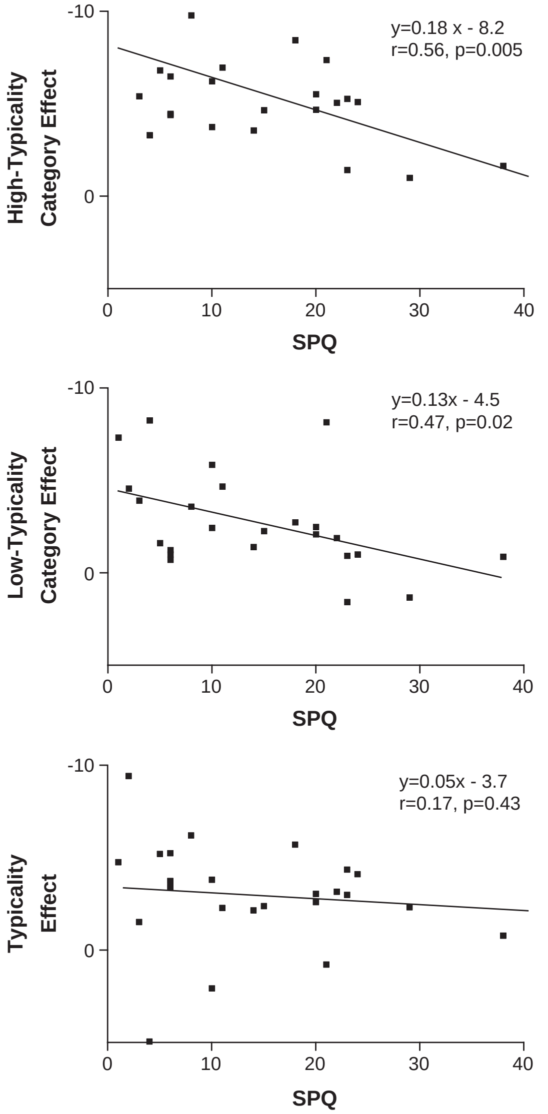

Fig. 5. Scatterplots of difference wave mean amplitudes (between 300–500 ms at MiPa) vs. total SPQ scores.

low-typicality category effect and the Interpersonal score did not differ significantly from the correlation between the low-typicality category effect and either the Cognitive score ($z^*=1.07$, $p=0.58$) or the Disorganized score ($z^*=1.36$, $p=0.25$).

4. Discussion

In this experiment, we investigated the relationship between schizotypal personality and semantic processing by using the N400 component of the ERP elicited during a category-verification task. Participants were presented with category primes, each followed after a relatively long interval by a target noun. Across all participants, the N400 amplitude to targets was largest (i.e. most negative) for unrelated non-exemplars, smallest for high-typicality exemplars, and intermediate for low-typicality exemplars. In addition, the amplitudes of the N400 effects between non-exemplars and both exemplar types (i.e. both the high-typicality category effect and the low-typicality category effect) were significantly correlated with SPQ score. As schizotypy increased, both category effects decreased in size, due to decreased N400 amplitudes for non-exemplars, and increased N400 amplitudes for both types of exemplars. In contrast, the N400 typicality effect was not significantly correlated with SPQ score, as N400 amplitude increased with schizotypy equally for both types of exemplars.

These results are consistent with an association of higher schizotypy with impaired context use, leading to less than normal activation (i.e. larger N400s) for both types of exemplars (as related targets), and less than normal inhibition or greater than normal activation (i.e. smaller N400s) for non-exemplars (as unrelated targets). Our results, on the other hand, apparently do not support the hypothesis of increased or broader activation of related concepts with higher schizotypy. This would be expected to cause a smaller N400 to high- or low-typicality exemplars or both, unlike what we observed. It is important to note, however, that we used a relatively long SOA between prime and target (2400–2800 ms) in order to ensure participants had enough time to read the longer

Table 5
Correlations of SPQ scores with difference wave mean amplitudes from 300–500 ms at MiPa ($n=24$)

	High-typicality category effect		Low-typicality category effect		Typicality effect	
	r	*p*	*r*	*p*	*r*	*p*
SPQ (total)	0.56	0.005	0.47	0.02	0.17	0.42
SPQ factors						
Cognitive-perceptual	0.36	0.08	0.30	0.15	0.11	0.61
Disorganized	0.34	0.11	0.22	0.30	0.16	0.46
Interpersonal	0.63	0.001	0.57	0.004	0.15	0.48

category definitions. Thus, although we found no ERP evidence for increased or more broadly spreading activation of related concepts as a function of schizotypy at long SOAs, our study design did not allow us to test whether this might be present at short SOAs. Further studies, with different stimuli that allow the inclusion of short SOAs, are necessary to examine this question.

Overall, our results indicate that semantic processing differences, as reflected in N400 effects, vary with schizotypy across the general population. They are consistent with a previous finding of a reduced N400 amplitude difference between congruent and incongruent sentence endings (Kimble et al., 2000), in high- vs. low-schizotypy individuals from a general-population sample. To the extent that these findings parallel N400 evidence for impaired context use in schizophrenia (Condray et al., 2003; Kostova et al., 2003; Ohta et al., 1999; Strandburg et al., 1997) or schizotypal personality disorder (Niznikiewicz et al., 2002, 1999), they add to the body of data suggesting that various neuropsychological and neurophysiological findings associated with schizophrenia also increase in prevalence across the general population as a function of schizotypy (Della Casa et al., 1999; Ettinger et al., 2005; Kimble et al., 2000; Klein et al., 1998; Lubow and De la Casa, 2002).

Our results thus accord well with the model of Cohen and Servan-Schreiber (1992), who hypothesized that schizophrenia is associated with an impaired ability to maintain an internal representation of context. This model is based on the hypothesis that in schizophrenia, there is a deficiency of dopamine in prefrontal regions postulated to be responsible for representing context, and that dopamine maintains the gain in a neural network, potentiating both excitatory and inhibitory responses to afferent inputs. Whatever pattern of activated and inhibited neurons normally represents a particular context, in schizophrenia these are hypothesized to be activated and inhibited, respectively, to a lesser degree. This in turn would lead to decreased activation of related items, and decreased inhibition or increased activation of unrelated items. A diminution in prefrontal dopaminergic activity could result from a neurodevelopmental lesion (Weinberger, 1987) which might lead to either schizophrenia or schizotypy depending on other genetic or environmental factors (Siever and Davis, 2004). Evidence for dopaminergic dysfunction has in fact been found in both schizophrenia and schizotypy (Davis et al., 1985; Siever et al., 1993; Siever and Davis, 2004).

Behavioral studies in the schizophrenia spectrum have provided evidence both for decreased activation of items related to context (Barch et al., 1996), and decreased inhibition of unrelated items (Kuperberg et al., 1998; Mohr et al., 2001; Titone et al., 2000). However, unlike our results, which are consistent with both these effects, previous N400 studies in these populations have reported evidence for the former (Kostova et al., 2003; Niznikiewicz et al., 1997; Ohta et al., 1999; Strandburg et al., 1997) but not the latter. The reason for this discrepancy is unclear, but a possible explanation may relate to our experimental stimuli and task. In our materials, the target could be viewed as completing either a true or false proposition—it either was or was not a “true” member of the category; moreover, participants’ task was to indicate whether or not this proposition was true. These characteristics were not present in previous studies which used either word–word or sentence-context/final-word paradigms.

This characteristic of our study materials—that the target items carried specific truth values— might suggest a possible alternative explanation for our findings. Perhaps in individuals higher in schizotypy, it is not unrelated items per se (as in the impaired context use hypothesis), but false items that are more activated. Schul et al. (2004) found that, after experimental manipulations designed to induce mistrust, university students exhibited greater than normal priming for adjectives that were opposites (e.g. *hollow-full*), and less than normal priming for adjectives that were synonyms (e.g. *hollow-empty*), in a grammatical-class identification task. They proposed that mistrust may be associated with increased activation of message-incongruent associations and decreased activation of message-congruent associations, by encouraging a person to focus more on the possibility that a message is invalid. They further speculated that this might occur not only within individuals when mistrust is induced, but also in chronically mistrustful individuals as compared to less mistrustful individuals. Since schizotypy is associated with chronic mistrust, consistent with our results, individuals with higher compared to lower schizotypy, when presented with the category-verification task, might activate words comprising an invalid proposition to a lesser degree, and words comprising a valid proposition to a lesser degree, which would also fit our results.

One unexpected finding was that, of the three SPQ factors, only the Interpersonal factor was significantly correlated with reduction of N400 category effects. Since the hypotheses we examined aimed to explain disorganized speech in schizophrenia, we would have expected the Disorganized factor (which includes the Odd Speech subscale) to correlate most highly with these N400 effects. Nevertheless, it must be noted that, for both the high- and low-typicality category effects, the numerical difference in the correlations between the category effect and the Disorganized factor, and between the category effect and the Interpersonal effect, was not statistically significant. Thus, it cannot be definitively concluded that N400 effect differences were more highly associated with the Interpersonal factor than with the Disorganized factor. Previous ERP studies of schizotypy have not analyzed the N400 in relation to separate schizotypal traits or factors. Likewise, N400 studies that provided evidence for decreased context use in schizophrenia (Kostova et al., 2003; Ohta et al., 1999; Strandburg et al., 1997) did not report correlations with separate symptoms. Unless confirmed by additional studies with greater statistical power, the possibility that N400 category effect reduction is specifically correlated with the Interpersonal factor of schizotypy remains speculative. It is potentially important, because if it were true, it would call into question the inference that N400 differences reflect the semantic processing differences leading to disorganized speech.

If future studies were to confirm the specificity of this correlation there could still be a number of possible explanations. First, as previously mentioned, it may be that in our category-verification task, individuals with higher mistrust or suspiciousness were activating words comprising an invalid proposition to a lesser degree, and words comprising a valid proposition to a lesser degree. This is because the trait of suspiciousness loads on the Interpersonal factor, and other traits loading on this factor—including social anxiety, defined in schizotypal personality as being "associated with paranoid fears rather than negative judgments about self" (American Psychiatric Association, 1994), and lack of close friends—also may be etiologically related to suspiciousness. Second, trait-like semantic processing differences might induce the development of a suspicious personality over time. Finally, it might be that the traits loading on the Interpersonal factor are most specific for the genetic diathesis for schizophrenia. Within a general population, these traits have sometimes been found to be most highly correlated with various neurophysiological and neuropsychological abnormalities also seen in schizophrenia (Kendler et al., 1991; Park and McTigue, 1997; Siever, 1985; Suhr and Spitznagel, 2001). It might be that odd speech in the general population, though qualitatively similar to disorganized speech in schizophrenia, has a variety of etiologies, some unrelated to schizophrenia. This would decrease the correlation between the Disorganized factor and N400 differences that reflect semantic processing differences associated with schizophrenia.

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